PROCEEDINGS OF THE

4TH INTERNATIONAL BLUE ECONOMY CONFERENCE

IBEC-2025

THEME: “Harnessing the Blue Economy: Leveraging Innovative and Sustainable Development”

VENUE: Sir Dawda Kairaba Jawara International Conference Center, Banjul, The Gambia

DATE: February 19-21, 2025

SPECIAL GUEST OF HONOUR AND KEYNOTE SPEAKER:

HIS EXCELLENCY ADAMA BARROW,

President of the Republic of The Gambia

SPONSORS

PROCEEDINGS OF THE 4TH INTERNATIONAL BLUE ECONOMY CONFERENCE (IBEC-2025)

ORGANIZE BY THE REGIONAL MARITIME UNIVERSITY (RMU) IN COLLABORATION WITH THE DAR ES SALAAM MARITIME INSTITUTE (DMI) UNDER THE AUSPICES OF THE MINISTRY OF TRANSPORT, WORKS AND INFRASTRUCTURE OF THE REPUBLIC OF THE GAMBIA

CONFERENCE THEME

“HARNESSING THE BLUE ECONOMY: LEVERAGING INNOVATIVE AND SUSTAINABLE DEVELOPMENT”

SPECIAL GUEST OF HONOUR
AND KEYNOTE SPEAKER

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VENUE

SIR DAWDA KAIRABA JAWARA INTERNATIONAL CONFERENCE CENTER, BANJUL, THE GAMBIA

PREFACE

The Blue Economy which is the sustainable use of the ocean resources for economic growth, according to the United Nations (UN) Department of Economic and Social Affairs (DESA), generates between three (3) to six (6) billion dollars annually. This includes employment and ecosystem services. It is also estimated that fisheries contribute about one hundred (100) million dollars and two hundred and sixty (260) million jobs to the global economy.

Recognizing the potential, role and importance of the blue economy to national development and livelihood of millions worldwide, the Regional Maritime University (RMU) in collaboration with the Dar es Salaam Maritime Institute (DMI) after signing an MoU organized the 1st International Blue Economy Conference on the 4th to 5th of July, 2024 in Dar es Salaam, Tanzania on the theme: "Navigating the Future: Integrating Maritime Safety and Security, Climate Change Actions and Technological Advancements in the Blue Economy" which brought together over six hundred (600) stakeholders focusing on promoting the blue economy to lead employment in Africa. The conference provided a platform for capacity building and networking with stakeholders.

With such level of collaboration between RMU and DMI, it was agreed that the 2025 Blue Economy Conference will be hosted by RMU. Since RMU is a regional university owned by five member countries; Cameroon, The Gambia, Ghana, Liberia and Sierra Leone, the immediate past Chancellor of RMU and Chairman of the Board of Governors, Hon. Ebrima Sillah, Minister of Transport, Works and Infrastructure of the Republic of The Gambia was approached by RMU Management for the 2025 Blue Economy Conference to be held in The Gambia on the theme: "Harnessing the Blue Economy: Leveraging Innovative and Sustainable Development".

The conference seeks to bring together international stakeholders and partners to promote the innovative and sustainable use of the blue economy within the context of maritime security, safety and development with the aim of establishing a platform for knowledge sharing, networking and capacity building among stakeholders and partners, leveraging innovative and sustainable development.

A total of sixty-one (61) abstracts were received and peer reviewed with forty-one (41) accepted. Out of these accepted abstracts, twenty-nine (29) manuscripts were received for presentation at the conference. The conference featured ten (10) renowned speakers including the Honourable Minister of Transport, Works and Infrustructure, Hon. Ebrima Sillah; Secretary General of the International Maritime Organization (IMO), Mr. Arsenio Dominguez and the Secretary of the Maritime Organization for West and Central Africa (MOWCA), Dr. Paul Adalikwu. The Guest of Honor and keynote speaker for the conference is His Excellency Adama Barrow, President of the Republic of The Gambia.

With heartfelt gratitude, sincere thanks and appreciation go to the President of the Republic of The Gambia, the Minister of Transport, Works and Infrastructure, Republic of The Gambia and to the staff of the Ministry for their tireless efforts in hosting the conference. A special thanks to the organizers of the conference, Dr. Jethro W. Brooks, Jr., Ag. Vice Chancellor of the Regional Maritime University (RMU) and Prof. Tumaini S. Gurumo, Rector, Dar es Salaam Maritime Institute (DMI). Profound gratitude also goes to the Conference Organizing Committee from the Ministry of Transport, Works and Infrustructure, Regional Maritime University (RMU) and Dar es Salaam Maritime Institute (DMI) to all special guests and all participants and service providers for making the conference a success.

Dr. Baboucarr Njie,
University Registrar (RMU) and Chairman, Conference Organizing Committee

SPECIAL GUEST OF HONOUR AND KEYNOTE SPEAKER

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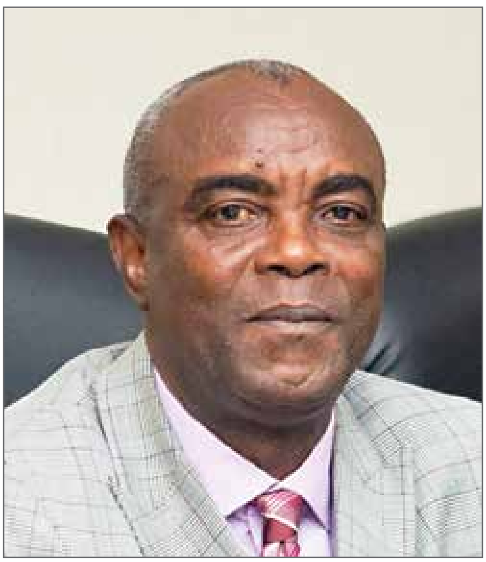

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Institute for Poverty, Land and Agrarian Studies
School of Economics and Management Sciences
University of the Western Cape, South Africa

SPEAKING ON

Blue Justice Approach to Blue Economy Policy Development and Implementation to Social Safeguard Small-scale Fishers in Africa.

ABSTRACT

In Africa, the Sustainable Blue Economy conference in Nairobi, Kenya, in late 2018 launched the continent's ocean development strategy which strongly aligned with the United Nations (UN) Sustainable Development Goals (SDGs) focused on the promotion of bonds, investments, large scale aquaculture, exclusive luxury and tourism. This blue growth agenda needs strong State involvement through formulating, implementing and mainstreaming of Blue Economy policies and strategies including clearing the beaches, declaring MPAs, and setting-up Marine Spatial Planning. To what extent have these developments impacted on the access to livelihoods, lands, foods, and small-scale fishers? To what extent will the Kunming-Montreal Global Biodiversity 30 x 30 Framework protected spaces for exclusive, luxury and adventure tourism and further alienate relations between locals. Hence, if blue economy policies want to adopt a blue justice approach to its formulation and implementation, it needs to be aligned with the UN-FAO guidelines for Tenure, Small-Scale Fisheries (SSF) and right-to-food guidelines. How is communal land accessing the MPAs for livelihoods, food, spiritual and cultural practices impacted by a Sustainable Blue Economy framework in Africa? To what extend have the governance processes created space for SSF to fully participate in the negotiations and decision-making about their lives and livelihoods; whether it is blue economy development or the protection of critical biodiversity areas? Finally, this presentation focuses on how to ensure the social safeguarding of SSF through the lenses of social and spatial justice

H.E. PAUL MASSAQUOI

Sierra Leone Ambassador to the Republic of South Korea

SPEAKING ON

Digital Transformation of the Blue Economy

ABSTRACT

The maritime sector in Africa continues to be confronted with challenges as a result of numerous factors: globalization, political instability in some regions and unfair maritime practices. Study shows that world ocean-based industries such as shipping, fisheries, energy and minerals, renewable energies, seaports, tourism, marine genetic resources, marine biotechnology, etc.; are contributing as key driving forces to the flourishing global economy. However, whilst Africa boasts of a huge 38 Coastal and Island States with an annual value of the African maritime industry estimated to have reached $1 trillion, it is a bitter truth that Africa's marine and coastal environment remain under assault and ominous threat owing to human-induced causes such as over-extraction/exploitation of resources, environmental pollution, oil spills, littering of plastic wastes, underwater noise pollution and above all climate change which all remain the single biggest risk facing the growth of our blue economy. This presentation examines the approach to digital innovation in ocean-based industries while mitigating negative effects like overfishing, habitat destruction, and pollution will offer a significant potential for job creation, poverty reduction, and climate resilience, particularly for coastal and island communities. The presentation also highlights the importance of the blue economy as a pathway to achieving the United Nations' Sustainable Development Goals and can be used to tackle the challenges of poverty, food insecurity, energy crisis, and ecological imbalances to create employment opportunities for all.

PROF. FELIXTINA JONSYN-ELLIS
Former Vice Chancellor, University of The Gambia

SPEAKING ON
Food Safety Concern: A Priority in the Blue Economy

ABSTRACT

There is no doubt that the ocean and its diverse and immense species play a crucial role to the health of planet earth by supplying Oxygen, absorbing Carbon Dioxide and most of all providing food for the inhabitants. The Fisheries and Aquaculture sectors provide income and sustenance for a host of people, particularly low-income families. The Blue Economy, according to the World Bank is the "Sustainable use of the ocean resources for economic growth, improved livelihoods and jobs, while preserving the health of the ocean ecosystem". The Blue Economy is a very laudable and promising undertaking. However, while it strives to balance economic growth, poverty reduction and environmental preservation, the issue of Food Safety does not appear paramount. It has been established that four (4) categories of Food Safety hazards: Biological, Chemical, Physical and Allergenic are present in the marine and aquaculture ecosystems. This presentation, however, limits itself to one aspect of chemical hazards, namely Mycotoxins, as there appears to be a critical dearth of knowledge of these chemical substances in Fisheries and Aquaculture ecosystems. It must be categorically stated that addressing the various Food Safety hazards, requires the engagement and collaboration of key stakeholders.

MR. ISMAEL A. KIMIREI
Director General, Tanzania Fisheries Research Institute

SPEAKING ON

Aquaculture Innovation: Sustainable Practices for the Future of Seafood and Livelihood

ABSTRACT

Aquaculture production holds a key to the future of food and nutrition security of Africa's ever-growing human population. The global fish production data indicate that production from aquaculture has already surpassed that from capture fisheries, projecting it as a beacon-of-hope for sustainable seafood production, food and livelihood security. Africa's population is projected to be 2.5 billion people by 2050, which will create a demand of about 29 million tons of fish - an approximately 190% increase from the current figure of 10 million tons. Against these statistics - and the ever-changing climate causing water stress and insecurity, Africa needs to invest in innovative aquaculture production techniques, which will help bridge the demand gap and ensure food and livelihood security. This presentation discusses ways Africa can take advantage of the vast water resources to innovate and increase seafood production, ensuring environmental sustainability, and economic benefits for the African populace.

DR. NANCY KAIRARIA
Managing Director, Adept Blue Economy Solutions, Kenya

SPEAKING ON

Ocean Governance: Policy for Sustainable Blue Economy Development

ABSTRACT

Africa maritime domain, with its extensive coastlines, exclusive economic zones, and rich marine ecosystems, offers significant potential for trade, food security, and livelihoods, positioning the blue economy as a transformative path for innovative and sustainable development. Realizing this potential requires robust ocean governance frameworks that balance equitable resource use, environmental protection, and socio-economic inclusivity. Ocean governance, a critical tool for achieving Africa's development aspirations, involves systems and policies that regulate ocean interactions to ensure sustainability and fair resource distribution. Key policy areas include integrated maritime policies, sustainable fisheries and aquaculture management, marine spatial planning, climate resilience, and innovative financing mechanisms. However, challenges such as fragmented governance, limited capacity, and data gaps hinder effective implementation. Addressing these requires regional cooperation, technology adoption, institutional capacity building, and inclusive governance. This presentation explores strategies and actionable recommendations for policymakers to unlock Africa's maritime potential while preserving ecological and cultural heritage.

DR. EMMANUEL KOFI MBIAH
Maritime Law Consultant, Accra-Ghana

SPEAKING ON

Climate Change Adaptation and Mitigation: Legal Instruments of Climate Change on Marine Environments and Costal Communities

ABSTRACT

Climate change may be better described than defined and has thus been described variously. One thing that stands projected either in the description or definition is its calamitous impacts. The change in weather patterns and the associated droughts and flooding, destroying agriculture and deepening food insecurity fall within the description of climate change. This presentation outlines the need for the adaptation to climate change especially with respect to the inevitabilities and their socioeconomic impacts. The international legal framework for climate change together with strategies for adaptation are also examined. The key legal instruments viz: The United Nations Framework Convention on Climate Change, The Paris Agreement and the Sustainable Development Goals all provide a framework for climate change adaptation. The legal framework is examined in relation to the capacity to build resilience to lessen the impact of the deleterious effects of climate change. Going green, cutting down greenhouse gas emissions, adopting renewable energies, etc. would be the key drivers towards lessening the negative effects.

H.E. FATOU B. BENSOUDA

Immediate past Prosecutor of the International Criminal Court & Gambia's High Commissioner to the United Kingdom

SPEAKING ON

Ensuring Maritime Safety and Security

DR. SALUM SOUD HAMED

Director of Fisheries and Aquaculture Development, Ministry of Blue Economy and Fisheries, Zanzibar, Tanzania the United Kingdom

SPEAKING ON

Sustainable Fisheries Management: Innovation for the Future-Assessing Emerging Technologies such as Block chain, AI and IoT in promoting Sustainable Fishing Practices and Traceability in Seafood Supply Chain

ABSTRACT

The growth and sustainability of blue economy need to overcome various challenges such as economic challenges, competition and the equitable distribution of the benefits of aquatic resources. The Emerging Technologies such as Block chain, Artificial Intelligence (AI) and Internet of Things (IoT) hold the promise of revolutionizing the blue economy sectors including fisheries and aquaculture industries by enhancing operational efficiency, and promoting resource conservation. Thus, by analyzing vast amounts of data collected through the Emerging Technologies offers valuable insights to optimize fishing and aquaculture operations. In addition, utilization of Emerging Technologies, has the capability to forecast seasonal patterns, precisely recognizing species, and even detect illicit fishing and aquaculture practices that lead to mitigate adverse effects on aquatic ecosystems. These technologies also play part on supporting the accurate identification of the origin of fish and aquaculture products and their traceability throughout the supply chain which are crucial issues in the fight against illegal, unreported and unregulated fishing. In these regards the future sustainability of fisheries and aquaculture industries require the integration of IoT, AI, and Blockchain technologies as emerging promising solution. Given this perspective, this presentation aims to delve into the essential role played by IoT, AI, and Blockchain in promoting Sustainable Fishing and Aquaculture Practices and Traceability in Seafood Supply Chain.

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Harnessing Renewable Energy for Sustainable Blue Economy Development

ISAAC OWUSU-NYARKO, PATRICK ADJEI

Regional Maritime University

ABSTRACT

The transition to renewable energy is essential for sustainability in Ghana's blue economy, particularly in fisheries, aquaculture, ports, and coastal tourism. This study explores how renewable energy integration can mitigate environmental impacts and ensure economic viability. Key objectives include: (1) assessing current energy consumption in coastal Ghana,

(2) evaluating renewable energy technologies for cost-effectiveness, scalability, and emission reductions, (3) analyzing global case studies of successful adoption, and (4) proposing policies to promote renewable energy. A mixed-methods approach combines quantitative data on fuel use, energy intensity, renewable capacity, and carbon emissions with qualitative insights from interviews with experts, policymakers, and stakeholders. Technologies such as offshore wind, solar, tidal, and wave energy are evaluated for their potential economic and environmental benefits. The study also considers biodiesel alternatives (Jatropha oil, Sunflower oil, Algal oil) for logistics in the sectors under review. Challenges include high initial costs for ports, technical limitations in fisheries (e.g., solar-powered vessels), limited local expertise, and inconsistent energy supplies affecting processing and tourism. Drawing on global and local case studies, the research identifies scalable renewable energy models. Policy recommendations include financial incentives, mandates, investments in R&D, public-private partnerships, and supportive regulatory frameworks to accelerate renewable energy adoption. These strategies aim to meet global climate goals while enhancing the economic and environmental resilience of Ghana's coastal communities.

Keywords: *Aquaculture, blue economy, coastal tourism, fisheries, ports, renewable energy.*

1. INTRODUCTION

The blue economy encompasses the sustainable use of ocean and coastal resources for economic growth, improved livelihoods, and marine ecosystem health (Underwood & Stempel, 2022). In Ghana, key sectors such as fisheries, aquaculture, maritime transport, and coastal tourism form the foundation of the blue economy, contributing significantly to the country's socioeconomic development (Ministry of Fisheries and Aquaculture Development, 2021). However, the heavy dependence on non-renewable energy sources in these sectors raises critical environmental, economic, and sustainability concerns (Knodt et al, 2023; Hagan & Amissah, 2022). Ghana's location along the Gulf of Guinea makes its blue economy central to the livelihoods of millions, with fisheries and aquaculture playing a vital role (Energy Commission of Ghana, 2020). These sectors employ over 2 million people and rely on energy- intensive processes, such as diesel-powered artisanal fishing vessels and electricity-dependent refrigeration and processing facilities (FAO, 2016; Ministry of Fisheries and Aquaculture Development, 2021). Similarly, aquaculture operations require substantial energy for water pumping, aeration, and temperature control, with costs exacerbated by the reliance on fossil fuels (Energy Commission of Ghana, 2020). Ports like Tema and Takoradi are also energy- intensive hubs, consuming large amounts of diesel and electricity for cargo handling, refrigerated storage, and lighting (Ministry of Fisheries and Aquaculture Development, 2021). Coastal tourism, another expanding sector, requires significant energy for accommodations, water desalination, and hospitality services. With tourism poised for further growth, energy inefficiencies pose a risk to sustainable expansion (United Nations, 2020). The reliance on fossil fuels in Ghana's blue economy brings numerous challenges. High energy costs and exposure to volatile fuel prices impact operational efficiency, while greenhouse gas emissions contribute to climate change (Hagan & Amissah, 2022). These challenges emphasize the urgent need to transition to renewable energy solutions that can stabilize costs, reduce environmental impacts, and align with Ghana's climate commitments under the Paris Agreement (United Nations, 2020). Renewable energy technologies such as solar, wind, and marine energy hold promise for powering Ghana's blue economy sustainably. Solar energy, given Ghana's abundant sunlight, can be utilized for aquaculture water pumping, fisheries refrigeration, and lighting in coastal tourism facilities (Energy Commission of Ghana, 2020). Coastal wind energy can support port operations and maritime activities, while marine energy from tides and waves offers long-term potential to complement the renewable energy mix (Cavagnaro et al, 2020). The integration of renewables can mitigate climate change impacts, enhance energy security, and support Ghana's Renewable Energy Master Plan, which aims for a 10% renewable energy share in electricity generation by 2030 (Energy Commission of Ghana, 2020). Transitioning to renewables not only aligns with Ghana's Nationally Determined Contributions (NDCs) but also offers economic benefits for coastal communities vulnerable to climate change (United Nations, 2020). Despite the advantages, several barriers hinder the widespread adoption of renewable energy in Ghana's blue economy. High upfront costs, limited technical expertise, and inadequate policy frameworks are major obstacles (Ministry of Fisheries and Aquaculture Development, 2021). For instance, deploying solar and wind systems requires significant investment in infrastructure and capacity-building. Integrating renewables into existing operations, such as fishing vessels and port activities, poses technical challenges that demand targeted research and development (Hagan & Amissah, 2022). Addressing these barriers presents opportunities for innovation and collaboration. Public- private partnerships (PPPs), international development assistance, and advancements in renewable technologies can drive the adoption of clean energy solutions (FAO, 2016). Government initiatives like the National Energy Transition Framework and policies that incentivize renewable energy investments are critical for overcoming financial and technical hurdles (Ministry of Energy, 2022). Global collaboration can further accelerate

Ghana's transition to a sustainable blue economy. This research explores renewable energy's potential to power Ghana's blue economy efficiently and sustainably. It examines current energy consumption patterns, evaluates renewable technologies, and identifies integration pathways for fisheries, aquaculture, ports, and tourism. By providing actionable insights and policy recommendations, the study aims to enhance livelihoods, preserve marine ecosystems, and bolster Ghana's climate resilience (United Nations, 2020). Ultimately, the goal is to foster a sustainable blue economy that aligns with national and global climate action goals (Energy Commission of Ghana, 2020).

2. RESEARCH METHODOLOGY

This section outlines the approach and methods used to investigate the integration of renewable energy, specifically offshore wind, solar, tidal, wave energy and biodiesel into Ghana's blue economy. The section looked at the historic energy consumption for all the four key sectors of the blue economy Thereafter, the future demand fuels and electricity consumption were modelled to determine possible GHG emissions into the future for all the four sectors of the blue economy. The methodology comprises the following steps.

A. **Data Collection:** Data collection was carried out using surveys, interviews, and site visits. The main sources of data are Ghana Port and Harbour Authority, Ministry of Fisheries and Aquaculture Development (MOFAD), Fisheries Commission and Ministry of tourism

- **Surveys:** Distributed to stakeholders within the blue economy, including fishermen, aquaculture operators, port authorities, and tourism operators, to gather insights into their energy requirements.
- **Interviews:** Conducted with policymakers, renewable energy experts, and business leaders to understand barriers and opportunities for renewable energy adoption.

- **Site Visits:** Conducted at fishing ports, aquaculture farms, and coastal facilities to assess real-world energy needs and identify suitable locations for renewable energy installations.

B. **Technical and Economic Feasibility Assessment:** The technical and economic feasibility of implementing renewable energy in blue economy projects was evaluated. This include assessment of renewable energy potential, available technologies, and site- specific conditions. Also, estimating installation costs, operational savings, greenhouse emissions savings and return on investment (ROI) to determine the financial viability of renewable energy integration.

C. **Case Study Analysis:** Case studies and success stories of renewable energy integration in blue economy sectors, both within and outside Ghana, were analyzed. These examples provided insights into best practices, lessons learned, and critical factors for effective implementation, such as stakeholder engagement and technological considerations.

D. Policy Recommendations and Strategy Development: Based on findings from the previous steps, policy recommendations and strategies were developed to address barriers to renewable energy adoption. These included suggestions to enhance regulatory frameworks, incentivize investments, and promote sustainable energy practices across Ghana's blue economy.

Scope of the study

The study is specifically focused on the coastal areas of Ghana. Ghana's coastline spans several regions, each with unique features. Greater Accra Region, known for its capital city, Accra, and bustling urban beaches like Labadi Beach. Central Region which is famous for historical landmarks like Cape Coast Castle and Elmina Castle, as well as scenic beaches. Western Region is also home to some of Ghana's most pristine beaches, including those in Takoradi, Axim, and Busua. Volta Region also known for its coastal lagoons, rivers, and scenic beaches, such as those in Ada and Keta.

Specific areas where this work focused on are Ghana port (Tema port and Takoradi port), Aquaculture (key ares are Kpeve, Kpong, and Akosombo, Asuogyaman District, lake volta adjacent areas, Tema, Kumasi, Nzema East and Shama, Winneba and Cape Coast, Tano River), Fisheries (key areas are Tema, Jamestown (Accra), Teshie and Nungua, Cape Coast, Elmina, Winneba, Anomabo, Takoradi, Axim, Dixcove, shama, Keta, Anloga, Ada, Half Assini) and Coastal tourism (key areas are Labadi Beach (Accra), Bojo Beach, Jamestown, Cape Coast, Elmina, Anomabo, Winneba, Takoradi, Busua Beach, Axim, Dixcove, Keta, Ada Foah, Half Assini)

3. RESULTS AND DISCUSSION

3.1 Fuel Energy Consumption for Ghana Port Operation

Energy consumption at the Ghana Ports and Harbours Authority (GPHA) involves both electrical and fuel energy across its two main ports namely, Tema and Takoradi. These energy sources power port operations, equipment, facilities, and infrastructure. Fuel consumption is essential for heavy-duty machinery, transport, and backup power in the port, particularly for activities where electricity isn't viable due to high power requirements or operational demands. The primary fuel sources used are diesel and marine fuel. The data from Ghana Port and Harbour Authority provided details of fuel consumption at Ghana's port operations across various equipment categories, including cranes, forklifts, tugboats, pilot boats, salvage boats, patrol boats, mooring launches, and generatorsThe Reach Stackers have the highest daily fuel consumption, likely indicating their intensive use or higher operational demand. The data lists six tugboats with fuel consumption ranging from 645 to 1,823 liters per day. The Josephine Asante tugboat has the highest daily consumption (1,823 liters), while the T.T. Addy has the lowest at 645 liters. Variation in fuel consumption suggests different usage intensities or power capacities among the tugboats. Patrol Boats: Consumption varies, with Joseph Adorkor using
193 liters and Cletus Adugbire using 93 liters. Pilot Boats: Consumption ranges from 80 to 482 liters, with the Adjei Kumi Sam being the highest consumer at 482 liters, while others, like Osagyefo and Frederick Damalie, consume less (90 and 80 liters, respectively). The difference in fuel consumption may reflect variations in operational distances or the frequency of missions for each vessel. The data also lists several generator sets, varying in

capacity (250 KVA to 1.7 MVA), with fuel consumption per year ranging from 507.76 liters (GPHA F.H Security) to 7,882.83 liters (GPHA Reefer Terminal). Larger capacity generators, such as the 1.7 MVA at GPHA Sub #6, generally have higher annual fuel needs. However, some lower-capacity generators like the 550 KVA at the Reefer Terminal exhibit high annual consumption, which could indicate sustained usage. Among equipment, Reach Stackers use the most diesel daily, with vessels, the Josephine Asante tugboat is the largest consumer and for generator sets, GPHA Reefer Terminal has the highest annual consumption.

3.1.2 Annual Energy Consumption Estimate

The annual energy consumption for Ghana Port Operation refers to the total amount of energy required over a year for all operations at the port, including equipment, vessels, and generators. It is calculated based on the daily diesel consumption values provided and converted into energy using diesel's energy content. Figure 3.2 depicts the annual fuel usage by equipment type. Diesel fuel has an approximate energy content of 10 kWh per liter. This is used to convert diesel consumption (in liters) into energy (in kilowatt-hours, kWh). The annual Diesel

3.1.3 Projected Annual Energy Consumption

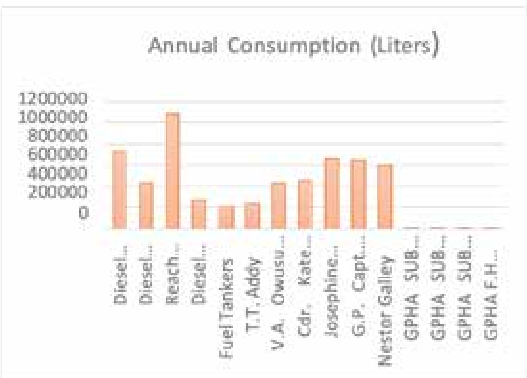


Figure 3.2: Annual fuel usage by equipment type

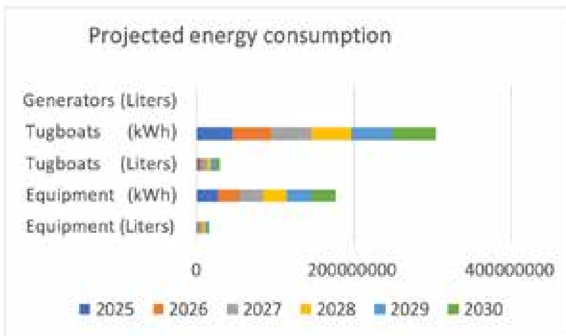


Figure 3.3: Projected energy consumption from 2025 -2030

Consumption for each item = Daily Consumption (liters) × 365. Annual Energy Consumption (kWh) for each item = Annual Diesel Consumption × 10. By summing up the energy consumption for equipment, vessels, and generators, the grand total is 58,145,046kWh/year(≈58.1GWh/year).

The projected annual energy consumption refers to the total energy requirement for Ghana Port operations, derived from the projected diesel consumption for various categories: Figure 3.3 projected energy consumption from 2025 -2030 Equipment, Tugboats, and Generators. It is calculated by converting diesel consumption into energy (kilowatt-hours, kWh) using diesel's energy content. Projected annual energy consumption is given by the expression, Base Annual Consumption×$(1-h)$ 2025. The projected annual diesel consumption from 2025 to 2030 reveals key insights into energy demand trends for Ghana Port operations across Equipment, Tugboats, and Generators. The 3% annual growth rate applied to all categories results in a consistent increase in diesel consumption over the six-year period. The total diesel consumption grows from approximately 5.84 million liters (58.39 GWh) in 2025 to 6.77 million liters (67.69 GWh) in 2030, representing a 16% increase over the projection period.

3.1.4 Projected Greenhouse Gas Emissions

Using the emissions factor of 2.68 kg CO_2 per liter of diesel, GHG emissions increase proportionally with energy consumption. Figure 4 gives projected emission from 2025 -2030. The total emission grows from approximately 15.64 million kg CO_2 (15,640 metric tons) in 2025 to 18.14 million kg CO_2 (18,140 metric tons) in 2030, representing a 16% increase over the projection period, mirroring the rise in diesel consumption.

3.2 Energy Consumption in Fishing Sector of Ghana

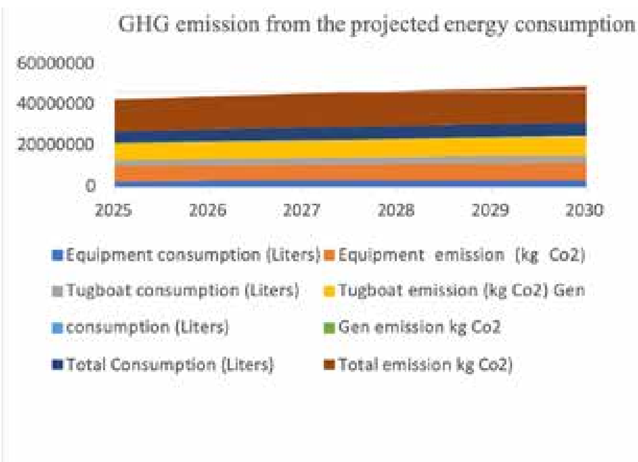


Figure 3.4: Projected emission from 2025 -2030 in the port sector

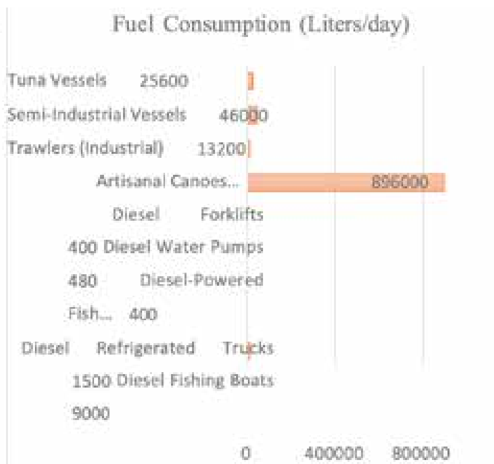


Figure 3.5: Daily energy consumption per day in the fishing sector

The daily energy consumption is the sum of the fuel consumption for all equipment listed in the dataset. Figure 3.5 shows daily energy consumption per day. Each equipment type contributes a specific amount to the overall daily fuel usage. The total daily energy consumption is 992,580 liters per day.

3.2.1 Projected Energy Consumption (2025–2030)

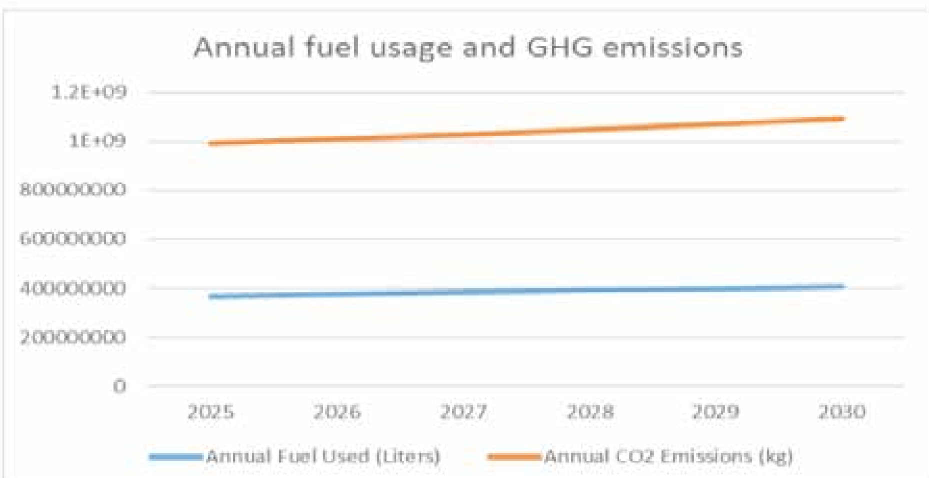
To forecast future energy consumption, the annual growth rate is assumed to be 2%. This rate accounts for increased activity, growth in operations, or population changes in the fishing community. The base year is 2024, with daily consumption of 992,580 liters. Future Consumption = Current Consumption $\times (1-h)$ 2025. Table 1 shows daily and annual usage in the fishing sector while Figure 3.6 depicts annual GHG emission for fishery sector. The daily consumption grows from 1,012,431 liters/day in 2025 to 1,117,806 liters/day in 2030. This reflects a steady rise in energy demand, driven by the assumed growth rate. By 2030, the daily consumption is projected to increase by about 12.6% compared to 2024 levels. By 2030, daily energy consumption increases by approximately 12.6% compared to 2024 levels. Also, by 2030, annual CO_2 emissions will rise to 1.092 million tons, an increase of around 12.6% from 2024.

3.3 Energy Consumption in Aquaculture Sector of Ghana

Table 1: Daily and annual fuel usage in fishing sector

Year	Daily energy consumption (Liters)	Annual fuel use (Liters)
2025	1012431	369535315
2026	1032680	376923200
2027	1053333	384432469
2028	1074400	392064456
2029	1095888	399820578
2030	1117806	407702439

Figure 3.6: Annual GHG emission for fishery sector



The total daily energy consumption for the aquaculture equipment provided is calculated by summing up the average fuel consumption (in liters/day) for each equipment type. Figure 3.7 shows the daily energy consumption for aquaculture sector. The total daily energy consumption is 58800liters/day, representing the amount of fuel required to operate all the equipment on an average day.

3.3.1 Projected Energy Consumption (2025–2030)

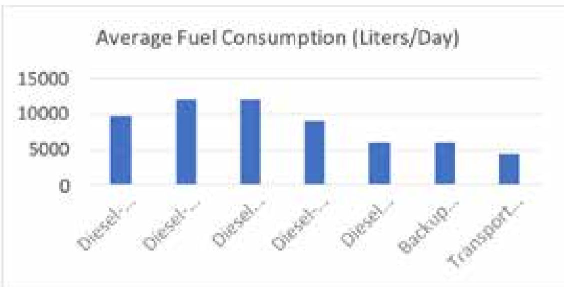


Figure 3.7: Daily energy consumption for Aquaculture Sector

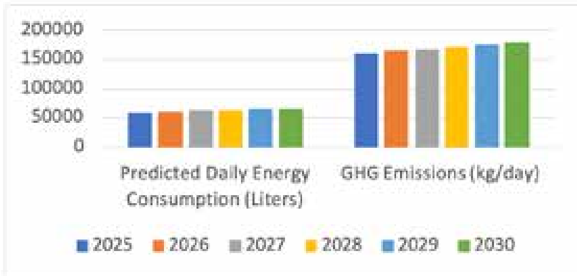


Figure 3.8: Forecast of energy consumption and GHG emission in the Aquaculture sector

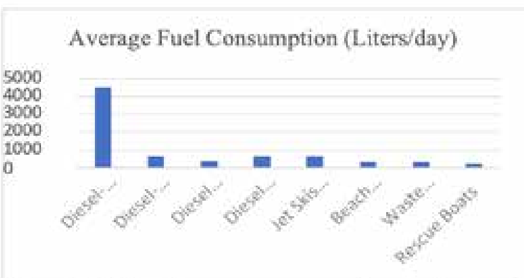


Figure 3.9: (a) Daily energy consumption in the Coastal Tourism

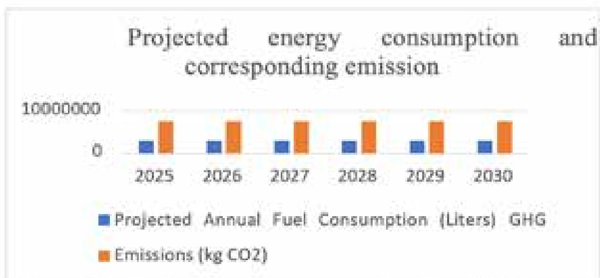


Figure 3.10: Projected energy consumption from 2025 to 2030 in the Coastal Tourism

To predict the daily energy consumption from 2025 to 2030, work assumed an annual growth rate of 2%. This reflects a gradual increase in fuel usage, potentially due to expansion in operations, additional equipment, or increased usage. The formula for calculating each year's projected daily consumption is given by the expression, Future Consumption =Current daily Consumption×Current Consumption × $(1-h)$ 2025. Figure 3.8 shows the forecast of energy consumption and GHG emission. The predicted daily consumption

increases each year due to the 2% growth assumption. By 2030, the daily consumption is expected to reach approximately 66,217 liters/day, which is about 12.5% higher than the current daily consumption of 58,800 liters/day. This pattern provides insights into planning for fuel supply, operational costs, and potential environmental impacts over the next decade. To estimate greenhouse gas (GHG) emissions, work considered an emission factor that relates fuel consumption to the amount of GHG emitted. For diesel fuel, a commonly used emission factor is 2.68 kg of CO_2 per liter of
diesel burned. The expression for GHG emissions from 2025 to 2030 is given by GHG Emissions (kg/day) = Daily Consumption (liters)×2.68.

3.4 Energy Consumption in Coastal Tourism Sector of Ghana

The provided data outlines the average daily fuel consumption for various diesel-powered equipment. This data was used to calculate the total daily energy consumption and project annual energy consumption from 2025 to 2030. Figure 3.9 shows daily energy consumption in the tourism sector while Figure 3.10 shows the projected energy consumption from 2025 to 2030. The total daily and annual fuel consumption are 7425liters/day and 2,709,125liters/year respectively. This total reflects the daily operational demand for diesel fuel by tourist boats, buses, forklifts, and other equipment. The greenhouse gas emissions are estimated using the diesel emission factor of 2.68 kg CO_2 per liter. GHG Emissions (kg CO_2) = Fuel Consumption (liters)×2.68. The annual GHG Emissions is estimated to be 7,259,457kg CO_2/year. This means that the operations would release approximately 7,259 metric tons of CO_2 annually.

3.5 Total Daily and annual Fuel Consumption for the Four Sectors of Blue Economy The analysis provides insights into the current and projected energy consumption and corresponding greenhouse gas (GHG) emissions for the critical sectors (fisheries, aquaculture, ports, and coastal tourism) of the blue economy. The total energy consumption is 1,081,568 liters/day. This figure represents the sum of diesel usage across all listed equipment and vehicles operating daily at all the four sectors under study. Major contributors include artisanal canoes with outboard motors, trawlers, tuna vessels, and other high-consuming units. Similarly, the total annual energy consumption is 394,807,952 liters/year. This is derived by adding annualized daily consumption (daily total × 365 days) to directly provided annual consumption figures. It highlights the immense energy demand of the port's operations over a year.

A. Future Energy Consumption and GHG Emissions

A 3% annual growth rate reflects an expected increase in operations of all the four critical sectors of the blue economy, population, or industrial activities, leading to higher energy needs. From 406 million liters in 2025 to 471 million liters in 2030, consumption grows steadily each year. Also, diesel consumption translates into significant emissions due to diesel's emission factor (2.68 kg CO_2 per liter). Emissions rise from 1.09 billion kg CO_2 in 2025 to 1.26 billion kg CO_2 in 2030, reflecting the environmental impact of increasing energy use. Table 2 gives detail analysis of the future consumption and the GHG emission patterns.

B. Feasibility and Benefit of Adoption of Replacing Diesel with Biodiesels

Table 2: Projected Energy Consumption and GHG Emissions (2025–2030)

Year	Energy Consumption (liters/year)	GHG Emissions (kg CO2/ year
2025	406,652,191	1,089,827,872
2026	418,851,757	1,122,522,708
2027	431,417,309	1,156,198,389
2028	444,359,829	1,190,884,341
2029	457,690,623	1,226,610,871
2030	471,421,342	1,263,409,197

To evaluate the feasibility and benefits of replacing diesel with biodiesels such as Jatropha oil, Sunflower oil, and Algal oil biodiesel for all the four sectors of the blue economy, certain key aspects is analysed: technological readiness, cost-effectiveness, scalability, and emissions reduction potential.

1. Technological Readiness - Biodiesel Compatibility

With Jatropha Oil it is highly compatible with existing diesel engines after minimal modification. It has proven as a viable fuel in various applications; supported by adequate research and field tests. Sunflower Oil is readily usable in modified diesel engines; straight vegetable oil (SVO) also an option but requires pre-heating. It has higher viscosity than diesel, leading to potential clogging without blending. Algal Oil is a newer option and requires advanced production technology. It can be converted to biodiesel via transesterification, suitable for conventional diesel engines. Jatropha and Sunflower oils are immediately deployable with existing engine technology. Algal oil biodiesel is less mature, needing further innovation to optimize extraction and conversion.

2. Cost-Effectiveness - Production and Market Costs

Jatropha Oil has relatively low production cost and requires marginal land unsuitable for food crops. The estimated production costs range from \$0.50 to \$1.00 per liter, cheaper in regions where Jatropha grows naturally. Sunflower Oil has higher production cost due to competition with edible oil markets and intensive cultivation inputs. The costs are typically higher than Jatropha (\$1.10–\$1.50 per liter). Algal Oil has high production cost (\$5–\$10 per liter) due to energy-intensive cultivation, harvesting, and oil extraction processes. It shows sign of significant potential for cost reduction with technological advancements and economies of scale. Jatropha oil biodiesel is the most cost-effective option for immediate deployment. Algal oil is currently expensive but holds long-term potential.

3. Scalability - Supply Chain and Resource Availability

Jatropha Oil has high scalability in Ghana and other tropical regions. It can be cultivated on non-arable land but the large-scale adoption may face limitations in seed production and processing infrastructure. The sunflower Oil has limited scalability in regions where Sunflower cultivation is not already widespread. It competes directly with food markets, leading to concerns about food security. With Algal Oil, theoretical scalability is vast; algae can be grown in ponds, wastewater, or photo-bioreactors. It is currently hindered by lack of infrastructure and high capital investment requirements. Jatropha oil is the most scalable in local contexts, while algal oil could be scalable globally if costs decrease.

4. Emissions Reduction Potential - Lifecycle GHG Emissions

The lifecycle emissions of Jatropha oil are 40%–80% lower than diesel due to carbon sequestration during Jatropha growth. It has significant reductions in particulate matter and sulfur oxide emissions. The Sunflower oil is similar to Jatropha, the lifecycle GHG emissions are reduced by 50%–80% compared to diesel. The blended fuels reduce engine wear and enhance efficiency. Algal Oil offers the lowest emissions (up to 90% reduction compared to diesel), as algae absorb large amounts of CO_2 during cultivation. It has a potential to produce biofuel with minimal land-use impact. All options dramatically reduce emissions compared to diesel, with Algal oil offering the greatest reduction potential.

5. Operational Benefits

It has lower GHG emissions, since all biodiesels offer cleaner combustion. The use of biodiesel reduces dependence on imported diesel, especially if locally produced. It promotes local agriculture and industrial growth.

6. Operational Challenges

It has initial cost of engine modifications for compatibility. It requires investment in biodiesel production and distribution infrastructure. There is seasonal variability in feedstock supply for Jatropha and Sunflower oils. Table 3 provides a summary of the feasibility and benefits of replacing diesel with biodiesel.

C. Alternative Scenarios for Greenhouse Gas Emissions Savings Using

Table 3: Feasibility and benefits of replacing diesel with biodiesels

Factor	Jatropha oil	Sunflower oil	Algal oil
Technological Readiness	High	Moderate	Low
Cost-Effectiveness	High	Moderate	Low
Scalability	High	Low	Moderate-High
Emissions Reduction	Moderate-High	Moderate	High

Biodiesel The replacement of diesel with biodiesel fuels from Jatropha oil, Sunflower oil, and Algal oil significantly reduces greenhouse gas (GHG) emissions. Below is an evaluation of GHG savings under different scenarios, considering the lifecycle emissions reductions provided by each biodiesel type.

1. Key Assumptions

Current Diesel Usage: Based on the four sectors (fisheries, aquaculture, ports, and coastal tourism) operations, total annual diesel consumption is approximately 394,807,952 liters/year Emission Factor for Diesel: 2.68 kg CO_2 per liter of diesel. Emission Reductions: Jatropha oil: 0.6–1.6 (70%–85% reduction compared to diesel), Sunflower oil: 0.7–1.7 (65%–80% reduction) and Algal oil: 0.3–0.6 (85%–90% reduction). Table 4 shows alternative reduction for greenhouse gas emission savings. The emission reduction for Jatropha oil saved 426 to 821 million kg CO_2/year while sunflower oil saved 387 to 782 million kg CO_2/year. The algal oil saves 821 to 940 million kg CO_2/year, offering the largest reduction. Even the least effective alternative (Sunflower oil at a 65% reduction) saves over 380 million kg CO_2 annually. Transitioning entirely to Algal oil could cut emissions by up to 90%, a reduction of nearly 940 million kg CO_2.

D. Combined Strategy Scenarios Assumptions:

Table 4: Alternative Scenarios for Greenhouse Gas Emissions Savings

Fuel Type	Emission Factor (kg CO_2 /liter)	Annual Emissions (kg CO_2 /year)	Savings (%)	Savings (kg CO_2 /year)
Diesel	2.68	1,058,057,332	Baseline	-
Jatropha Oil	0.6–1.6	236,884,771–631,692,723	70%–85%	426,364,609–821,172,561
Sunflower Oil	0.7–1.7	276,365,566–671,172,519	65%–80%	386,884,812–781,691,766
Algal Oil	0.3–0.6	118,442,386–236,884,771	85%–90%	821,172,561–939,614,946

Fuel Requirement: Replace all diesel consumption (394,807,952 liters/year). Blending Ratios: Different shares of Jatropha, Sunflower, and Algal biodiesels are considered:
Scenario 1: 50% Jatropha, 30% Sunflower, 20% Algal.
Scenario 2: 40% Jatropha, 40% Sunflower, 20% Algal.
Scenario 3: 30% Jatropha, 30% Sunflower, 40% Algal. Yields and Costs (per hectare/year):
Jatropha: 1,500 liters, \$0.50–\$1.00/liter. Sunflower: 800 liters, \$1.10–\$1.50/liter.
Algal Biodiesel: 40,000 liters, \$5.00–\$10.00/liter.

Table 5 shows combined strategy scenarios of the sources of biodiesel. Land requirements are highest for Scenarios 1 and 2 due to the larger share of Jatropha and Sunflower oils, which have lower yields. Scenario 3 requires the least land but shifts the cost burden to Algal biodiesel, which has high production costs. Scenario 1 is the most cost-effective, with total costs ranging from \$666M–\$1.22B/year. Scenario 3 is the most expensive, primarily due to the reliance on Algal biodiesel. Scenario 3 offers the highest GHG savings (80%) due to the larger share of Algal biodiesel. Scenario 1 strikes a balance, offering significant GHG savings (77.5%) at a lower cost.

E. Financial Viability of replacing diesel with Biodiesel

Table 5: Combined Strategy Scenarios

Scenario	Land (ha)	Cost ($/year)	GHG Savings (%)
Scenario 1	**Jatropha**: 131,603	**Jatropha**: $98.7M–$197.4M	77.5%
50% Jatropha	**Sunflower**: 148,052	**Sunflower**: $173.1M–$236.9M	
30% Sunflower	**Algal**: 1,974	**Algal**: $394.8M–$789.6M	
20% Algal	**Total**: 281,629	**Total**: $666.6M–$1,223.9M	
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Scenario 2	**Jatropha**: 105,283	**Jatropha**: $78.9M–$157.6M	75%
40% Jatropha	**Sunflower**: 197,404	**Sunflower**: $230.8M–$315.8M	
40% Sunflower	**Algal**: 1,974	**Algal**: $394.8M–$789.6M	
20% Algal	**Total**: 304,661	**Total**: $704.5M–$1,263M	
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Scenario 3	**Jatropha**: 78,962	**Jatropha**: $59.2M–$118.9M	80%
30% Jatropha	**Sunflower**: 148,052	**Sunflower**: $173.1M–$236.9M	
40% Algal	**Algal**: 3,948	**Algal**: $789.6M–$1,579.2M	
Total: 230,962	**Total**: $1,021.9M–$1,935M		

This aspect estimates the installation costs, operational savings, greenhouse gas (GHG) emissions savings, and return on investment (ROI) for using Jatropha, Sunflower, and Algal biodiesel to replace diesel. Table 6 shows a comprehensive table that demonstrates the financial viability of replacing diesel with Jatropha, Sunflower, and Algal biodiesel. This includes installation costs, annual savings, GHG emissions savings, monetized GHG savings, and ROI. The results show that Jatropha has annual savings of $276.4M (minimum cost scenario) to $79M (maximum cost scenario). With the corresponding GHG Savings of 821,172 tons of CO_2 (minimum emissions scenario). The return of investment (ROI) is 127% (maximum cost scenario) to 803.88% (minimum cost scenario). The sunflower biodiesel has annual savings of $39.5M (minimum cost scenario) to a loss of $118.4M (maximum cost scenario), while GHG savings is 781,692 tons of CO_2 (minimum emissions scenario). The ROI is 90.46% (minimum cost scenario) to -83.68% (maximum cost scenario). Algal biodiesel has annual Losses of $1.5B (minimum cost scenario) to $3.4B (maximum cost scenario). The GHG Savings is 939,614 tons of CO_2 (minimum emissions scenario), while ROI is -367.91% (minimum cost scenario) to -434.87% (maximum cost scenario). Jatropha biodiesel is the most financially viable option due to its low production costs and moderate GHG emission factor. The substantial cost savings and high ROI in the minimum cost scenario make it ideal for large-scale adoption. Sunflower biodiesel offers moderate GHG savings but struggles with cost-effectiveness. The minimum cost scenario yields a positive ROI, but high production costs in the maximum scenario lead to financial losses. Algal biodiesel achieves the highest GHG savings, reducing emissions by up to 90%, but is extremely costly due to its high production and infrastructure requirements. Negative ROI in both scenarios highlights that algal biodiesel is not financially viable with current technology. Long-term investments in research and development are needed to lower costs and make it competitive.

V. Integrating Offshore Renewable Energy Sources into Ghana's Blue

Table 6: Biodiesel Financial Viability

Metric	Jatropha (Min)	Jatropha (Max)	Sunflower (Min)	Sunflower (Max)	Algal (Min)	Algal (Max)
Annual Diesel Consumption (liters)	394,807,952	394,807,952	394,807,952	394,807,952	394,807,952	394,807,952
Diesel Price ($/liter)	1.20	1.20	1.20	1.20	1.20	1.20
Biodiesel Cost ($/liter)	0.50	1.00	1.10	1.50	5.00	10.00
Diesel Cost Avoided ($)	473,769,542.40	473,769,542.40	473,769,542.40	473,769,542.40	473,769,542.40	473,769,542.40
Biodiesel Cost ($)	197,403,976.00	394,807,952.00	434,288,747.20	592,211,928.00	1,974,039,760.00	3,948,079,520.0
Annual Savings ($)	276,365,566.40	78,961,590.40	39,480,795.20	(118,442,385.6)	(1,500,270,217.6)	(3,474,310,477.6)
GHG Emissions Diesel (kg)	1,058,057,332	1,058,057,332	1,058,057,332	1,058,057,332	1,058,057,332	1,058,057,332
GHG Emissions Biodiesel (kg)	236,884,771	631,692,723	276,365,566	671,172,519	118,442,386	236,884,771
GHG Savings (tons)	821,172.56	426,364.61	781,691.77	386,884.81	939,614.95	821,172.56
Monetized GHG Savings ($)	41,058,627.90	21,318,230.25	39,084,588.50	19,344,240.50	46,980,747.50	41,058,627.90
Total Savings ($)	317,424,194.30	100,279,820.65	78,565,383.70	(99,098,145.10)	(1,453,289,470.1)	(3,433,251,849.7)
Installation Cost ($)	39,480,795.20	78,961,590.40	86,857,749.44	118,442,385.60	394,807,952.00	789,615,904.00
ROI (%)	803.88	127.03	90.46	(83.68)	(367.91)	(434.87)

Economy Sectors Integrating offshore wind, solar, tidal, and wave energy into fisheries, aquaculture, ports, and coastal tourism within Ghana's blue economy can significantly reduce emissions and operational costs. Offshore wind farms can supply electricity to onshore fish processing plants, cold storage facilities, and aquaculture operations. Co-locating offshore aquaculture cages beneath wind turbines optimizes ocean space usage, providing clean energy directly to the farms for equipment like aerators, pumps, and feeding systems. Ports can use offshore wind energy to power electric cargo cranes, shore power systems for docked ships, and electric vehicle (EV) charging stations. Also, the integration of offshore wind farms into microgrids for port operation can ensure low-carbon energy supply. In the case of coastal tourism, offshore wind farms can supply clean energy to coastal hotels, resorts, and tourism facilities. Tours of offshore wind farms can attract environmentally conscious tourists. Per the data available for fisheries, aquaculture, ports, and coastal on electrical equipment, the total daily and annual grid power consumption are 62,785.2 kW/day and 22,916,598 kWh/year.

A. Predicted Annual Grid Power Consumption (2025–2030)

Figure 3.11 estimates the total energy demand on the grid from 2025 to 2030. Using a 3% annual growth rate, we account for increased usage of existing equipment, potential addition of new equipment or facilities and gradual expansion of operations. Annual grid demand is expected to rise by about 3% each year, adding approximately 680,000–800,000 kWh annually. By 2030, grid power consumption is expected to increase by about 4.5 million kWh, or approximately 20% more than 2025.

B. Feasibility and Benefits of Replacing Grid Power

A mix of offshore wind and solar offers the best near-term feasibility and scalability. Tidal and wave energy can complement as they mature technologically and become more cost-effective (Green et al, 2019). Replacing the 22.9 GWh/year grid power entirely with renewables can reduce annual emissions by 12,500–15,000 metric tons of CO_2, assuming grid power has an average emissions factor of 0.54 kg CO_2/kWh. The challenges are high upfront investment for infrastructure, the need for energy storage or complementary sources to manage intermittency (especially for solar and wind) and site-specific environmental and regulatory hurdles. The advantages are Near-zero operational emissions from renewables (Giannoumis, 2021), and reduced reliance on fossil fuels and volatile energy markets. Declining costs of renewables make them cost-competitive with traditional grid power. Table 6 shows the capital and operational expenditure assessment based on the data from the four sectors of the blue economy.

I. Successful Renewable Energy Strategies in the Blue Economy Sectors

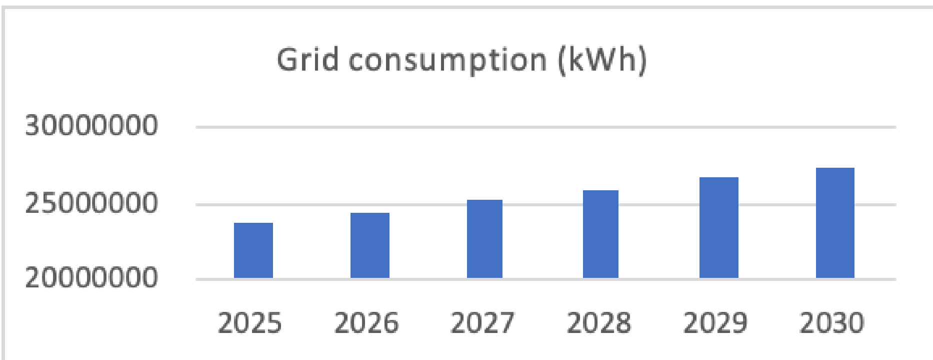


Figure 3.11: Predicted Annual Grid Power Consumption (2025– 2030)

Figure 6: Capital and operational expenditures renewable energy technology.

Energy Source	Required Capacity (MW)	CAPEX ($M)	OPEX ($M/year)	LCOE ($/MWh)	Annual Cost ($M)
Offshore Wind	5.8	20.3–29.0	0.41–0.87	75–110	1.72–2.52
Solar (Onshore)	13.1	10.5–15.7	0.11–0.31	30–60	0.69–1.37
Solar (Floating)	13.1	18.3–26.2	0.18–0.52	50–90	1.15–2.06
Tidal Energy	6.5	29.25–39.0	0.88–1.56	150–250	3.43–5.73
Wave Energy	7.5	37.5–75.0	1.13–3.75	200–500	4.58–11.45

Onshore Solar is the most cost-effective option with the lowest LCOE and CAPEX. However, it may require substantial land area and is weather-dependent. Offshore Wind provides reliable energy with moderate costs and high scalability. Tidal and Wave Energy are significantly more expensive and less mature but offer long-term potential. Floating Solar is promising but currently costlier than onshore solar.

Global case studies highlight innovative renewable energy adoption strategies across the fisheries, aquaculture, ports, and coastal tourism sectors, providing pathways for reducing emissions and enhancing sustainability in the blue economy. Table 7 depicts global case studies for adoption of renewable energy into various sectors of the blue economy which showcases innovative technologies, successful policies, and proven renewable energy solutions. Renewable energy adoption is most mature in ports (e.g., cold ironing in Germany) and least integrated into fisheries and aquaculture. Biodiesel is gaining traction in logistics, especially in countries like Ghana, to reduce reliance on diesel fuels. Large-scale offshore wind projects for aquaculture can exceed $50M, while smaller solar or biodiesel projects for ports and fisheries are more affordable. Biodiesel costs remain high due to feedstock production needs. CO_2 reductions of up to 86% are possible with renewable integration, though initial costs and infrastructure readiness remain barriers This provides adaptable solutions that align with Ghana's unique challenges and opportunities, such as biodiesel adoption for logistics. Renewable energy integration remains in its early stages, with solar PV and wind showing potential to reduce emissions significantly (up to 86%) However, cost barriers (e.g., increased electricity costs by 34%) and seasonal challenges (e.g., short fishing seasons) slow adoption. Wave and offshore wind energy dominate renewable initiatives, particularly in Europe and Asia. These technologies address the energy demands of remote operations and align with environmental goals Co-locating aquaculture with offshore wind farms reduces costs and optimizes marine space usage. While promising, these projects face high capital costs, exceeding $50M for large-scale systems. Ports are leading in renewable energy adoption through cold ironing and hybrid systems powered by solar and wind. Germany and the UAE showcase successful implementation. These systems cut operational emissions significantly and modernize logistics, but initial infrastructure investments remain a challenge. Renewable energy adoption in resorts (e.g., floating solar, wind) aligns with eco-tourism trends in the Caribbean and Maldives. Smaller-scale projects ($500K–$5M) achieve substantial branding and environmental benefits, attracting sustainability-focused travellers. Ghana's focus on biodiesel (e.g., Jatropha and Sunflower) for logistics shows significant emissions reductions (70%-85%). However, production costs ($197M–$395M annually) and land use requirements limit scalability.

II. Policy Recommendations to Facilitate Renewable Energy Usage in the

Table 7: Global case studies for adoption of renewable technology

Sector	Country	Technology Adopted	Biodiesel Integration	Project Cost (Estimates)	Key Insights
Fisheries	USA (Mississippi, Alaska)	Solar PV, Wind	Limited; focus on diesel replacement	$1M–$5M for solar installations	Solar/wind systems for catfish farming reduced CO_2 by 86% but increased electricity costs.
	Norway, Netherlands	Offshore wind, hybrid power	Exploring biodiesel in vessel engines	Varies; hybrid vessel retrofit $2M	Co-location of offshore wind and aquaculture supports emissions reductions
Aquaculture	Japan, China	Floating Solar, Wave Energy	Trials on biodiesel for remote aquafarms	$3M–$8M for pilot-scale projects	Solar and wave energy address offshore needs while reducing emissions.
	UK	Wave Energy, Wind Farms	Not integrated	$50M–$100M for large-scale systems	Wave Hub Project powers aquaculture and tourism with renewable energy.
Ports	Germany	Cold Ironing, Hybrid Systems	Biodiesel adopted for port logistics	Solar systems ~$10M; hybrid trucks ~$1M/unit	Cold ironing and hybrid logistics reduce operational emissions.
	UAE (Jebel Ali)	Solar PV	Limited biodiesel for terminal equipment	$20M–$50M for large solar installations	Solar panels power cranes and port infrastructure.
Coastal Tourism	Caribbean (Jamaica, Aruba)	Solar, Wind	Limited	$500K–$2M per resort	Eco-tourism boosts with renewable-powered resorts.
	Maldives	Floating Solar	Trials in logistics for biodiesel-powered boats	$2M–$5M for installations	Floating solar offsets diesel dependency in island resorts.
Logistics	Ghana	Biodiesel (Jatropha, Sunflower)	Transitioning from diesel to biodiesel	$197M–$395M annually for biodiesel	Biodiesel logistics reduce emissions by 70%–85% while requiring substantial land.

Blue Economy Based on the data and global case studies, these policy recommendations target the fisheries, aquaculture, ports, coastal tourism, and logistics sectors. The focus is on reducing emissions, optimizing costs, and enhancing sustainability. Figure 11 (a) illustrates the proportion of energy consumption that each sector aims to offset with renewable energy sources while Figure 11 (b) reflects goals to reduce energy intensity through efficiency upgrades and the electrification of diesel-powered equipment. The renewable energy targets of 20% for fisheries and aquaculture, 50% for ports, and 30% for coastal tourism are set based on each sector's energy consumption patterns, operational requirements, and potential for renewable energy integration. Also, the efficiency and electrification targets are tailored to reflect the energy usage intensity, potential for improvements, and the operational constraints of each sector in Ghana's blue economy. These targets balance feasibility, economic considerations, and sustainability goals. Moderate targets reflect the fisheries and aquaculture sectors reliance on grid electricity for energy-intensive equipment like refrigeration and water pumps. Integrating renewable energy (e.g., solar or wind) for these sectors could support auxiliary equipment and reduce operational costs sustainably. Ports have the highest renewable energy target due to their significant energy demand, particularly from large equipment like electric cranes, shore power systems, and cold storage units. Ports are ideal for large-scale solar panel installations or wind turbines, given their open spaces and constant demand. Moderate renewable energy target for coastal tourism aligns with the sector's reliance on grid power for guest amenities like lighting, refrigeration, and air conditioning. Installation of solar panels and solar water heaters in resorts can significantly contribute to achieving this target.

Key Policy Recommendations:

i. Energy Audits and Efficiency Standards: Periodic energy audits must be conducting to identify high-consumption equipment and enforce minimum energy efficiency standards.

ii. Renewable Integration: Investments in renewable energy must be encouraged (e.g., on- site solar installations) to offset grid power usage, especially for shore power systems and water pumps. Ports to reduce energy intensity by 15% through upgrades by 2030. Coastal tourism to target a 10% reduction in grid reliance by implementing solar solutions and LED lighting.

iii. Incentives for Modernization: There should be a provision of tax benefits or subsidies for upgrading to energy-efficient technologies like LED lighting, efficient HVAC systems, and variable-speed motors. Convert 50% of diesel-powered forklifts and shuttle buses to electric by 2028.

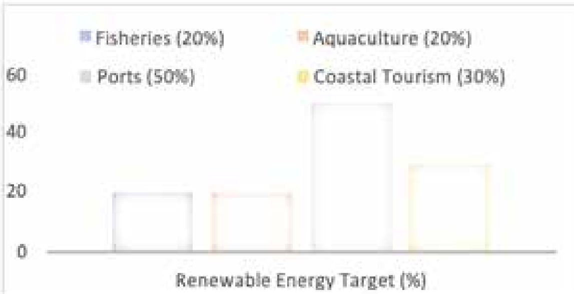
iv. Deploy electric boats in tourism and aquaculture sectors, aiming for a 30% replacement rate by 2030.

v. Demand-Side Management: Time-of-use tariffs must be introduced to shift energy usage to off-peak periods, minimizing strain on the grid.

vi. Smart Energy Solutions: There should be IoT-enabled devices and energy management systems to optimize consumption patterns based on real-time data.

vii. There should be promotion of the cultivation of Jatropha and Sunflower for biodiesel on underutilized lands to avoid food security conflicts. Subsidies must be provided for biodiesel production and use in logistics, particularly for heavy equipment like cranes, trucks, and vessels. Example: Ghana's focus on Jatropha biodiesel has the potential to reduce logistics emissions by 70%-85%.

4. Conclusion



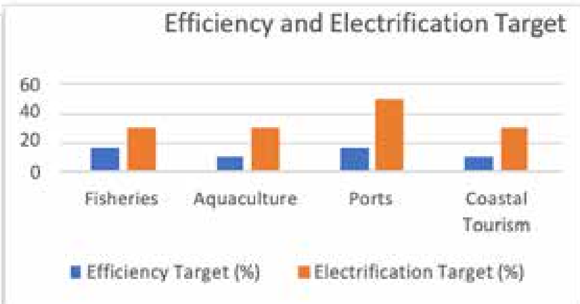


Figure 11: (a) Renewable energy target by sector *(b) Efficiency and electrification by sector*

This study underscores the significant impact and potential of renewable energy integration in Ghana's blue economy sectors namely, ports, fisheries, aquaculture, and coastal tourism. By transitioning from diesel-based operations to renewable energy sources like solar, wind, tidal, and biodiesel, Ghana can significantly enhance sustainability, reduce greenhouse gas (GHG) emissions, and optimize operational costs. Current diesel consumption across the four sectors totals approximately 394.8 million liters annually, resulting in emissions of 1.09 billion kg CO_2/year. By 2030, diesel consumption is projected to increase to 471 million liters/year, with emissions reaching 1.26 billion kg CO_2/year (16% increase). Replacing diesel with biodiesel can reduce emissions by 70%-85% using Jatropha oil, saving 426 to 821 million kg CO_2/year. 85%-90% using Algal oil, saving up to 940 million kg CO_2/year. Combined biodiesel strategies, such as a mix of 50% Jatropha, 30% Sunflower, and 20% Algal oil, could achieve a balanced 77.5% emissions reduction. With regards to energy cost and savings, using biodiesel (e.g., Jatropha oil) instead of diesel yields annual savings of up to $276 million, with a return on investment (ROI) of 127%–803%, depending on production costs. With regards to renewable energy integration feasibility, replacing annual grid power consumption of 22.9 GWh in fisheries, aquaculture, ports, and coastal tourism with renewables can reduce emissions by 12,500–15,000 metric tons CO_2/year. Offshore wind energy (5.8 MW capacity) and solar energy (13.1 MW capacity) are the most viable options, offering moderate costs and high scalability. With regards to sector-specific goals, port has a target of 50% renewable energy adoption by 2030, reducing energy intensity by 15%. Fisheries and Aquaculture aim to achieve 20% renewable energy reliance and electrification of 30% of equipment by 2030. Coastal Tourism aim for 30% renewable energy reliance and 10% grid energy reduction by adopting solar and LED technologies. With regards to projected renewable costs and emissions impact, offshore wind and onshore solar have the lowest levelized costs of energy (LCOE) at $30–$110/MWh, while tidal and wave energy, though less mature, provide long-term benefits at higher costs.

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Assessment of the Effectiveness and Challenges of Beach Management Units' Participation in Managing Fisheries Resources along the coast of Tanzania

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Abstract

Understanding institutional arrangements and operation boundaries is crucial for effectively enforcing management measures. The introduction of (BMUs) in 2003 at the landing site was to ensure community participation in management conserving fishery resources, and improving production. Despite these efforts, illegal fishing continues to increase, indicative of BMU's failure to achieve its objectives. The effectiveness of BMUs in implementing their roles is not well known. This study assessed the effectiveness and challenges of BMU participation in managing marine resources along the Tanzanian coast. The Ghent Participation Scale (GPS) was used to measure BMU participation in managing coastal marine resources under a co-management strategy. "Four hundred and fourteen respondents were interviewed, including fishers, traders, processors, porters, and 26 key informants (KII). Three BMUs were sampled on Kilindoni, Kipumbwi, and Kilwa Kivinje between January and November 2019. Data collection methods structured questionnaires, KII and focus group discussions. Two instruments the IPA and USER-P were used to verify the validity and reliability of GPS. Cronbach's alpha coefficient was used to scale reliability statistics. Data analysis was conducted using statistical packages for Social Sciences version 23. Content analysis was used to analyse qualitative information. Results showed the internal consistency with Cronbach's alpha coefficient of 0.768), implying that GPS is reliable for measuring participation. Findings indicate that there was low participation in implementing BMU activities. Results showed that the mean score of delegated activities (78.3%: ± 18.6) exceeded the mean score for self-performed) activities (68.2%: ± 16.1), implying low participation. Based on the findings using the GPS model, the study concludes that there was low participation in implementing BMU activities, which negatively affected performance. However, low participation was attributed to a lack of finance and government support. Funding mechanisms such as grants and government support are recommended for effective BMU performance.

Keywords: *Effectiveness, Beach management units, Participation, GPS, Challenges*

1.0 Introduction

In Tanzania, fisheries resources are protected, conserved, and managed under the Fisheries Act No. 22 of 2003, Fisheries Regulations of 2009, and Fisheries Policy of 2015. Understanding institutional arrangements and operation boundaries is crucial for effectively enforcing management measures (Mahonge, 2010). The main mechanism to guarantee community participation in the management of fisheries resources in their fishing regions is the establishment of (BMUs) in 2003 as a local institution at the landing site level (URT : MLFD, 2003). Although BMUs were involved, there is a lack of information regarding their performance/effectiveness in monitoring, controlling, and surveillance tasks and the efficiency of their involvement in sustainable fishery management (Kanyange et al., 2014).

Fisheries experts understand that by including fishermen, conflict sources can be diminished and managed sustainably. Conflicts, therefore, decrease when stakeholders are more actively involved in rights distribution, management, and equal access (Pomeroy et al., 2007). Population growth in communities depending on natural resources in emerging nations is increasing the risk of conflict (Robinson, 2016). The dependent groups compete more for a resource when the primary resource base is exhausted and there are no substitutes (Jimenez et al., 2019).

Four problems were noted by Abdurrahim et al. (2020) as potential explanations for the onset of conflict: Competition for natural resources, a) demographic shift (rapid influx of immigrants possibly due to deteriorating economic or ecological well-being in other sectors), and b) growing reliance on natural resources can intensify competition for resources and space. c) A shift in government policy from protecting livelihoods to promoting food production; and d) Modifications to laws that forbid or severely restrict access to resources for reliant sections in society.

The institutional framework that governs the fishing sector is known as fishery management. These could be determined by environmental pressure groups, fisher organizations, the government (fisheries authority), or social customs (Njaya, 2007). Using aquatic resources, fishery management analyzes potential courses of action and puts them into practice to achieve human aims and objectives (Kateka, 2010).

2.0 Material and Methods

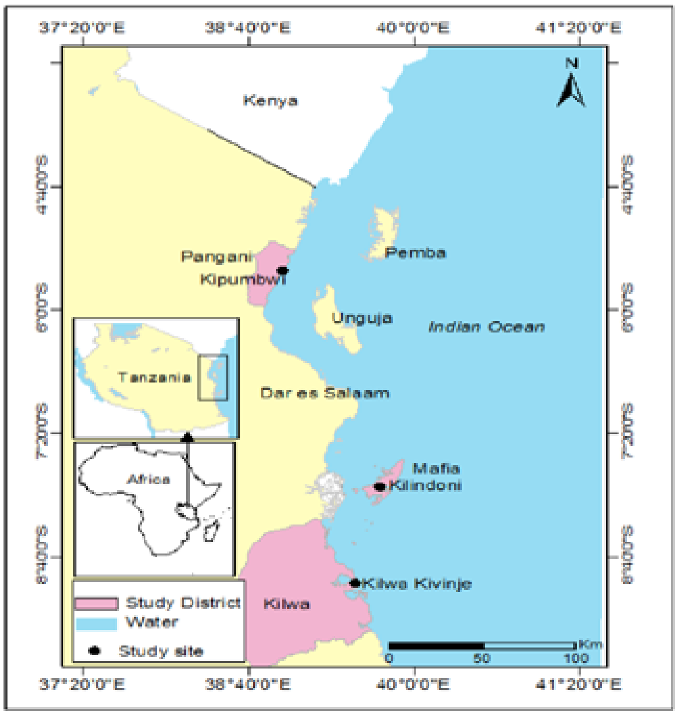
2.1 Description of the Study Area

This study was conducted in three landing sites, Kilindoni, Kipumbwi, and Kilwa Kivinje, found in the Mafia, Pangani, and Kilwa Districts, respectively (Figure 1). The study focused on areas with dominant landings of small pelagic fish, including Clupeidae (*Sardinella neglecta*) and Engraulidae (Stolephorus commersonii), locally known as dagaa (Breuil & Bodiguel, 2015). Most fisher communities in the study area depended mostly on fishery resources for their well-being due to the impoverished nature of coastal communities (Kapapa et al., 2024). The significant economic undertaking in the study area includes fishing and farming crops (rice, maize, sweet potatoes, cassava, coconut and cashew nuts, and livestock keeping) (Kapapa et al., 2024).

Kilindoni site is located at latitude. 7° 50′ S and longitude 39° 45′ E. According to the

Population and Housing Census, 2022 the population of Kilindoni was 25,680, and they depended on fishing activities for their income (DHS, 2022; Kapapa et al 2024), and inhabited by Swahili. Kilwa Kivinje (Kilwa District) is located at latitude 8° 45′ S and longitude. 39° 24′ E. Reported a population of 32,362, (DHS, 2022)), and the main economic activities are fishing, crop production, and livestock keeping. Kipumbwi (Pangani Districts located at latitude. 5° 38′ S and longitude 38° 54′ E is home to around 12,268 people (DHS, 2022), the majority heavily reliant on marine fisheries for income generation (Richmond et al., 2002).

The weather conditions of these study areas are that the study area experiences two monsoon wind seasons: Northeast, which starts from November to March, and southeast, from April to October (Fabiani et al., 2022). The monsoon winds facilitate water mixing and turbulence, transporting organic and inorganic nutrients from below the thermocline to the euphotic zone (Mcclanahan et al., 2008). The coastal area also experiences annual precipitation of between 1029 and 1289 mm (Mahongo et al., 2012). The weather in the coastal areas is the hottest and generally humid. The temperatures vary between 22°C and 31 °C throughout the year.



2.1.1 Study Area Map

Figure 1: Map of Tanzania showing the location of Kilindoni, Kipumbwi, and Kilwa Kivinje (Kapapa et al., 2022)

2.2 Sampling procedure and Sample Size determination

In this study, 20% of the total fisher's population was sampled, which is considered appropriate according to Gay et al. (2012). The sample sizes were determined using random sampling. The respondents per fishing vessel interviewed were fishers, including (master fishermen and crew. members (experienced 2- 5 years in fishing activities), dagaa processors "wachemshaji" local dagaa traders and porters. At Kilindoni, 20 active fishing vessels were sampled, while at Kipumbwi, 10%, and at Kilwa Kivinje, 10% of active dagaa fishing vessels were sampled. During the sampling period, the total number of active fishing vessels at Kilindoni was 20, as Kipumbwi and Kilwa Kivinje had approximately 100 active fishing vessels. One type of small pelagic (dagaa) fishing vessel was sampled.

The overall total population was 2,070. In total, the sample size was 414, which involved small pelagic fishers' communities (*n* = 217, including 40 master fishermen, based on the number of small pelagic fishing vessels sampled, and 177 crew members), processors (*n* = 63), porters (*n* = 39), and small pelagic/dagaa traders (*n* = 95; Table 2a) (). were sampled from three landing sites (Kilindoni - 184, Kipumbwi – 97 and Kilwa Kivinje - 133) to represent the entire population, which were used to get the sample from each landing site. Three (3) landing sites were purposefully selected for the study (Kapapa et al., 2004). The primary study key players were small pelagic fishers (master fishermen/captains and crew members) involved in fishing activities.Women engaged in post-harvesting activities (processors and local fish traders), fisheries officers, beach management unit (BMU) leaders, and in total seven village officials, three from Kilindoni, two from Kipumbwi, and two from Kilwa Kivinje (Table 2c)

From the given global (N), which is 414, with a total population of 2,070, then the sample size required from each landing site was as follows;

$\imath.v \approx \frac{N_v}{N_t} * 414$ where; *nv* = Sample size required within landing site, *Nv* = Population in a landing site, *Nt* = Total population in all landing site

Then, the Sample size in the study area was

Table 2a: Respondent category, Population and Sample size in the study area

Respondent Category	Population	Sample size
Small pelagic fishers	1085	217
Processors	315	63
Porters	195	39
Traders	475	95
Total	**2,070**	**414**

The study sample was selected for interview from the chosen landing site using the sample size for the population available on the landing site. Therefore, sample size and total population per landing site are indicated in Table 2b columns 6 and 7.

Table 2b: Number of respondent's categories, total population and sample size per landing site

Landing site /BMU	Number of respondent's categories, Sample size per landing site					
	Fishers	Local traders	Processors	Porters	Sample size	Population
Kilindoni	120	36	20	8	184	920
Kipumbwi	60	21	12	4	97	482
Kilwa Kivinje	37	38	31	27	133	665
Total	**217**	**95**	**63**	**39**	**414**	**2,070**

Table 2c Number of key informants interviewed (KII) in the sampled landing sites

Landing sites	**No. of Fisheries officers**	**Number. of BMU leaders**	**Number. Village officials**	**NGO/WWF/ MPRU**	**Total**
Kilindoni	5	3	3	2	13
Kipumbwi	3	2	2	0	7
Kilwa Kivinje	2	2	2	0	6
Total	**10**	**7**	**7**	**2**	**26**

Source: Modified from Kapapa et al. (2024)

2.3 Sampling Procedures

Multiple sampling techniques employed in this study were based on semi-structured questionnaire interviews. The questionnaire was divided into three sections for BMU members and BMU leaders and key informants' interviews. GPS was applied to measure participation in managing marine resources using Beach management units' members. GPS measures participation based on objective and subjective factors, leading to one final score. GPS has been administered to all BMU stakeholders, comprised of BMU leaders and BMU members (fishers, traders, processors, and porters). Ten (10) subjective determinants for participation related to self-performed or delegated activities in the individuals' BMU members were employed as indicated in MLFD (2009) activities /roles and responsibilities of BMUs.

The ten determinant roles included (1) Enforcement of the Fisheries Act and fisheries (2) Status of beach sanitation and hygiene; (3) Collection of fisheries data, (4)Awareness to fishers of the impact of illegal fishing and other environmental issues, (5) Preparation of economic sub-projects, (6) Sense of security of the people and property, (7) To develop annual/quarterly work plan, (8) Ensure fisheries licenses are paid by BMU timely, (9) To settle fisheries conflicts, and (10) Collection of revenues. Furthermore, two objectives, such as (1) Frequency or actual time spent in the activities and (2) the limitations/ restrictions or the need to delegate the activities, were considered under the GPS, as also noted by Van de Velde et al. (2016).

The item source for the GPS is based on qualitative research with BMU members and other fisheries stakeholders. The criteria were the age of not less than 18 years. A total of (26) key informants were interviewed. Key informants' interviews (KII) consisted of BMU leaders, District fisheries officer/ Fisheries officers (DFO/FO), Village Officials, and staff of the NGOs WWF/ MPRU (Table 2c).
First, the respondents were asked to list activities outlined in the BMU guidelines (MLFD, 2009). Second, the respondent prioritized the most important activities performed personally and the activities delegated to others using the activities outlined in the BMU guideline. Based on these prioritized activities., the respondents were asked to assess the different statements using a Likert – three-point scale ranging from (1) indicating "agree", (2) Indicating disagree, (3) indicating I doubt, and a four-point scale ranging from (1) indicating "not effective", (2) indicating; "somehow effective", (3) indicating." very effective" and (4) "Do not participate. A sample item for the self-performed activities was *"it was completely my choice to engage in this activity"* and Sample items for the delegated activities were *"I experienced more control by delegating this activity"* modified/ adopted from Van de Velde et al. (2016).

2.4 Data Processing and Analysis

The primary data were coded, and all the quantitative data were compiled. The content analysis was used to analyse qualitative data obtained from FGD and KII. While SPSS version 23.0 was used for statistical analysis, such as quantitative data obtained from questionnaires, cross-tabulation was used to compare the information across the landing sites.
BMUs effectiveness /performance was analysed based on the GPS model, which used subjective (includes roles or responsibilities of BMUs as indicated in the BMUs guideline 2009) (MLFD, 2009) and three objectives, including time spent on implementation of self-performed activities., number of performed activities, and frequency of implementation of self-performed activities.
Two scales were used to assess the validity and reliability of GPS. These include (1) Impact on participation and autonomy (IPA) because the first subscale (personal choices and wishes) is linked to autonomy, and (2) The second subscale, self-performed activities (appreciation and acceptance) and the third subscales (delegated activities) of the GPS correspond to Satisfaction and Restrictions, respectively The Utrecht scale for Evaluation Rehabilitation-Participation (USER-P) was applied, measured three aspects of participation Frequencies, Satisfaction and Restrictions. The statistical reliability between items was expressed in Cronbach's alpha coefficient. It was calculated for three sub-scales, as also noted by Van de Velde et al. (2016).

2.5 Scores

The current study›s score ranged from 1-3, and 1- 4 was evaluated using a Likert point scale. A total score is calculated by summarizing the mean scores/percentage of all the statements for the performed and the delegated activities divided by the number of items. An overall score ranged from (1-100). It is more convenient than others These were modified to comply with the nature of the present study. The time spent, number of performed activities, and frequency of implementing activities were used as the determinants of participation in self-performed activities to quantify the performance of the implementation of activities. Scores for self-performed activities (SPA) are based on (1) time spent on implementing activities and (2) the frequency of performing the activities. The number of delegated activities was measured using the score for the delegated activities. The score was categorized based on the three categories proposed in the present study: (1) (0 - 40%), which indicated low participation; (2) (41% - 60%) indicated medium /average participation and (3). high participation (61- 100%). The validity and reliability of the Ghent participation scale, scores and subscales of the GPS were tested using the Cronbach Alpha Coefficient and were correlated with the corresponding subscales of the Impact on Participation and Autonomy using Pearson›s correlation coefficient (Van de Velde et al., 2016, 2017). The total score was calculated by summarizing the mean (%) of all statements for the performed activities and the mean (%) for the delegated activities divided by the number of items.

Although some variables were modified and adopted, the present study applied GPS which was also applied by Van de Velde et al. (2017) to measure participation in medical research. Some items, such as the International Classification for Functioning (ICF- F3-WHO), were not considered at present. Therefore, the modification was made based on the nature of the study (measure the participation of BMU in managing fisheries/natural resources.

2.6 The Utrecht Scale for Evaluation Rehabilitation Participation

The Utrecht scale for evaluation and rehabilitation participation (USER-P) includes a set of variables designed to capture perceived satisfaction with each activity performed and the restrictions affecting those activities. In the USER-P, restriction corresponds to the delegated activities, while Satisfaction corresponds to Self-performed activities. The USER-P measures three aspects of participation: (i) Frequency consists of 3 items -time spent on paid work, unpaid work, and housekeeping per day. Each item scored using a Likert scale ranging from [1] (none at all) to 4 (4.30 hrs /day and above), (ii) Restrictions were assessed by asking the respondent if they experienced restrictions in the implementation of (10) activities listed in BMU guidelines. The items' scores ranged from [1] not possible), [2] with difficulty, and [3] without difficulty. (iii) Satisfaction: assessed by asking the respondent to indicate their satisfaction with participation in (10) activities (outlined in the BMU guidelines 2009). Items were scored on a scale ranging from [1] - (not satisfied) to [2]. (Satisfied)- to [3] (very satisfied). The sum scores for each scale (Frequency, Restrictions, and Satisfaction) were converted into a score on the scale ranging from (0 – 100). Higher scores indicate greater participation (frequency and satisfaction) and less restriction (Van de Velde et al., 2017). The final score was recalculated as mean/ percentage of participation; a higher value indicates greater participation and verse -versa. *Similar activities (10 roles /responsibilities of BMUs) used for scoring in subscales one, two and three were also used for scoring in the Satisfaction and Restriction subscales of USER-P*

3.0 Results

3.1 The Most Important Activities Performed by BMU Members

During the administration of GPS questionnaires, the respondents were asked to list the five most important activities that had been performed. The results showed that (51.45 % (213) could record the most important activities performed by BMU members, whereas 48.55% (201) could not list the BMU activities as outlined in the guideline. They reported that this was due to a lack of knowledge /awareness of the roles of BMU in co-management strategy. Most respondents perceived that the government imposed the BMU organizations, which meant fishers were unwilling to participate. Therefore, the fisher's community lacked ownership and acceptance of BMUs, negatively impacting the performance of BMUs such as /patrolling fishing grounds (51.2%, n = 213), ensuring beach sanitation and hygiene (27.2%, n = 213), and recording fisheries data (12.2%, n = 213).

3.2 Cronbach's α Coefficient.

The Cronbach's alpha coefficient is consistent and is within the acceptable range, as shown in the present study (Tables 3.1a, 3.1b, and 3.1c). The statistical consistency between the items has been expressed in Cronbach's alpha and calculated for the three subscales (Van de Velde et al., 2016). Results showed three underlying dimensions within the GPS (1) performing activities; Subscale 1 (according to preferred choices and wishes) (Cronbach's α ranges from 0.658 - 0.782; Table 3.1); (2) Subscale 2 (Social appreciation and acceptance) Cronbach's α 0.561- 0.639; Table 3.2) and (3) Subscale 3 the need to delegate activities Cronbach's α (0.819 - 0. 896. Table 3.2a) explaining 55.8% of the total variance. More than half of the statement showed a good to strong homogeneity (item-total ranged from (0.521 to 0.714) and a strong internal consistency (Cronbach's α ranged from 0.658 – 0.782 Table 3.1a Column 5). The rephrasing of the subjective determinants resulted in nine statements for the self-performed activities and six statements for the delegated activities (Tables 3.2a) Statements for self-performed and delegated activities).

3.3 Items in the Scale

Table 3.1a: Subscale 1a: Activities according to the choices and wishes (n = 413)

Item-Total Statistics				**Statistics**		
Statement	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	Mean ±STD
S1 It was entirely my choice to engage in this activity	10.22	4.666	0.521	0.341	0.731	2.64 ± 0.673

S2 I performed this activity entirely as I wished	10.32	3.929	0.714	0.606	0.658	2.54 ± 0.754
S3 During this activity, I was ultimately able to be myself	10.29	4.157	0.632	0.526	0.690	2.57 ± 0.745
S4 This activity was completely self-fulfilling	10.28	4.739	0.472	0.235	0.747	2.58 ± 0.690
S5 During this activity, I experienced a feeling of complete control	10.34	4.966	0.365	0.169	0.782	2.52 ± 0.712
Source: Modified from Van del Veld *et al., 2016); Statements S1- S 5 = used for scoring*						

Table 3.1b: Summary Statistics Sub-scale one	
N	414
Mean ± Std	85.75 ± 17.169
Median	93.33
Range	67
Minimum	33
Maximum	100
Cronbach's Alpha	0.768
Number of (S) items /statement	5

Statements were chosen based on the nature of the present study (participation and performance in the implementation of BMU activities). Statements on SPA, such as *"It was ultimately my choice to engage in this activity"* and statements on Delegated Activities, such as *"It was completely my choice to let someone else perform this activity",* were adopted/ modified from Van de Velde et al. (2016).

The variables for the mean score of 85.75 were calculated based on subjective (includes ten roles or responsibilities of BMUs as found in the BMU guideline 2009) and Objectives (time spent on self-performed activities, number of self-performed activities and frequency of performed activities). These were scored using a Likert three-point scale: 1. *"disagree 2' indicates "I doughty and 3' indicates "Agree".* Five (5) Statements were modified from Van de Velde et al. (2016, 2017) to comply with the nature of BMU activities.

Table 3.1c: Sub-scale 1 according to preferred choices and wishes

Item-Total Statistics (n = 413)						**Item Statistics**
BMU roles and responsibilities	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	Mean ± Std.
a) Enforcement of Fisheries Act and fisheries regulations	36.94	75.894	0.349	0.190	0.581	3.99 ± 2.236
b) preparation of bylaws	35.96	82.469	0.242	0.099	0.606	4.97 ± 1.907
c) Ensure beach sanitation and hygiene	37.78	78.884	0.292	0.120	0.595	3.15 ± 2.129
d) Collection of fisheries data	36.87	72.339	0.421	0.207	0.561	4.06 ± 2.332
e) Awareness to other fishers of the impact of illegal fishing and environmental issues	36.97	73.217	0.409	0.189	0.565	3.96 ± 2.288
f) Preparation of economic sub-project	35.43	90.124	0.108	0.044	0.626	5.50 ± 1.297
g) Ensure the security of the people and property	37.73	87.754	0.081	0.037	0.639	3.2 0 ± 1.944
h). Develop an annual and quarterly work plan	35.26	90.287	0.136	0.064	0.622	5.67 ± 1.130
I. Ensure fisheries licenses are paid by BMU members timely	38.08	71.758	0.422	0.233	0.561	2.85 ± 2.383
j. To settle fisheries disputes/conflicts	37.35	74.778	0.354	0.196	0.580	3.58 ± 2.329

(Source: BMU roles and responsibilities: MLFD BMU guideline; 2009)

Results showed that the overall Cronbach's confidence for the sub-scale 1 was within the acceptable range of 0.561- 0.639 (Table 3.1c Column 6), noted by Nunnally (1994) that the Cronbach's coefficient should not be lower than 0.30. The acceptable range was 0.300 and above. The coefficient calculated in the current study showed the validity and reliability of the Ghent participation scale for measuring BMU participation in managing marine resources.

3.3.1 Sub-scale Two: Self-performed Activities

The second subscale refers to self-performed activities that lead to appreciation and acceptance of implementing activities. Four statements were used for scores based on the Likert three-point scale (Table 3.2a & b). Cronbach's a efficiency for Subscale 2 ranged between (0.601- 0.765) and, in summary, statistics (0.739) (Table 3.2a column 6) was also within the acceptable range between 0.30 - 0.70, (Nunnally, 1994).

Table 3.2a: Scores for sub-scale 2: According to appreciation Self-performed activities (n = 413)

Item-Total Statistics (n = 413)						Item statistics
Statements	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	Mean ± Std. Deviation
S1 During this activity, I felt very safe	7.28	2.915	0.502	0.309	0.696	2.48 ± 0.699
S2. During this activity, I felt a strong appreciation	7.37	2.579	0.664	0.475	0.601	2.39 ± 0.711
S3. During this activity, I felt as if I was an important person	7.30	2.757	0.595	0.389	0.644	2.46 ± 0.691
S.4 During this activity, I had a strong feeling of belonging there (being part of the group)	7.33	3.000	0.387	0.162	0.765	2.43 ± 0.762

Table 3.2b: Summary table for subscale 2 two scores

Sub scores	Statistics
N	413
Mean ± Std. Deviation	17.9 ± 81.3358
Median	83.3333
Range	66.67
Minimum	33.33
Maximum	100.00
Cronbach's alpha	0.739
N (number of statements used to score)	4

Source: S1- S4 indicates Statements adopted from (Van de Velde, Bracke, et al., 2016)
Note: *"The summary statistics mean these were calculated from subjective and objectives scored using the Likert 3-point scale as originated (Van del Velde et al., 2016)".*

3.3.2 Sub-scale Three: Delegated Activities

Results showed good internal consistency on Cronbach's alpha coefficient, which ranges between 0.819 and 0.866 (Table 3.2c). The overall Cronbach's alpha was 0.858, scored using six statements. The Cronbach's alpha score was higher than 0.70, as suggested by Nunnally (1994). Sub-scale 3 (Delegated Activities) linked to restriction in performing activities (had higher values compared to the sub-scale 1a (0.768) and sub-scale 1b 0.621; Subscale two 2 (0.739). The number of delegated activities negatively impacts the perceived level of participation, affecting performance. The number of delegated activities was measured using the score for the delegated activities (DA) in BMUs activities indicated in BMUs guidelines.

Table 3.2c: Sub-scale three Delegated activities

	Item-Total Statistics (n = 411)					Item statistics
	Scale Mean if Item Deleted	**Scale Variance if Item Deleted**	**Corrected Item-Total Correlation**	**Squared Multiple Correlation**	**Cronbach's Alpha if Item Deleted**	**Mean ± Std. Deviation**
S1. It was ultimately my choice to let someone else perform this activity	11.55	8.457	0.646	0.585	0.837	2.53±0.629
S2 I completely trusted the person(s) who performed this activity for me	11.58	8.688	0.585	0.557	0.846	2.51±0.622
S3. I felt that the others loved to perform this activity for me	11.69	7.947	0.741	0.578	0.819	2.40 ± 0.674
S4. Because others performed this activity, I did not worry about it anymore	11.75	7.788	0.718	0.576	0.822	2.34 ± 0.725
S5. I felt safer by asking someone else to do this activity for me	11.73	7.928	0.733	0.601	0.820	2.35 ± 0.684
S6. I experienced more control by asking someone else to do this activity for me	12.12	7.263	0.566	0.389	0.866	1.96 ± 0.981

Source: Statements:(S1- S6) adopted from Van-del-Velde et al. (2016)

The value "scale means if an item deleted, such as "11.55" in the context of a scale analysis, refers to the average score of the entire scale (set of items/questions) a respondent would have if a specific item were removed from the scale.

3.3.4 Satisfaction on Implementation of BMU Activities

The present study assessed satisfaction by asking respondents to indicate their satisfaction with participation in (10) activities (shown in the BMU guidelines). The items scored on a Likert three-point scale ranging from (1) indicates - "not satisfied", (2) indicates "satisfied ", and (3) indicates "very "satisfied". Results showed that the mean percentage ranges from 1.67 – 2.64, indicating that the preparation of economic subproject had the lowest mean percentage (1.67), followed by Developing the annual/ quarterly work plan mean /percentage (1.90). The large mean /percentage was (2.64), ensuring BMU timely pays fisheries licenses and awareness raising on the impacts of illegal fishing (2.62) (Table 3.4 column 7). All the calculated mean /percentage scores ranged between (0% and 40%) indicating low participation in BMU activities.

Table 3.4: Satisfaction on Implementation of BMU Activities

Item-Total Statistics						**Item statistics (n = 42)**
BMU's roles/ responsibilities	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Corrected Item-Total Correlation**	**Squared Multiple Correlation**	**Cronbach's Alpha if Item Deleted**	**Mean±Std**
a). Enforcement of Fisheries Act and fisheries regulations	20.81	13.963	0.664	0.499	0.743	0.618±2.36
b) Preparation of by-law	21.14	13.784	0.468	0.569	0.764	0.841± 2.02
c)Ensure beach sanitation and hygiene	20.71	14.404	0.503	0.314	0.760	0.670±2.45
d)Collection of fisheries data	20.79	14.368	0.453	0.426	0.766	0.731±2.38
e).Awareness to other fishers of the impacts of illegal fishing	20.55	14.937	0.474	0.579	0.765	0.582±2.62
f).Prepare economic sub-projects	21.50	14.110	0.482	0.712	0.762	0.754± 1.67
g)Ensure the security of the people and property	20.62	14.242	0.630	0.606	0.748	0.593± 2.55

h)Develop an annual / quarterly work plan	21.26	15.613	0.173	0.600	0.804	0.821± 1.90
i)Ensure BMU pays fisheries license	20.52	14.792	0.434	0.449	0.768	0.656±2.64
j)To settle fisheries disputes / conflicts	20.60	14.198	0.403	0.286	0.774	0.831±2.57

Note: The "mean ± Std " in the "Item statistics" column across tables refers to each item's average score or response level (question or statement). The mean provides a central tendency measure, indicating the participants' average response to each item. It helps understand participants' general agreement or disagreement regarding specific statements or questions.

3.3.5 What Has Been Found in this Study

The outstanding internal consistency and homogeneity that GPS has demonstrated ranges from 0.62 to 0.785, which is within the range that other researchers have advocated (Altuntaş et al., 2021; Van de Velde et al., 2016, 2017). According to this study, GPS model results were reliable and appropriate for gauging participation in the management of fisheries resources.

The GPS model results showed that BMUs' low engagement in completing their tasks and responsibilities had a detrimental impact on their performance. Furthermore, the findings showed that low levels of participation were brought on by mistrust of BMU, a lack of reliable financing sources, and a lack of operational resources like patrol boats. The current study identified the uniqueness of GPS by combining objective and subjective data, and it generated "one final score," which may be used to maintain consistency with other studies, such as Altuntaş et al. (2021) and Van de Velde et al. (2016, 2017).

3.4 Construct and Discriminative Validity

This justifies the validity and reliability of GPS by demonstrating the ICC results for each subscale on which the operationalization of GPS depends. The present study found that the internal consistency (ICC) and Cronbach's alpha values were more than 0.7. This indicated moderate and good internal consistency in different sub-scales, as Polit & Yang (2016) noted. Table 3.5 demonstrates the results of internal consistency for each sub-scale. The current study showed that GPS has a strong relationship/ association with other sub-scales, except with the subscale of Satisfaction (- 0.224). Pearson Correlation is not significant (- 0.224) (Table 3.5). Van de Veld et al. (2016) noted that the higher the frequency and higher satisfaction, the lower the restriction implies higher participation. However, the statement was not varied based on the findings in the present study, which showed that restriction was higher than the frequencies and satisfaction (Table 3.5), indicating low participation in implementing BMU activities in the study area.

Table 3.5: Homogeneity Pearson Correlation GPS instruments (IPA &USER-P)

	GPS	SPA	Sub1	Sub2	Sub3_DA	USER-P n = 413		
						Freq	Rest.	Satisfy.
GPS	1.00	0.660**	-0.209**	-0.244**	0.755**	0.186**	-0.382*	-0.224
SPA	0.660**	1.00	-.302**	-.310**	0.006	-.153**	-0.610**	-0.383*
Sub1	-0.209**	-0.302**	1.00	0.406**	-0.016	-0.016	0.140	0.125
Sub2	-0.244**	-0.310**	.406**	1.00	-0.047	0.066	0.136	0.210
Sub3_DA	0.755**	0.006	-0.016	-0.047	1.00	-0.112*	0.036	0.064
Frequency	-.186**	-0.153**	-0.016	0.066	-.112*	1	-0.096	0.079
Restriction	-0.382*	-0.610**	0.140	0.136	0.036	-0.096	1.00	.453*
Satisfaction	- 0.224	-0.383*	0.125	0.210	0.064	0.079	0.453*	1.00
****. Correlation is significant at 0.01 level (2-tailed).**								
***. Correlation is significant at 0.05 level (2-tailed).**								

Note: In statistical analyses, significance levels are thresholds used to determine the probability at which we can reject the null hypothesis. Common significance levels are 1%, 5%, and 10%, corresponding to p-values of 0.01, 0.05, and 0.10, respectively. These levels help to decide whether the observed data are sufficiently unlikely under the null hypothesis, indicating that the effect observed is statistically significant and not due to random chance.

3.4.1 Homogeneity of the Sub Scales

Cronbach's alpha was calculated for the three subscales. Items that did not contribute to the internal consistency or homogeneity (item-total correlations under 0.4) were considered unreliable and excluded from the final measure in the present study (Table 3.6) Subscale 2 (4th statement). The internal consistency using the homogeneity of the three subscales was considered reasonable to strong. However, the internal consistency of the subscale 'Activities leading to appreciation and social acceptance' (Sub-scale 2: (0.74) Table 3.5) was lower than the internal consistency of the two subscales on self-performed activities. The reason for this observation was attributed to the lower item-total relationship for the item (0.39) 'During these activities, I had a strong feeling to belong there (being part of the group)' Table 3.6.

Table 3.6: Verification of the validity of GPS in measuring participation based on BMU activities

Statements for sub-scales	Internal Consistency	
	Item-total correlation	Cronbach's alpha
Subscale 1: Self-Performed Activities (SPA)		0.62
Subscale 1a: Activities per choices and wishes		0.77
It was ultimately my choice to engage in this activity	0.52	
I performed this activity completely as I wished	0.71	
During these activities, I was ultimately able to be myself	0.63	
This activity was completely self-fulfilling	0.47	
During these activities, I experienced a feeling of complete control	0.37	
Subscale 2: Activities leading to appreciation and social acceptance (SPA)		0.74
During this activity, I felt very safe	0.50	
During this activity, I felt a strong appreciation	0.66	
During these activities, I felt as if I was an important person	0.59	
During these activities, I had a strong feeling of belonging there (being part of the group)	0.39	
Subscale 3: Delegated Activities (DA)		0.86
It was ultimately my choice to let someone else perform this activity	0.65	
I completely trusted the person(s) who performed these activities for me	0.58	
I felt that the others loved to perform this activity for me	0.74	
Because others performed this activity, I did not worry about it anymore	0.72	
I felt safer by asking someone else to do this activity for me	0.73	
I experienced more control by asking someone else to do this activity for me	0.57	

Source: Statements adopted /modified from Van de Velde et al., (2016)

3.5 The Determinants of Participation

Determinants are the factors that decisively affect the outcome of something. Based on the present study, time spent on performed activities, number of completed activities, and frequency of self-performed activities were used to affect BMUs' participation in the implementation of their roles/responsibilities using the GPS model had a positive impact on the involvement as noted in this study also indicated by Van de Velde et al. (2017).

3.5.1 Time Spent in the Implementation of Activities

It is one of the determinants of participation in implementing BMU activities. Scores for self-performed activities (SPA) based on (1) time spent in most essential activities, (2) Frequency of performing the activities and a higher amount of time spent executing activities had a positive impact on the perceived participation level (Van de Velde et al., 2016). The time spent on specific activities had implications on participation and performance in the respective activities. The present study showed that most respondents spent more time on paid work in a week than in unpaid work /volunteering (BMU activities); these negatively affected performances.

Respondent reported that they might use 10 – 30 min on BMU activities such as beach cleaning; however, on activities such as processing dagaa, they wake up around 5.00 am, go to the beach, weigh dagaa for traders, clean processing grounds, make firewood, boiling, drying, and package took 8 – 10 hrs. a day

However, ensuring the security of the people and property may take many hours or some days, depending on the nature of the incidents that occurred. For example, during fieldwork at the Kilindoni landing site on 5th March 2019, a crew member drowned in the ocean and lost his life due to the strong wind. They spend more than 12 hours searching for the dead body.

3.5.2 Frequency or Number of Implemented Activities

- The number of activities was used to determine participation in the present study. As Van de Velde et al. (2017). The current study showed that the number/ frequency of delegated activities (DA) exceeded the number of self-performed activities (SPA) per landing site (Table 3.7). Results showed that the overall percentage /mean time spent on implementing BMU activities per landing site was 23.17%, 22.3%, and 15.9% for the Kilindoni, Kipumbwi, and Kilwa Kivinje, respectively. All responsibilities performed by BMUs imply low participation in BMU activities. Percentage/meantime is the time spent on the implementation of BMU activities. The percentage of time spent was used to determine participation. These were calculated as percentages or mean time. These had negative or positive effects on participation, hence affecting performance.

  Based on the scale I proposed in the present study (0% to 40 %) indicates low participation, (41% to 61%) indicates medium participation, and (61% to 100%) indicates high participation. Thus mean /% score was between (0% - 40 %); (Table 3.7). In the study area, the overall mean was 20.635 /percentage, which was between (0% - 40%) in all sites (Table 3.7), indicating low participation, which was perceived to have negative implications in participation and hence affected performance.

3.5.3 Hypotheses in Effectiveness on Implementation of BMU Activities

At this stage, two hypotheses were tested to assess the participation of BMUs in implementing their duties /responsibilities. H0 Participation in implementing BMU activities in the landing site does not result in high performance. H1 Participation in the implementation of BMU activities in the landing site results in increased performance. Based on the nature of the study, participation was anticipated to result in high performance, which should be reflected in the health status of the stocks. High performance was quantified using GPS modes. However, the study found that achieving high performance in all BMU activities was difficult

Table 3.7 indicates the mean or percentage of time spent on the implementation of BMU activities, agreeing with the H0 Hypothesis "Participation of BMU members on the implementation of BMUs activities does not result in high performance"The Result showed that overall mean (%) time spent on implementation of BMU activities in the study area was between 0% - 40% (Table 3.7) implies low participation in the implementation of BMU activities harmed performance

Table 3.7: Mean /% Time spent on implementing BMU activities in Kilindoni, Kipumbwi and Kilwa Kivinje

Landing site	Mean (%) ± SD	N
Kilindoni	23.1785 ± 13.04082	183
Kipumbwi	22.3081 ± 12. 32812	97
Kilwa Kivinje	15.9148 ± 12.90328	133
Total	**20.6349 ± 13.21387**	**413**

3.6 The sub-scale 3 Linked to Delegated Activities

The number of delegated activities by any individual negatively impacts a perceived level of participation. Additionally, GPS was assessed by considering the number of delegated activities by Van de Velde et al. (2016, 2017). Van de Velde et al. (2016) noted that the operationalization of GPS depends on subscales, including sub-scale 1 (according to choice and wishes), sub-scale 2 according to appreciation and acceptance, and subscale 3 linked to the delegating activities. The number of delegated activities was measured using the score for the delegated activities. (as described above). Using" Yes" or "No" responses, the proportional were computed: (1) 'Yes' indicated Self-performed Activities (SPA), and (2) 'No' indicated delegated Activities DA. Results showed that the number of (DA) was higher compared to the number of self-performed activities (SPA) across the landing sites (Figure 3.2), which had an impact on BMU members' participation in BMU activities and was perceived to affect performance.

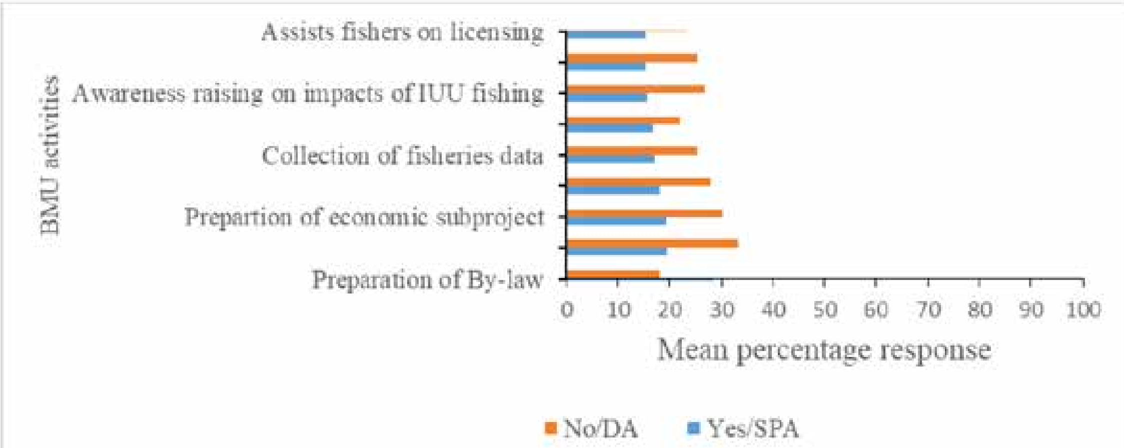


Figure 3.2: Mean/percentage of responses on delegated activities (DA) and Self-performed activities (SPA)

3.6.1 Rating Performance of BMUs in the Implementation of Activities

Results showed a significantly different (p = 0.000) implementation of BMU activities except for some activities, such as conducting meetings (p = 0.900). Preparation of the work plan showed no significant difference (p = 0.336). The study examined how respondents perceived BMUs as a tool for managing marine and coastal resources. Most BMU members viewed BMUs as an effective tool for managing marine and coastal resources. The main reason was that the fishing communities engaged in conservation activities under the co-management strategy created a sense of ownership. Also, BMUs participate in the reduction of illegal fishing practices by reporting illegal fishing incidences to the responsible authority for further action.

The present study examined the effectiveness of the implementation of BMU activities. It was reported that initially, during the establishment of BMUs, it was hypothesized that the fisher communities' participation in managing marine resources using a co-management strategy could result in effective performance on BMU activities, which grantee the health status of the stock (MLFD, 2018). The results showed that 59.2%, n = 414) of respondents reported that BMUs were very effective in ensuring the security of people and property, solving conflicts, and collecting revenue (47.8%, n = 414). However, the small pelagic fisher's ranking of BMUs performance was low in initiating economic subprojects and keeping inventories (44.2%, n = 414), conducting meetings (34.5%, n = 414), and in the collection of fisheries data (34.3%, n = 414) (Table 3.8a and b columns 1 to 4). (Table 3.8a). Two hypotheses were used because of examining two distinct predictions or relationships within the study.

Table 3.8a: Percentage response on performance of some BMU activities

BMU activities /roles	% Responses (n = 414)
Ensuring the security of people and property	59.2
Resolving disputes/ conflicts	47.8
Collecting revenue	47.8
Initiating economic subprojects and keeping inventories	44.2
Collection of fisheries data	34.3

Table 3.8b: Respondents' rating on BMU and Chi-squared calculation for effective implementation of fisheries activities

BMU activities / Fisheries regulations	Respondent's ratings (n = 414)				
	(1) Very effective (%)	(2) Somehow effectively (%)	(3) Not effective (%)	(4) Do not participate (%)	the p-value for the site
a) Enforcement of the Fisheries Act and Fisheries Regulation, e.g. gear restriction	31.2	32.4	18.1	18.4	0.000
b). Preparation of by-law	26.1	26.1	22.9	24.9	0.000
c). Ensure beach sanitation and hygiene	28.3	27.8	22.5	21.5	0.000
d.) Collection of fisheries data	34.3	24.6	21.5	19.6	0.000
e) awareness to other fishers on the impact of illegal fishing and other environmental	24.9	27.8	26.6	20.8	0.000
f) Prepare economic subprojects	9.7	7.0	39.1	44.2	0.000

g). Ensure the security of the people and property	59.2	23.7	8.0	9.2	0.000
h.) Resolving disputes/ conflicts	47.8	25.1	12.3	14.7	0.000
i.) Collecting revenue	47.8	16.4	15.2	20.5	0.000
j). Conducting meetings	19.8	19.3	26.3	34.5	0.000
k.) Keeping inventories	8.5	13.3	34.1	44.2	0.000

Note. In this study, the Enforcement of Fisheries Act & Regulation considered Patrolling fishing grounds, providing information on migrant fishers, and Reporting the incidence of IUU fishing.

3.6.2 Ratings of the Performance of BMU in Executing their Roles

The effectiveness /performance of BMUs on implementation of roles /regulation (found in the guideline) gears towards managing marine resources to ensure their sustainability was assessed. "Does BMU implement the following regulations effectively?" The study assessed the performance of BMUs in different activities using a four-point Likert scale: (1) indicating "very effective", two indicating "somehow effective", three indicating "not effective" and four indicating that they "do not participate" The findings showed that licensing fishing vessels (63.5%), licensing fishers and fish traders (60.9%), and arresting culprits (39.9%) were perceived to be very effective compared to other activities (Table 3.9). In addition, patrolling fishing grounds and confiscating illegal gear were seen as compelling. (Table 3.9).

Table 3.9: Performance/effectiveness on implementation of BMU activities

Activities	Very effective (%)	Somehow effectively (%)	Not effective (%)	Do not participate (%)	The p-value for the landing site
Patrolling fishing grounds	28.0	39.9	19.8	12.3	0.000
Confiscating illegal gears	21.7	39.9	25.6	12.8	0.000
Arresting offenders	36.7	29.0	17.9	16.4	0.000

Registration of fishing vessels	33.6	31.9	19.1	15.5	0.000
Arresting culprits	39.9	24.4	17.6	18.1	0.000
Licensing of fishing vessels	63.5	17.4	5.8	13.3	0.000
Licensing of fishers and fish traders	60.9	21.0	6.0	12.1	0.000

Note: The Likert 3 and 4-point scales were used. It is more convenient than others, and the supervisor advised adding one more scale "do not participate" was added to make participation more operational.

These P-values were tested and provided a measure of the strength of evidence against the null hypothesis. P-values are a fundamental component of statistical theory. In the present study, SPSS, Version 23, was used for computing P-values, which automates the calculations and provides accurate P-values based on the input data and selected tests.

3.7 Major Challenges to the Implementation of BMU Activities in the Study Area

The major challenges for BMU in implementing management measures were examined. The outcomes are shown in Figure 3.3. Inadequate knowledge of fisheries issues (38.2%) and lack of support from other stakeholders/government (31.9%), insufficient capacity to enforce management measures such as lack of patrol boats and equipment, adequate resources and funds to sustain BMU activities (14.3%), corruption (7.5%), and others such as illegal fishing, lack of commitment, and nepotism «muhali», (8.2%) were highlighted as significant constraints facing BMUs in the study area (Figure 3.3).

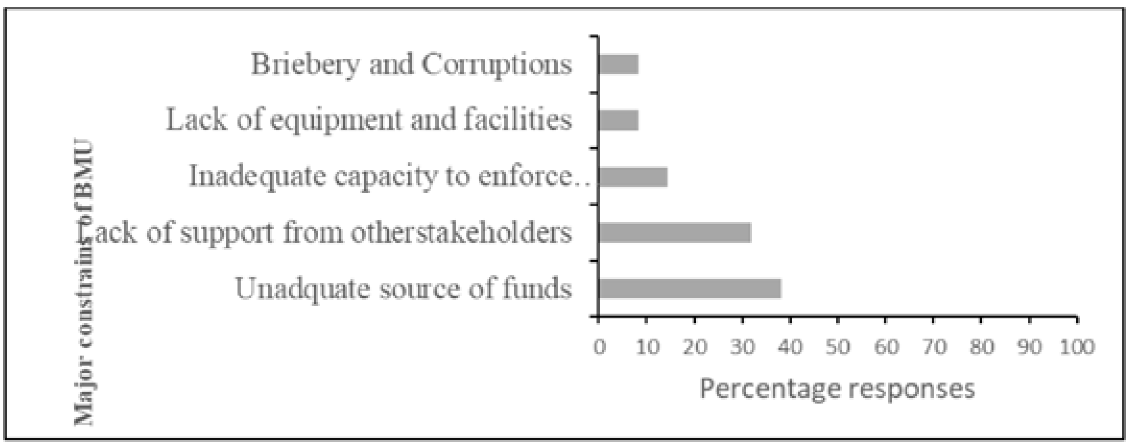


Figure 3.3: Major constraints for BMU in implementing management measures in the study area

3.7.1 Unreliable Source of Funds and Inadequate Resources

Inadequate resources for BMUs to perform their mandated roles are highlighted as a source of poor performance. In particular, BMUs lacked human resources, equipment, and funds to facilitate the functions required. The key informant explained that BMUs need funds to carry out their duties. In most cases, BMUs depend on donors' projects such as WWF and Rufiji, Mafia, and Kilwa sea scape project (RUMAKI); for example, in the Kilindoni, where the activities ceased as soon as the project ended. The present study noted that BMU activities, such as patrolling fishing grounds, raising awareness on the impacts of illegal fishing, data collection, and performance, were perceived to be good during project support. However, after the end of the project, Kilindoni BMU was inactive, did not perform better in several activities, and contributed to ineffective. KII at Kipumbwi and Kilwa Kivinje landing sites reported that BMUs sometimes receive 10 % dividend funds as part of revenues from small pelagic fish catches from the Local Government Authority. A Key informant in Kilwa Kivinje explained that, sometimes, funds could be available for other development activities, such as the construction of school buildings and dispensaries.

Despite the concept of decentralized fisheries management, it was assumed that the Local Government Authority (LGA) took initiatives in fisheries management on behalf of the central government, which was rarely done. However, LGAs were collecting a significant amount of revenue from the fisheries resources, which were among the primary sources of income. Additionally, none of the BMUs in the study area had initiated income-generating activities. The present study observed that non-BMUs had established savings and credit facilities. Key Informants explained that this had been attributed to a lack of skills and expertise, knowledge in financial management, and record keeping. BMUs across the study areas need financial assistance through donor funds, facilities/ equipment, and legal empowerment to implement their activities effectively.

3.7.2 Costly Implication on Some BMUs Activities

It was explained that some activities with cost implications were not managed at the village level. For example, patrolling on the fishing grounds requires a patrol boat, fuel, and other accessories; however, it was reported that BMU members involved in patrols lacked facilities and incentives.

KII at the Kilindoni landing site added that some BMU leaders were tempted to bribe once they apprehended expensive fishing gear. Therefore, for smooth implementation of BMU activities, the fishers' community perceived that both central and local governments need to facilitate BMU activities with the necessary equipment, such as patrol boats and engines, to enable them to enforce fisheries regulations.

3.8 Discussion

3..8.1 Reliability

To ensure the validity and reliability of the scale, Cronbach (1951) and Tavakol & Dennick (2011) stated that internal consistency is determined before a test can be employed for research or examination purposes. Cronbach alpha, developed by Lee Cronbach in 1951, was used to measure the internal consistency of a test or scale, expressed by a number ranging from 0 – 1. Internal consistency describes the extent to which all the items in a test measure the same concept. Therefore, it is connected to the inter-relatedness of the things in the test, as shown in the present study. Internal consistency (ICC) of the GPS was assessed using Cronbach's alpha. The ICC and Cronbach's alpha of more than 0.7 indicated moderate and good internal consistency in different sub-scale levels (Polit & Yang, 2016). The present study is in line with and conquered with Van de Velde et al. (2016), who noted that a higher percentage indicated a higher perceived participation level, and a lower percentage indicated lower perceived participation. Also, the frequency /number of delegated activities (DA) was more than that of self-performed activities (SPA). Therefore, the current study showed low participation, affecting the performance of respective activities. The overall (DA)mean (Standard deviation (SD) was 78.3 ±18.6, and for SPA, the mean/SD was 68.2 ±16.1. Delegated activities were more than SPA. (Table 3.7)

3.8.2 The Standard Acceptable Values of Cronbach's Alpha Coefficient

Nunnally (1994) proposed Cronbach's alpha coefficient should not be lower than 0.30. Additionally, Wade & Halligan (2003) documented that the acceptable Cronbach›s alpha values ranged from 0.70 to 0.95. These were consistent with the observed values in the current study, with Cronbach›s alpha ranging from 0.62 to 0. 79. An increase in Cronbach›s alpha values depends on the test length, a short time, reducing alpha value (Altuntaş et al., 2021); therefore, they recommended that alpha could increase with the more related items testing the same concept should be added to the test. It is worth noting that alpha is a property of the scores on a test from a specific trial sample. Tavakol & Dennick (2011) reported that Cronbach's alpha should be measured each time. Unlike in the present study, Cronbach's alpha was not calculated each time based on the nature of the survey. Alpha was measured once. For good internal consistency, the Cronbach alpha ranges from 0.70 and above (Van de Velde et al., 2016).

3.8.3 Usefulness of Using GPS in Measuring Participation in Natural Resources

The results showed that GPS is a valuable instrument in measuring participation regardless of the field one is dealing with, as it was recommended by other scholars (Van de Velde et al., 2016). Also, in the present study, all items and scores were summarized using Cronbach's coefficient, GPS, leading to one final score. Hence making the uniqueness of this model. as noted by Altuntaş et al. (2021), Terwee et al. (2007) and Van de Velde et al. (2016, 2017). Similar findings have been observed in the present study. The present study used GPS to measure participation in managing natural resources. Still, Cronbach's alpha coefficients showed good internal homogeneity among the items in all sub-scales. The Cronbach's alpha for sub-scale 1 (self-performed activities was 0.62) for activities according to choice and wishes (Cronbach's alpha. 0.77) and for Subscale 2 (activities according to appreciation and acceptance was 0.74) (Table 3.4.0). In contrast, the recommended Cronbach's alpha should not be lower than 0.30, according to Nunnally (1994) and other studies such as

Van de Velde et al. (2016). Cronbach's alpha coefficient was 0.70. Therefore, the findings in the current study agree with other scholars' results, as indicated above. The GPS model is advantageous because it measures the participation of BMUs in managing fisheries resources to improve effectiveness or performance.

3.8.4 Delegated Activities

Delegated activities had Cronbach's alpha of 0.86, and SPA showed a lower Cronbach's alpha of 0.62 (Table 3.2c). The frequency and number of delegated activities were higher than self-performed activities. The GPS model statistics test revealed that the mean and standard deviation for delegated activities 78.3± 18.6 were higher than the mean/standard deviation for self-performed activities (mean 78.3 ± 18.6; 68.2 ± 16.1). The means were calculated by summarizing all the statements on SPA and DA divided by the number of items. This indicates that the higher mean on SPA implies high participation, positively impacting performance. The mean time spent and number of performed activities were used to determine the involvement in respective activities.

According to the focus group discussion findings and the fishermen›s perception, the number of delegated activities was more significant than the number of self-performed activities, implying low participation and negatively affecting performance. This pattern was observed in the current study, which means that BMU members did not perform most of the activities in the study area. The majority did not participate much in the BMU activities, as shown in the guideline, leading to low performance. The low participation in the present study is evidenced through the mean time spent (%) in implementing BMU activities, which ranges between 0% - 40%, indicating low participation and implied low performance of BMU activities, hence affecting the health status of marine resources.

Notably, restrictions in implementing activities were not explicitly asked for in the GPS. However, the individuals were asked to indicate which activities they had delegated and whether they wanted to perform them themselves.

3.8.5 Small Pelagic Fishers' Perceptions on BMU Performance

Luomba (2014) documented that local assessment of opinions is essential for effective management to identify potential areas of weakness and direct management measures. Evans (2009) noted that different actors perceive involvement in leadership and response to governance strategies differently. According to Luomba (2014), fishers› views on executing activities and perceptions should not be ignored. Still, they should be considered to reflect how they perceive BMU activities. Thus, the results of BMU perceptions on effectiveness/performance in implementing activities could be used to understand the weaknesses and focus on improving them for better performance/effectiveness (Breuil & Bodiguel, 2015) reported that efficiency in the management of Tanzania›s small pelagic marine fishery should involve adequate collaborative mechanisms between the MLFD of mainland Tanzania and the MLF of Zanzibar. He also underlined that establishing an inter-ministerial committee on small pelagic would be a good starting point. Based on the specificity of the country. The same author added that there is a need to raise the political will of both governments to ensure, firstly, the formal establishment of an inter-ministerial committee for small pelagic.

Active participation, including financial and human support, the possible priority areas for collaboration for the concerted management of Tanzania's small pelagic fishery include but are not limited to the harmonization of regulations with emphasis on licensing and technical management measures as well as the promotion of a convention on minimum conditions of access to small pelagic resources in Tanzania and a convention on minimum conditions for small pelagic fish trade (Ibengwe et al., 2022; MLFD, 2018).

3.8.6 Hypothesis

Results showed differences in perceptions of small pelagic fishers on activities performed by BMU in executing activities such as enforcement of the Fisheries Act and fisheries regulation (patrolling fishing grounds), ensuring the security of the people and property, resolving conflicts, conducting meetings and revenue collections. This observation indicates that levels of performance in BMU activities differ across BMUs. As noted during the current study, some activities had a mean (%) or more frequency, as explored by the Ghent Participation Scale model, which implies low participation and, hence, low performance. The findings were conquered with Van de Velde et al. (2016). Onyango & Jentoft (2007) argued that BMUs had not performed as expected. On the other hand, Nunan (2010) added that BMUs had failed to control the migration of fishers.

The present study found that perceptions of small pelagic fishers in the performance / effectiveness of BMU were different among the landing sites/BMUs in conducting meetings, collecting revenues, and patrolling fishing grounds. The observed difference in effectiveness among the BMUs in the study area indicates specific strengths and weaknesses, and the need calls for a particular area of improvement. Therefore, assessing the effectiveness of all BMU activities is of paramount importance. Ogwang et al. (2005) noted a similar pattern in the achievement of BMU. The observed pattern in the current study could be attributed to various factors, such as the BMU members› and leaders› lack of commitment to carrying out their roles and responsibilities as outlined in the National BMU guideline (MLFD, 2009). Additionally, the lack of incentives, and lack of support from other stakeholders in co-management, as found in the Kilwa Kivinje and Kipumbwi BMUs hence BMU were not effective, was contrary to the observation that the Kilindoni BMUs were cooperating with village officials supported by RUMAKI were at least performing better than others

Most women were not participating in BMU meetings, and in the case of gender, participation was limited to men. Hence, decision-making regarding managing marine resources is biased toward men. Also, porters and processors reported that they do not participate in BMU activities compared to fishers and traders, which affects performance.

3.8.7 Time Spent and Frequency of Performing the Activities

The time spent and the number of performed activities were used as a determinant for participation, influencing the performance/ effectiveness of BMU activities. Overall, the

study found low participation, low frequency, and time spent exulting BMU activities, which were evidenced through high restriction, low frequency and low satisfaction. The lower mean or percentage range of 0% - 40 % indicated low participation. Based on the proposed scale in the present study, low participation in implementing roles geared to managing marine resources had adverse effects on performance.
Frequency and Time spent on implementing activities are determinants of participation in the implementation of activities, as proposed by Van de Velde et al. (2017). Van de Velde et al. (2016) observed that high frequency and high satisfaction, with low restrictions, indicate high participation. Some activities include ensuring the Fisheries Act and fisheries regulation (buying fishing licenses) taking 30 min licenses), taking 30 minutes per person. In contrast, other activities, such as security for the people and property, took many hours, depending on where the incidents occurred. Based on the findings of this study, BMUs have made some progress in carrying out their roles as outlined in the National BMU guideline (MLFD, 2009), such as patrolling fishing grounds, collecting revenues, and ensuring the safety of people and property. However, some BMUs faced some challenges or limitations, as explained, including a lack of other stakeholders› support, inadequate capacity to enforce management measures, and a lack of funds and equipment (patrol boats). As highlighted by Ogwang et al. (2009) and Lawrence & Watkins (2012), the weakness exhibited in the devolution of power and inadequate support from other stakeholders in implementing fisheries activities is why some BMUs have not been effective in executing their roles /responsibilities.

4.0 Conclusion

The GPS has been modified/ to suit the local environment, such as using BMUs members› participation in managing small pelagic fisheries, the first study to be reported in Tanzania. that can be used as a benchmark for one who wishes to do this kind of study in marine fisheries resources It is established that implementing–management using BMU in a study area has led to visible successful management to ensure the sustainability of marine resources. However, it is worth noting that achieving high performance in all management aspects is challenging. Still, BMU can improve their performance as co-management develops.

All participants completed GPS once (IPA & USER-P) performed to analyze the validity and reliability of GPS measuring participation in marine resources. Cronbach›s alpha was used to scale reliability statistics, and the subscales› internal consistency was found to be satisfactory, with Cronbach's alpha of 0.768, which is greater than the 0.700 recommended.

The mean or percentage (%) was (20.63 mean/%), with time spent on implementing BMU activities ranging between (0% to 40%) this implies low participation which negatively impacts performance. Based on the scale suggested in the present study, (0% -40%) indicates low participation) 41% to 60% medium or average participation and 61 to 100% indicated high participation.

The results obtained from the validity and reliability study using the Ghent Participation Scale proved that the GPS has validity and reliability at a sufficient level to measure the participation of BMUs in managing the small pelagic fishery. There are different levels of performance across the BMUs when implementing fisheries policy. Based on the findings obtained using the GPS model, the study concludes that there was low participation in implementing BMU activities, which negatively affected the performance, negative affect the fish stock in combination with illegal fishing and environmental factors (climate change and variability (noted in chapters four & five in this thesis) respectively.

5.0 Recommendations

- The Ministry in charge of fisheries management, policymakers, and researchers were advised to employ GPS to provide a more comprehensive understanding of participation and performance managing small-scale coastal pelagic fishery in marine waters fisheries resources.
- Based on the findings BMU were not effective enough in performing their duties due to lack of working facilities therefore, Support from a different stakeholder in the co-management structure is required for the effective operationalization of BMU.
- Regardless of the field being studied, GPS helped track participants. The GPS has shown to be a useful model that demonstrated consistency and validity in evaluating participation in the management of marine fisheries resources, according to the results of the current study. Consequently, more research is required to apply GPS to a wider coverage of small-scale coastal pelagic fisheries (the present study covered only three sites).

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Unveiling the Synergy between Infrastructure Development, Port Policies, and Leadership Commitment for Operational Performance

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1.0 Introduction

In the contemporary era, the global maritime sector has experienced substantial changes propelled by a myriad of influences including globalization, technological progressions, and alterations in trade dynamics (Notteboom & Yang, 2017). Amidst this dynamic milieu, ports stand as pivotal hubs enabling the flow of commodities and nurturing economic progress (Rodrigue & Notteboom, 2020). Nevertheless, amidst these opportunities, complexities emerge pertaining to the formulation of port policies, infrastructure expansion, and the dedication of leadership, all of which profoundly impact port efficacy. Furthermore, the significance of leadership commitment emerges as a critical determinant in translating port policies into effective implementation strategies (Duru et al., 2020). Strong leadership characterized by a clear vision, strategic planning, and stakeholder engagement is imperative for navigating the complexities of port governance and fostering improvements in operational performance (Duru et al., 2020). Absent robust leadership commitment, even well-conceived port policies may struggle to achieve their intended objectives.

In light of this context, it becomes imperative to comprehend the intricate interplay among port policy, infrastructure development, leadership commitment, and operational performance (Ha et al., 2019; Hossain et al., 2019). Scholars such as Ha et al. (2019) and Hossain et al. (2019) have underscored the necessity for comprehensive approaches to assess port performance that encompass multifaceted factors extending beyond conventional metrics. By scrutinizing indicators such as cargo throughput, vessel turnaround time, and customer satisfaction, researchers can offer insights into the holistic repercussions of port policies and infrastructure investments on operational efficiency and competitiveness.

Although existing literature provides valuable insights into diverse facets of port management and sustainability, there exists a need for deeper exploration of the interrelationships among port policy, infrastructure development, leadership commitment, and operational performance. This study endeavours to fill this gap by examining the influence of various port policies on infrastructure development, the significance of leadership commitment in policy execution, and the overarching effects on port performance. Through this endeavour, it aims to augment the existing body of knowledge guiding port management practices and policymaking within an ever evolving and interlinked maritime landscape.

2.0 THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

Port Policies

Port policy encompasses a spectrum of regulatory frameworks and governance structures that delineate the operational landscape of ports. Privatization, deregulation, and investment in green infrastructure stand out as pivotal policy initiatives that have garnered prominence in recent times.

Port privatization offers a contentious balance of benefits and challenges. Proponents argue it enhances operational efficiency, cost-effectiveness, and service quality, driven by private operators' incentives to modernize infrastructure and integrate advanced technologies (Alamoush et al., 2021). According to Hossain et al., (2019), privatized ports demonstrate flexibility in adapting to shifting trade patterns and attracting private investment for large-scale projects. However, critics raise concerns about equity, labor rights, and public welfare. Privatization often results in job losses, reduced wages, and compromised working conditions due to cost-cutting measures (Hurley et al., 2019). Additionally, profit-driven operations risk exacerbating social disparities, monopolistic practices, and diminished accountability (Williamson, 1985). Empirical evidence highlights the need for careful evaluation of privatization's economic and social trade-offs (Alamoush et al., 2021; Hurley et al., 2019).

Deregulation in the port sector represents a shift from centralized control to market-driven mechanisms aimed at enhancing competition, efficiency, and innovation (Notteboom and Yang, 2017). This process reduces bureaucratic barriers and regulatory constraints, thereby fostering resource efficiency and encouraging market entry (Julus and Odiegwu, 2019). Key measures such as open access regimes, tariff deregulation, and privatization introduce competition and market discipline, driving investments, service quality, and consumer choice (Notteboom and Yang, 2017). Empirical studies reveal improvements in cargo throughput, vessel turnaround times, and operational efficiency, alongside investments in infrastructure and customer-focused services (Julus and Odiegwu, 2019). However, deregulation necessitates balanced regulatory oversight to address challenges like market concentration, equity, and environmental sustainability (Notteboom and Yang, 2017).

The growing global focus on sustainability has driven ports to invest in green infrastructure and adopt eco-friendly practices to enhance operational efficiency and mitigate environmental impacts (Alamoush et al., 2020; Azarkamand et al., 2020). Such measures align economic growth with environmental stewardship, offering benefits like reduced operating costs, improved resource efficiency, and heightened competitiveness (Alamoush et al., 2020). Moreover, green infrastructure strengthens ports' resilience to climate change, ensuring business continuity and bolstering community well-being (Azarkamand et al., 2020). Despite upfront costs and regulatory challenges, sustainable practices remain crucial for inclusive port development (Alamoush et al., 2020).

Infrastructure Development

Infrastructure development is vital for enhancing port capacity, efficiency, and resilience, with terminal expansion, dredging, and hinterland connectivity as pivotal components. Terminal development improves throughput capacity and addresses growing vessel sizes through initiatives like additional berths, automated equipment, and eco-friendly upgrades, which collectively enhance productivity and sustainability (Liu et al., 2021; Duru et al., 2020). However, challenges like funding and environmental constraints require strategic coordination. Similarly, dredging and channel deepening bolster port accessibility by enabling larger vessels, reducing navigational risks, and promoting maritime trade growth, albeit with environmental and stakeholder challenges (Li et al., 2019; Liu et al., 2020). Lastly, hinterland connectivity integrates ports with inland destinations, streamlining logistics and fostering regional development, demanding stakeholder collaboration to address infrastructure gaps (Ferchen and Perera, 2019; Nanyam and Jha, 2022).

Leadership Commitment

Leadership commitment is pivotal in shaping port governance to achieve strategic objectives and sustainable outcomes. It involves articulating a clear organizational vision, fostering stakeholder collaboration, and driving innovation. Julus and ODIEGWU (2019) emphasize that effective port leadership requires proactive stakeholder engagement, industry insight, and operational excellence.

A clear strategic vision is fundamental, guiding resource allocation and investment decisions to enhance efficiency and stakeholder value (Alamoush et al., 2021). This vision serves as a cornerstone for aligning port operations with broader economic and environmental goals. Beyond vision-setting, leadership commitment includes fostering collaboration among diverse stakeholders, such as government bodies, shipping lines, and local communities. By applying stakeholder theory, leaders can promote inclusive decision-making and build partnerships essential for sustainable port development (Gonzalez-Aregall et al., 2021).

In the context of rapid global changes, leadership commitment extends to championing innovation and continuous improvement. Leaders must adopt technological advancements and best practices to maintain competitiveness and resilience (Ashrafi et al., 2019). Accountability and ethical leadership are also critical, as they build trust and reinforce the port's role in global trade (Teerawattana & Yang, 2019). In sum, leadership commitment drives strategic alignment, collaboration, and innovation, serving as a linchpin for sustainable port governance and long-term prosperity.

Sustainable port development hinges on three critical pillars: stakeholder engagement, innovation, and capacity building. Effective stakeholder engagement integrates diverse perspectives, fostering transparency and collaboration essential for socially accepted port projects (Lawer, 2019; Gonzalez-Aregall et al., 2021). Mechanisms such as public hearings and advisory committees facilitate participatory decision-making, resolving conflicts and aligning development goals with stakeholder interests. By proactively engaging stakeholders, ports not only secure social licenses to operate but also mitigate risks of opposition and inefficiency (Gonzalez-Aregall et al., 2021). However, challenges like power imbalances and communication barriers necessitate inclusive and transparent approaches (Lawer, 2019).

Concurrently, innovation and best practices enhance operational efficiency and sustainability. Technologies like automation, AI, and blockchain streamline operations and improve supply chain visibility (Ashrafi et al., 2019). Benchmarking frameworks further identify performance gaps, enabling ports to adopt industry best practices and set ambitious improvement targets (Hossain et al., 2019). Corporate sustainability initiatives, encompassing energy efficiency and waste management, integrate environmental and social responsibility into port operations, fostering resilience amidst evolving market and regulatory demands.

Finally, capacity building is indispensable for nurturing talent and driving organizational growth. Training, mentoring, and leadership programs cultivate a skilled workforce capable of navigating industry complexities (Ibrahim et al., 2022; MacNeil et al., 2021). By fostering continuous learning and recognizing employee contributions, ports enhance motivation, productivity, and succession planning, securing long-term success. Together, these strategies underscore the multifaceted approach required for sustainable port management.

Operational Performance

Key performance indicators (KPIs), such as cargo throughput, vessel turnaround time, and customer satisfaction, are vital benchmarks for assessing port efficiency, reliability, and service quality (Ha et al., 2019; Moktadir et al., 2020). These metrics highlight how port policies, infrastructure investments, and operational strategies meet user and stakeholder expectations. Research by Ha et al. (2019) and Moktadir et al. (2020) underscores the intricate links between governance, investment, and performance, providing actionable insights for managers and policymakers.

Cargo throughput, a core measure of port productivity, reflects the volume of goods handled. High throughput signals enhanced capacity utilization and competitiveness, drawing shipping lines and generating economic value. Investments in terminal expansions, dredging, and equipment upgrades significantly bolster throughput by increasing capacity and reducing congestion (Moktadir et al., 2020). Similarly, vessel turnaround time, the period required for ships to complete operations, is critical for efficiency. Ports with reduced turnaround times minimize shipping costs and enhance reliability, aided by infrastructure upgrades and streamlined processes (Ha et al., 2019). Customer satisfaction, capturing port user perceptions, is another pivotal KPI. Efficient services, digitalization, and stakeholder engagement elevate satisfaction levels, strengthening partnerships and service standards (Moktadir et al., 2020). Comparative studies and case analyses, as Castellano et al. (2020) and Teerawattana and Yang (2019) demonstrate, further elucidate how policies and practices across diverse regions influence port outcomes. These methodologies reveal patterns, best practices, and strategies fostering operational excellence and sustainability, enriching the discourse on port management and policy.

Resource-Based View

The resource-based view (RBV) offers a strategic perspective on organizational management, emphasizing the role of internal resources and capabilities in achieving sustainable competitive advantage (Barney, 1991). When applied to ports' policy, Rodrigue (2020) succinctly suggested how the strategic management of port infrastructure can influence operational performance and long-term viability.

According to Rodrigue (2020) port infrastructure encompassing terminals, berths, cranes, and intermodal connections, constitutes a critical resource that underpins port operations and competitiveness. Ports endowed with well-developed infrastructure assets are better positioned to handle increasing cargo volumes, accommodate larger vessels, and provide efficient logistics services to customers (Liu et al., 2021).

Furthermore, the resource-based view highlights the importance of policies and leadership commitment in leveraging port infrastructure to achieve strategic objectives (MacNeil et al., 2021). Effective policies that promote infrastructure development, investment incentives, and public-private partnerships can enhance the availability and quality of port infrastructure. This, in turn, bolsters operational performance and attracts shipping lines and cargo owners (Hossain et al., 2019).

Leadership commitment is essential for aligning organizational resources, including port infrastructure, with strategic goals and stakeholder interests (Julus & Odieguwu, 2019). Port managers must show a steadfast dedication to investing in infrastructure upgrades, maintaining asset quality, and fostering a culture of innovation and continuous improvement (Alamoush et al., 2021).

Ports that adopt a proactive approach to infrastructure development and management are better positioned to adapt to changing market demands and technological advancements (Liu et al., 2020). By effectively leveraging their infrastructure assets, ports can differentiate themselves from competitors, attract new business, and sustain growth in an increasingly competitive global market (Ashrafi et al., 2019).

In summary, the resource-based view offers valuable insights into the strategic management of port infrastructure and its implications for operational performance. By recognizing port infrastructure as a critical resource for competitive advantage, ports managers can formulate effective policies, allocate resources wisely, and demonstrate leadership commitment to enhance their operational efficiency, resilience, and long-term sustainability (Teerawattana & Yang, 2019).

3.0 METHODOLOGY

3.0.1 Research Design

Previous research on port operational performance has been based primarily on cross sectional survey data (Rodrigue and Notteboom 2020; Alamoush et al. 2023; Cahoon et al. 2020). Following examples from such studies, we collected cross-sectional survey data to test our hypotheses. We sampled 450 key respondents operating in and around the two major ports in Ghana (Port of Tema and Takoradi). Obtaining secondary data to test the variables of interest was challenging. Hence the need to collect cross-sectional survey data. Though cross sectional data restrict the ability to make causal inferences (Kull et al., 2018). Rindfleisch et al. (2008) argue that such data can be used to test explanatory models grounded in relevant theories.

3.0.2 Measure development

We followed the measurement guidelines in MacKenzie et al. (2011) to generate and validate suitable indicators for the constructs. Prior to administering our questionnaire, two directors from both the Port of Tema and Takoradi, CEO of Meridian Port Service (A private port terminal operator), two operations managers from Ghana Maritime Authority and Ghana Shippers Authority and two professionals in academia who are experts in port management and terminal operations were asked to review the constructs' operational definitions and indicators. Based on their feedback, indicators with poor face validity and items found to be ambiguous were revised. We pretested our questionnaire by administering to 20 respondents. Upon analyzing the pilot study, no major concerns were found in the questionnaire.

3.0.3 Substantive variables

Dependent variable

We developed ten (10) reflective measurement items adapted from Rodrigue and Notteboom (2020) and Alamoush et al. (2023) to measure port operational performance, this was anchored on a five-point Likert scale from 1 = strongly disagree to 5 = strongly agree.

Independent variable

Two independent variables port policies and port infrastructure were used to predict port operational performance. Both port policies and port infrastructure were adapted from Rodrigue and Notteboom (2020) and Nguyen et al. (2021). Ten (10) different measurement items were developed to assess port policies and port infrastructure, all anchored on five-point Likert scale.

Moderating variable

We used ten indicators to measure leadership commitment. We drew insights from previous research (e.g., Akinyemi (2022).

3.0.4 Sample and data collection

We sampled respondents who were key port users and contribute in taking strategic decisions concerning port management and operations. We focused on respondents who hold strategic positions in various companies who directly depend on the port. For instance, logistics companies, port authority, shipping lines, port agencies, stevedoring companies, haulage companies. A total of 450 questionnaires were administered, over a period of 3 weeks, 390 was retrieved accounting for a response rate of 86%. 6 of the received questionnaires were discarded as they were incomplete, leaving 384 valid responses (i.e., 85% effective response rate). Our sample size and response rate compare favorably with other studies in maritime transport safety (Rodrigue and Notteboom 2020; Nguyen et al. 2021).

4.0 DATA ANALYSIS AND RESULTS

Demographic characteristics

RESPONSES	FREQUENCY n=384	PERCENTAGE (%)
Gender		
Male	257	66.90%
Female	127	33.10%
Age		
18-25 years	76	19.80%
26-35 years	174	45.30%
36-45 years	96	25.00%
46-55 years	38	9.90%
56 years and above	0	0.00%
Educational Qualification		
HND	113	29.50%
Bachelor's Degree	201	52.30%
Master's Degree	63	16.40%
Doctorate/Ph.D.	7	1.80%
Role/Position		
Directors	30	7.80%
General managers	30	7.80%
CEOs	23	6.00%
Operations managers	94	24.50%
SC managers	81	21.10%
Logistics managers	60	15.60%
Port authorities	5	1.30%
Freight Forwarders	61	15.90%

Years of Experience in the Port Industry		
Less than 5 year	131	34.10%
5 - 10 years	127	33.10%
11 - 15 years	51	13.30%
Over 15 years	75	19.50%

Source: Field Data, 2024

Structural Equation Model

To test the hypothesized relationships among port policies, leadership commitment, infrastructure development, and operational performance, a structural equation modeling (SEM) analysis was conducted using a sample of 384 respondents. The measurement model included four latent constructs: port policies (measured by 10 items), leadership commitment (10 items), infrastructure development (10 items), and operational performance (10 items).

Model Fit

The structural equation model was evaluated using multiple goodness-of-fit indices to ensure robust assessment of model fit. Several fit indices were examined: chi-square test (χ^2), comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).

The results indicated excellent model fit across all indices. The chi-square test was non-significant, χ^2 (728) = 756.82, p = 0.213, suggesting good fit between the hypothesized model and the observed data. The CFI (0.995) and TLI (0.994) both exceeded the recommended threshold of 0.95, indicating excellent comparative fit. The RMSEA value of 0.011 (90% CI [0.000, 0.019]) was well below the suggested cutoff of 0.06, demonstrating excellent absolute fit. Similarly, the SRMR value of 0.026 was well below the recommended threshold of .08, further supporting the model's fit to the data.

As shown in Table 4.1, all fit indices met or exceeded their respective thresholds, indicating excellent model fit. These results provide strong support for the hypothesized structural relationships among the study variables. The non-significant chi-square test, coupled with the high CFI and TLI values and low RMSEA and SRMR values, suggests that the model effectively represents the underlying relationships in the data.

Table 4.6: Goodness-of-Fit Indices for the Structural Equation Model (N = 384)

Fit Index	Value	Threshold	Interpretation
χ^2	756.82	-	-
Df	728	-	-
p-value	0.213	> 0.05	Excellent
CFI	0.995	≥ 0.95	Excellent
TLI	0.994	≥ 0.95	Excellent
RMSEA	0.011	≤ 0.06	Excellent
RMSEA 90% CI	[0.000, 0.019]	-	Excellent
SRMR	0.026	≤ 0.08	Excellent

Note. χ^2 = Chi-square; df = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation; CI = Confidence Interval; SRMR = Standardized Root Mean Square Residual.

Measurement Model

The measurement model was evaluated by examining the factor loadings of each indicator on its respective latent construct. Standardized factor loadings exceeded 0.50, with values above 0.70 considered ideal. Table 4.8 presents the standardized factor loadings for all measurement items.

All items demonstrated strong factor loadings ranging from 0.838 to 0.874, well above the recommended threshold of 0.70, indicating strong convergent validity. The high and significant factor loadings suggest that all items are reliable indicators of their respective constructs.

Table 4.7: Standardized Factor Loadings for the Measurement Model

Construct & Items	Factor Loading	SE	p-value
Port Policies			
Q1	0.851	0.032	< 0.001
Q2	0.843	0.033	< 0.001
Q3	0.862	0.031	< 0.001
Q4	0.838	0.034	< 0.001
Q5	0.856	0.032	< 0.001
Q6	0.849	0.033	< 0.001
Q7	0.845	0.033	< 0.001
Q8	0.857	0.032	< 0.001
Q9	0.841	0.034	< 0.001
Q10	0.853	0.032	< 0.001
Leadership Commitment			
Q11	0.867	0.03	< 0.001
Q12	0.859	0.031	< 0.001
Q13	0.871	0.029	< 0.001

Construct & Items	Factor Loading	SE	p-value
Q14	0.863	0.03	< 0.001
Q15	0.858	0.031	< 0.001
Q16	0.865	0.03	< 0.001
Q17	0.869	0.029	< 0.001
Q18	0.862	0.03	< 0.001
Q19	0.864	0.03	< 0.001
Q20	0.866	0.03	< 0.001
Infrastructure Development			
Q21	0.848	0.033	< 0.001
Q22	0.853	0.032	< 0.001
Q23	0.847	0.033	< 0.001
Q24	0.851	0.032	< 0.001
Q25	0.849	0.033	< 0.001
Q26	0.855	0.032	< 0.001
Q27	0.85	0.032	< 0.001
Q28	0.852	0.032	< 0.001
Q29	0.854	0.032	< 0.001
Q30	0.851	0.032	< 0.001
Operational Performance			
Q31	0.873	0.029	< 0.001
Q32	0.868	0.029	< 0.001
Q33	0.871	0.029	< 0.001
Q34	0.869	0.029	< 0.001
Q35	0.872	0.029	< 0.001
Q36	0.867	0.03	< 0.001
Q37	0.87	0.029	< 0.001
Q38	0.874	0.029	< 0.001
Q39	0.869	0.029	< 0.001
Q40	0.871	0.029	< 0.001

Note. SE = Standard Error. All factor loadings are significant at $p < 0.001$

Structural Model Results

The structural model examined the hypothesized relationships among the latent variables. Table 4.8 presents the standardized path coefficients for all hypothesized relationships. Based on the structural model results, the analysis revealed a significant positive relationship between port policies and operational performance, indicating that better port policies are associated with improved operational performance. Leadership commitment showed the strongest positive relationship with operational performance among all predictors, suggesting that higher levels of leadership commitment lead to better operational performance.

The analysis confirmed a significant positive relationship between infrastructure development and operational performance, indicating that improved infrastructure development contributes to better operational performance.

The model explained 67.3% of the variance in operational performance ($R^2 = 0.673$), indicating strong explanatory power. All three hypothesized relationships were supported, with leadership commitment showing the strongest effect (β = 0.385), followed by port policies (β = 0.324) and infrastructure development (β = 0.298). These findings suggest that while all three factors significantly contribute to operational performance, leadership commitment plays the most crucial role in determining operational performance outcomes.

Table 4.8: Standardized Path Coefficients for the Structural Model

Path	Estimate (β)	SE	t-value	p-value
Port Policies - Operational Performance	0.324	0.052	6.231	< 0.001
Leadership Commitment - Operational Performance	0.385	0.049	7.857	< 0.001
Infrastructure Development - Operational Performance	0.298	0.053	5.623	< 0.001

Note. SE = Standard Error

Moderation Analysis Results

To address the fourth research objective concerning the interactive effects, the study examined the moderating role of leadership commitment on the relationships between (1) port policies and operational performance, and (2) infrastructure development and operational performance. The moderation analysis was conducted using structural equation modeling with interaction terms as illustrated in Table 4.9.

Table 4.9: Results of Moderation Analysis

Path	Estimate (β)	SE	t-value	p-value
Main Effects				
Port Policies - OP	0.324	0.052	6.231	< .001
Leadership Commitment - OP	0.385	0.049	7.857	< .001
Infrastructure Development - OP	0.298	0.053	5.623	< .001
Interaction Effects				
PP × LC - OP	0.156	0.043	3.628	< .001
ID × LC - OP	0.142	0.044	3.227	0.001

Note. OP = Operational Performance; PP = Port Policies; LC = Leadership Commitment; ID = Infrastructure Development

Table 4.10: Simple Slope Analysis Results

Relationship	Leadership Commitment Level	Simple Slope	SE	t-value	p-value
PP - OP	Low (-1 SD)	0.168	0.057	2.947	0.003
PP - OP	High (+1 SD)	0.48	0.061	7.869	< .001
ID - OP	Low (-1 SD)	0.156	0.058	2.69	0.007
ID - OP	High (+1 SD)	0.44	0.062	7.097	< .001

Moderation Effect of Leadership Commitment on Port Policies-Operational Performance Relationship

The analysis revealed a significant positive interaction between port policies and leadership commitment ($\beta = 0.156$, $p < 0.001$) in predicting operational performance. The simple slope analysis indicated that the relationship between port policies and operational performance was stronger when leadership commitment was high ($\beta = 0.480$, $p < 0.001$) compared to when it was low ($\beta = 0.168$, $p = 0.003$). This suggests that leadership commitment enhances the positive effect of port policies on operational performance.

Moderation Effect of Leadership Commitment on Infrastructure Development-Operational Performance Relationship

Similarly, a significant positive interaction was found between infrastructure development and leadership commitment ($\beta = 0.142$, $p = 0.001$) in predicting operational performance. The simple slope analysis showed that the relationship between infrastructure development and operational performance was stronger under high leadership commitment ($\beta = 0.440$, $p < 0.001$) compared to low leadership commitment ($\beta = 0.156$, $p = 0.007$). This indicates that leadership commitment also strengthens the positive effect of infrastructure development on operational performance.

Interpretation of Moderation Effects

The moderation analysis revealed several key insights. Leadership commitment emerged as a significant moderator in two key relationships. First, it enhances the effectiveness of port policies in improving operational performance. Second, it strengthens the impact of infrastructure development on operational performance.

The moderating effects were found to be stronger for port policies ($\beta = 0.156$) compared to infrastructure development ($\beta = 0.142$), suggesting that leadership commitment plays a slightly more important role in the successful implementation of effective port policies than in infrastructure development initiatives.

In conditions of high leadership commitment, the effect of port policies on operational performance is nearly three times stronger compared to situations with low leadership commitment. Similarly, the effect of infrastructure development on operational performance is almost tripled when leadership commitment is high.

These findings indicate that while port policies and infrastructure development directly contribute to improved operational performance, their effectiveness is significantly amplified when coupled with strong leadership commitment. This highlights the pivotal role of leadership commitment as a catalyst in maximizing the benefits of both port policies and infrastructure development efforts.

Discussion

The results of this study provide valuable insights into the interconnected relationships between port policies, leadership commitment, infrastructure development, and operational performance. The strong model fit indices, including a non-significant chi-square test, high comparative fit index (CFI), and low root mean square error of approximation (RMSEA), support the robustness of the structural equation modeling (SEM) analysis, confirming the validity of the relationships tested.

In comparing these results to previous studies, the positive relationship between port policies and operational performance resonates with findings from Onwuegbuchunam et al. (2021), who examined Nigerian seaports. Their research also highlighted the role of sound port policies in improving operational outcomes, noting that well-structured policies can mitigate operational inefficiencies. Similarly, Nguyen et al. (2021) found a positive correlation between port policy implementation and performance in Vietnamese seaports, suggesting that policy reforms tailored to port-specific needs can have a substantial impact on performance outcomes.

The present study extends these conclusions by showing that the effect of port policies is further strengthened when leadership commitment is high. This finding builds upon existing knowledge by demonstrating the critical moderating role of leadership, which echoes the conclusions of Akinyemi (2022). Akinyemi's review of African port leadership pointed out that leadership commitment not only drives policy success but also fosters a culture of accountability and operational excellence. Thus, the current study confirms the importance of leadership as a reinforcing mechanism that ensures the successful application of port policies, particularly in diverse operational environments.

The results also demonstrate a significant positive relationship between infrastructure development and operational performance, which is consistent with studies such as Liu et al. (2021) in China and Munim and Schramm (2023) on a global scale. These scholars emphasized the critical role that modern infrastructure plays in enhancing port efficiency, reducing bottlenecks, and improving cargo handling capacities. In this study, the SEM results revealed that infrastructure development contributed meaningfully to performance improvements, though the impact was slightly weaker than leadership commitment's role.

The moderation analysis highlights that leadership commitment not only improves the direct relationship between policies and performance but also significantly amplifies the effect of infrastructure development. This supports the view presented by Cahoon et al. (2020), who emphasized that leadership's influence is pivotal in realizing the full potential of infrastructural investments. Effective leadership can align infrastructure projects with strategic objectives, thus maximizing their impact on performance. This interaction effect between leadership and infrastructure development has been observed in Canadian ports as well, where leadership played a crucial role in bridging the gap between infrastructure upgrades and performance outcomes (Ashrafi et al., 2019).

However, while leadership commitment's moderating effect on infrastructure development is significant, the results of this study show a slightly stronger moderation effect on the relationship between port policies and operational performance. This implies that leadership commitment may play a more vital role in policy implementation than in the success of infrastructure development. This finding contrasts with earlier work by Ferchen and Perera (2019), who found that in Chinese infrastructure projects, leadership's role was more critical in ensuring that infrastructure developments aligned with operational goals. The differences could be attributed to the specific contexts of the studies; in more regulated environments such as China, infrastructure projects may be more directly influenced by government leadership compared to ports operating under market-driven frameworks.

The high explanatory power of the model ($R^2 = 0.673$) further underscores the substantial role that port policies, leadership commitment, and infrastructure development play in operational performance. This finding is supported by Rodrigue and Notteboom (2020), who noted that well-integrated port strategies tend to explain a significant proportion of performance variance in diverse settings. Moreover, the study's findings reinforce the conclusion that leadership commitment is the most influential factor among the predictors, as demonstrated by its largest path coefficient ($\beta = 0.385$). This corresponds with the observations of Alamoush et al. (2023), who concluded that leadership is often the driving force behind sustainable port performance.

In summary, the results of this study contribute to the literature by confirming the importance of port policies, leadership commitment, and infrastructure development in enhancing operational performance. The findings suggest that leadership commitment not only has a direct effect but also amplifies the effects of both port policies and infrastructure development, particularly in fostering an environment where these initiatives can thrive. These insights align with and extend previous research, adding depth to the understanding of how leadership can act as a catalyst in port operations. While policies and infrastructure are essential, their effectiveness is significantly enhanced when supported by committed leadership.

Managerial implications

The study findings suggest the need to develop leadership training programs focusing on strategic alignment, operational excellence, and change management to improve the application of port policies and infrastructure utilization.

Managers must engage in participatory leadership practices that involve employees, contractors, and other stakeholders in decision-making to build trust and foster a culture of accountability.

Port managers must acknowledge that infrastructure development projects are closely tied to specific operational performance goals coupled with commitment from leadership. It is again, important to emphasize that senior managers and leadership teams must be assigned to oversee key policy initiatives and ensure strategic alignment among policies, infrastructure and leadership.

Policy implications

In the quest to enhance performance at port, port authorities and policymakers must be encouraged to design policies that directly address key inefficiencies in port operations, with clear objectives linked to measurable outcomes. This means that performance-based policy frameworks must be developed to drive the achievement of operational goals.

Infrastructure-responsive policies plan is required to align long term strategic objectives of the port.
Policies must incorporate mechanisms that recognize and reinforce the role of leadership in their execution. For example, policies could mandate leadership oversight in infrastructure projects or establish accountability measures for leaders during policy implementation.

Limitations and Areas for Future research

The research relied on cross-sectional data, capturing relationships at a single point in time. This approach limits the ability to establish causal inferences or observe how relationships between port policies, leadership commitment, and operational performance evolve over time.
Future researchers could consider longitudinal studies to track the direction of policies and infrastructure development that is creating the required performance. This would provide deeper insights into the interactive effect of port policies, infrastructure and performance and their long-term impact.
While the study focused on internal drivers of performance (e.g., policies, leadership, infrastructure), external factors such as global trade disruptions, geopolitical risks, and technological advancements were not explicitly modeled, potentially leaving out key determinants of port performance. Further studies could integrate external variables such as global supply chain disruptions, trade policy shifts, or emerging technologies like automation and artificial intelligence, assessing their moderating or mediating effects on operational performance.
Expanding the analysis to include different leadership styles (e.g., transformational, transactional, servant leadership) could provide more granular insights into the specific leadership behaviors that maximize the effectiveness of policies and infrastructure investments.

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Assessing Challenges Facing the Small Island Developing States (SIDS) Towards Policy Coherence and Coordination in Managing Sustainable Blue Economy: A study of Zanzibar in Tanzania

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Abstract

The Blue economy policy set the course to sustainable development of ocean spaces in Zanzibar, however it is not clear this new concept requires a new set of government principles and policies or whether existing policy mechanism can accommodate it. In most recently years Zanzibar had taken steps to diversify the country's Blue economy resources by establishing Ministry of Blue economy together with adopting and implementing the Blue Economy Policy 2020.These steps has been taken for creation of jobs and enhance food security as well as protection of marine environment and boost economic growth. However full potential exploitation of these resources had not been realized due to lack of coherence and coordination in policy framework, legislation and resource management between state departments and Agencies responsible for Blue Economy. By using Zanzibar as a Small Island Developing states(SIDS) it has been found on policy coherence and coordination across a range of Maritime sectors that; existing governing systems appears to be largely consistent with the Blue economy aspirations. Strengthening connection between sectorial management arrangements through boundary organizations and amendments to existing instruments may therefore be an efficient and pragmatic approach to Blue economy implementation. This approach would allow more focused attention on bridging policy gaps and addressing deficiencies in existing systems in Zanzibar. This research has been conducted touching on various aspects of marine and maritime sectors in Zanzibar but little research has been done on challenges during implementation of the strategic blue print on the Blue Economy and the gaps that exist on the legal and regulatory frameworks which affect governance, finance and sustainable exploitation of the ocean resources hence need for this research with a view to find the solution for the effective implementation of the regulatory framework thus impact positively strategic planning, policy making and implementation. The research used both qualitative and quantitative method and data collection method used questionnaires and Focus Group Discussion, data analysis tool used descriptive method to analyze the findings of the research.

Keywords: *Challenges, SIDS, Policy coherence, Managing, Sustainable Blue Economy*

1.0 INTRODUCTION

1.1 Background

Zanzibar is an archipelagic state within the United Republic of Tanzania (URT) consisting of the two main islands of Unguja and Pemba and 53 islets. It shares maritime water with mainland Tanzania, the other part of the United Republic of Tanzania (URT). According to the Zanzibar Statistical Abstract report of 2019, the projected population of Zanzibar in 2020 was 1,671,598 with an annual growth rate of 2.8%.

The Zanzibar population is composed of 51% females, and 49% males, 36% of them are youths aged 15-35years. As an island state, Zanzibar greatly depends on the sea, coast and marine resources, the carrier of blue activities for socio-economic development. About 98% of Zanzibar's international trade by volume is seaborne. These blue activities contribute to about 29% of the Zanzibar Gross Domestic Product (GDP) and employ about one-third of the population.

The sea-based economy, or blue economy (BE) as it is currently known is not a new economic phenomenon. Zanzibar has been engaging in domestic and international ocean-based economic activities for centuries. Evidence shows that by the 15th century, Zanzibar was already a regional commercial hub due to the abundance of spices and fishery products exchanged internationally through long-haul seaborne trading routes along the Swahili coast and the Indian Ocean, especially with the Arab world and within East Africa. Acknowledging the importance of BE, the Revolutionary Government of Zanzibar (RGoZ) has formally incorporated the concept as part of its national development priorities.

That ambition has been fully reflected in the Zanzibar Development Vision 2050 (Vision 2050), the country's long-term development plan from 2020 to 2050. Vision 2050 recognizes BE as a distinct priority area to diversify Zanzibar's economy, catalyzing its transformation from subsistence-based agriculture and tourism-led services to higher value-added services and industrialization.

The Blue Economy initiative further strengthens the country's commitment to implement the United Nations Sustainable Development Goals (SDGs), especially SDG goal number 14, which emphasizes the conservation and sustainable use of the oceans, seas and marine resources for sustainable development. The Revolution Government of Zanzibar believes that if Zanzibar can adequately implement BE, it will enhance economic growth, increase incomes and help protect the environment. However, realizing the full potential of BE calls for the inclusion and participation of all related social groups and sectors through appropriate legal and institutional frameworks.

1.2 Statement of the problem

In most recently years Zanzibar had taken steps to diversify the country's Blue economy resources by establishing Ministry of Blue economy together with adopting and implementing the Blue Economy Policy 2020.These steps has been taken for creation of jobs and enhance food security as well as protection of marine environment and boost

economic growth. However full potential exploitation of these resources had not been realized due to lack of coherence and coordination in policy framework, legislation and resource management between state departments and Agencies responsible for Blue Economy.
Research has been conducted touching on various aspects of marine and maritime sectors in Zanzibar but little research has been done on challenges during implementation of the strategic blue print on the Blue Economy and the gaps that exist on the legal and regulatory frameworks which affect governance, finance and sustainable exploitation of the ocean resources hence need for this research with a view to find the solution for the effective implementation of the regulatory framework thus impact positively strategic planning, policy making and implementation.

1.3 Objectives of the research

The general objectives of the study were to assess the challenges facing Small Island developing states(SIDS) towards policy coherence and coordination in managing sustainable blue economy in Zanzibar

1.3.1 Specific Objectives of the research

i. Examine the degree of awareness of the Blue economy policy to people of Zanzibar
ii. Investigate the level of success achieved by different sectors in implementing blue economy policy
iii. Identify best practices undertaken in successful managing blue economy in Zanzibar

1.3.2 Research questions

i. How do you rate the degree of awareness in Blue economy policy to people of Zanzibar?
ii. What success has been achieved in implementing blue economy policy in Zanzibar?
iii. Which best practices should be taken in successful managing blue economy in Zanzibar?

2.0 Literature review

2.1 Established and emerging industries under the Blue economy

The projections suggest that between 2010 and 2030 on a “business-as-usual” scenario basis, the Blue Economy could more than double its contribution to global value added, reaching over USD 3 trillion. Particularly strong growth is expected in marine aquaculture, offshore wind energy, shipbuilding and repairs, port activities and seafood processing. (Professor Attri, 2016)

The following ocean-based industries have been identified

Established	Emerging
Capture Fisheries	Marine aquaculture
Sea food Processing	Deep-and-ultra-deep water oil and gas
Shipping	Offshore wind energy
Ports	Ocean renewable energy
Ship building and Repair	Marine and Seabed mining
Offshore Oil and gas(shallow water)	Maritime Safety and Surveillance
Marine Manufacturing and Construction	Marine biotechnology
Maritime and coastal Tourism	High technology marine products and services
Marine Business Services	Others
Marine R&D and education	
Dregging	

Source: OECD (2016) The ocean economy in 2030

2.2. Policy Strategies for Fisheries

(i). Infrastructure and information

- Developing statistical databases of fish stock, biomass and other important information systems to ensure stakeholders have access to reliable and accurate information.
- Investing in fisheries value chain development that includes production, processing, value addition and marketing, focusing on the following:
- Key fishing infrastructure, including ice-making plants and cold-storage facilities to store excess catch, for better marketing opportunities.
- Commissioning specialized fishing ports to serve all commercial fishing vessels in Zanzibar's territorial water. The fishing ports shall be fully equipped to deal with fish storage and vessel maintenance, whilst being designed to allow the efficient unloading of catch, with good transport networks to the rest of Zanzibar.
- Establishing supporting businesses to generate cluster effects around fishing ports, including plants to make fishing nets, engine repair and maintenance workshops as well as fish processing and canning factories.
- Ensuring a consistent supply of produce by improving energy security in rural areas through off-grid solutions, such as solar photo voltaic cells.

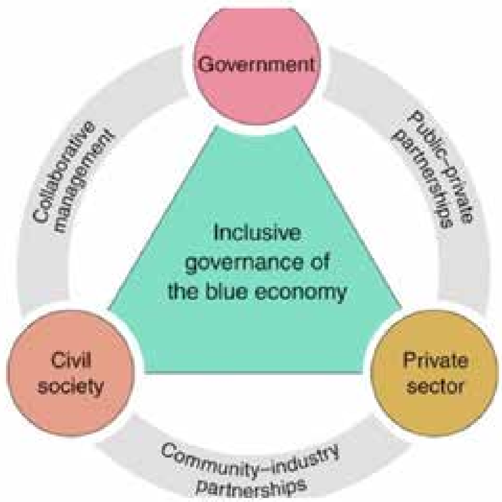
2.3 Policy Strategies for Maritime Trade and Infrastructure

(i) Port and maritime infrastructure

- Introducing automated vessel tracking systems covering Zanzibar's territorial water to ensure adequate communications between the port traffic controls and freighters.

- Harmonizing customs procedures by establishing a one-stop border-clearing agency at the port of entry with modern information systems, which will handle administrative clearance in areas including customs, health and technical standards and taxation.
- Promoting Zanzibar as a leading hub for international ship registration; and
- Promoting technology transfer to develop the infrastructural capacity of the maritime sector through cooperation with development partners and key stakeholders in the form of technical assistance, information sharing and training.

2.4 Conceptual framework



Source; publication, 2019

2.5 Theoretical framework

The research focused on the theory that was relevant in policy coherence and coordination. The institutional theory which primarily focuses on policy making was considered. The theory places emphasis on formal and legal aspects of government structures.

2.6 Institutional Theory

This theory focuses on the importance of policies. The theory stipulates that in order for an institution to succeed, there was need for policies and regulations. According to Delmas and Toffel (2005), institutional theory is concerned with external forces on the organizational process of decision-making with emphasis on the role of socio-cultural practices that are imposed on the organizations that influence on the practices and structures. The institutional theory as a policy, emphasize on the formal and legal government structure, as such, government agencies can directly or indirectly make some organizations to change their strategy. The theory explains why some aspects of practices can be chosen without necessarily bringing an economic value (Kraft and Scott, 2017 and Krell, Matook and Rodhe, 2016).

The institutional theory notes that some practices can be adopted. The blue economy should be guided by the institutional theory in the implementation of the Integrated National Maritime Policy (INMP) and for it to be a success, certain institutional frameworks must be in place to aid the penetration of the benefits of the blue economy including maritime policies and regulations. Zanzibar can manage the potential of the blue economy by ensuring formulation and implementation of a policy framework that provides for sustainable exploitation of resources and integration of mandates that are currently executed by multiple government agencies.

3.0 Data analysis and research Findings

Simple random sampling was used to select respondents from Ministry and Agencies responsible for the Blue Economy. With a target of 50 respondents which were set only 35 responded.

Table 3.1 Distribution of Respondents as per the Ministry and Agency

S/N	Ministry and Agency	Frequency	Percentage
01	Ministry of Blue Economy	10	28.6
02	Zanzibar Port Corporation(ZPC)	05	14.3
03	Zanzibar Maritime Authority(ZMA)	04	11.4
04	Ministry of Transport and Infrastructure	03	8.6
05	Ministry of Fisheries and Aquaculture	04	11.4
06	Ministry of Tourism	03	8.6
07	Private sectors	06	17.1
08	Total	35	100.00

Qualitative and quantitative data were analyzed using thematic content analysis and descriptive statistics respectively. Microsoft excel was used for data analysis and presentation through the use of tables, bar charts, pie charts, percentage and frequencies.. The researcher collected the data and edited it to check for errors, omissions or any other inconsistencies before analysis. This ensured completeness and accuracy of information filled in the questionnaires. The information was uploaded on excel sheet, this ensured that information that was collected was to be analysed simultaneously as alluded by (Vaismoradi, Trumen & Bandas, 2013) also, Stockdale (2002) and Watkins, (2012) support that excel is affordable and user friendly as compared to other alternatives that are equally expensive, Stockdale further argues that a researcher may use a variety of specialized data collection software to organize and a separate programme to analyse the data. Kupzyk and Kohen, (2015) alludes that a researcher using excel is able to manipulate the format of each document to produce a design conducive to research requirements. Ryan and Benard (2003) highlights that a researcher can create themes, codes and meaning with research by identifying single words and phrases colour to correlate similar information in the literature and conceptual framework. Yilmaz (2013) asserts that the researcher should avoid opinions and conclusions and data driven themes that might resonate in getting biased conclusions or personalized opinions as per the researcher's point of view

The study established that for Zanzibar to achieve full potential and sustainable exploitation of the blue economy resources to boost economic growth and development the **Intergrated National Maritime Policy(INMP)** must be established to bring coherence and coordination within state departments and Agencies mandated to oversee the blue economy agenda,

Blue economy activities are controlled by various laws and regulations; international laws/ treaties, regional regulations and national laws. Government Departments and agencies have been given different mandates resulting to conflict of interest and poor governance due to lack of cooperation between the oversight agencies, compartmentalization and silo management. This leads to duplication of resources without clear goals of achieving a sustainable blue economy. To achieve integrated approach and improved governance, the use of Integrated National Maritime Policy as tool would offer solutions to oversee overarching issues that arose in the institutional, legal and regulatory regimes with a view of providing amicable solutions for the successive implementation of sustainable blue economy. Zanzibar must also adopt different **international best practices** on legislation and policies to foster the rapid growth of Blue economy

4.0 Coordination and Implementation of Blue Economy Policy

The implementation of Zanzibar policy should be undertaken by an autonomous Blue Economy institution to be created within the Ministry responsible for national planning. The institution has been the central coordinator of all BE activities, taking ownership and responsibility for implementing the BE Policy. It has primarily played a coordinating role and oversee the development of various sectors, ministries, departments and agencies (MDAs), institutions, industries and associated programmes relevant to BE. It has also been responsible for managing the Blue Economy Fund.

The institution has been a multidisciplinary in its composition, whose members have expertise in key BE sectors, including fisheries, trade, energy and tourism, with backgrounds in economics, environmental sustainability, marketing, development, marine biology, security, maritime law and related fields.

Further, for Zanzibar's BE aspirations to be implementable, capacity building in all areas relating to maritime sectors and BE has been prioritized. **The Institute of Maritime Studies at SUZA** and the **Institute of Marine Sciences at the University of Dar es Salaam and Dar es Salaam Maritime Institute** must take a leading role of creating an enabling environment for marine and maritime studies and scientific research.

The implementation of the BE Policy shall be supported by the following MDAs and related stakeholders:

(i) Ministry responsible for finance

• Mobilising and allocating resources for the implementation of BE activities and programmes.
• Extending favorable terms and conditions of investment to local investors.
• Aligning financial and procurement law and regulations to support effective support to private enterprises on government expenditure.
• Enhancing and supporting microfinance institutions to empower MSMEs through regulations and resources.
• Implementing accounting standards and procedures for BE activities.
• Ensuring efficient, transparent and accountable collection and management of BE revenues.

(ii) Planning Commission

• Incorporating and integrating BE activities into national development plans and strategies.
• Facilitating and coordinating research related to BE in order to capture and disseminate relevant blue knowledge.
• Collecting, compiling and publishing national statistics on blue activities in alignment with the key performance indicators highlighted in Vision 2050.
• Advising MDAs responsible for the BE on national economic agendas, strategies and goals.

(iii) Ministry responsible for fisheries and aquaculture

• Facilitating the mainstreaming of fisheries and aquaculture activities and issues into associated policies, programmes and plans.
• Creating a conducive environment for artisanal fishers as well as smallholder seaweed and mar culture farmers to access technologies and motivate their engagement.
• Facilitating market links and promoting value addition programmes for marine products.
• Enhancing the capacity of artisanal fishers and local investors to engage in deep sea fishing.
• Safeguarding the rights of fishers and their respective fish landing sites from the potentially adverse impacts of integrated economic activities.

(iv) Ministry responsible for maritime transport and infrastructure

• Ensuring the implementation of certain maritime laws under the International Maritime Organization responsible for the prevention of oil spill pollution through the Zanzibar Maritime Authority.
• Facilitating the improvement of maritime infrastructure across the islands.
• Ensuring the functional capacity of the organization to handle maritime directives for investors

(v). Private sector

• Advocating, supporting and following all RGoZ initiatives and policies regarding BE activities.
• Collaborating with the RGoZ and other stakeholders to expand investment opportunities.

• Supporting processing, market diversification and product value addition among local business and enterprises.

5. Recommendations

• Establishing an autonomous institution to execute and coordinate BE-related activities has been done with flying colours but it has to create awareness of local blue knowledge through the effective operationalisation of the Institute of Maritime Studies at the State University of Zanzibar (SUZA), the Institute of Marine Sciences at the University of Dar es Salaam, Dar es Salaam Maritime Institute and other teaching and research institutions.

• Introducing a Blue Fund to facilitate the financing of BE-related programmes and projects has been done but an effective enforcement of law must be put in place to protect Marine Protected Areas in order to address illegal, unreported and unregulated fishing as well as to maintain coral reefs and mangroves and enhancing maritime security through collaboration between URT and RGoZ institutions.

• Strengthening preparedness response and recovery measures to natural marine hazards, human-induced risks and maritime accidents, including implementing the Oil Spill Contingency Plan has to be implemented in full swing with presence of viable institution and regulatory framework to conform with UNCLOS, IOTC and other relating bodies.

• Empowering local government authorities to carry out effective and sustainable waste collection, particularly in coastal areas with a high concentration of hotels and tourist activities, has to be in line with broadening equitable participation of men and women, youth and elders in the governance and handling of BE activities in order to ensure the effective implementation of BE-related policies, including the O&G Policy and the Zanzibar Environmental Management Act.

6. Conclusions

• Zanzibar's development plans place great focus on high quality and sustainable human development of Zanzibar's citizens, including a special focus on sustainable development of its oceanic resources. The BE Policy aligns with Vision 2050 which has the overarching goal of lifting Zanzibar economically and socially to attain upper middle-income status by 2050. The Vision consists of four pillars that target different aspects of Zanzibar's development, with BE sitting within Pillar I for Economic Transformation. This pillar calls for "a structural transformation of Zanzibar's productive capabilities through economic modernization and diversification with a focus on export-oriented and technology-driven development, translating national comparative advantage to competitive advantage."

• Blue Economy is of high priority to the Zanzibar vision whose strategic direction is to "Effectively coordinating and managing the development of the ocean and its endowments for significant contribution to economic prosperity." Relevantly, it has four aspirations, which emphasise: (i) the importance of a cohesive BE captured through sectoral linkages; (ii) high expertise in managing BE-related technologies through capacity building and research and development (R&D), (iii) sustainable exploitation of BE resources and (iv) continued adherence to regional and international BE institutions

• Internationally, the BE concept aligns with the majority of the SDGs, most importantly SDG 14 and goal 6 of the African Union's Agenda 2063, which aim to "conserve and sustainably use the oceans, seas and marine resources for sustainable development". The United Nations Law of the Sea Convention (UNCLOS) provides the legal framework for the attainment of these goals, setting out the rules within which all activities in the oceans and seas must be carried out. Zanzibar is a state party to UNCLOS through the URT and has already domesticated several UNCLOS provisions in its national maritime jurisdiction

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Challenges Towards Sustainable Small-Scale Fishing Industry (artisanal fisheries) in Tanzania: A Case Study of Coastal Area of Tanzania Mainland.

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1.0 INTRODUCTION

Coastal fisheries industry in the United Republic of Tanzania, as it is the case with many other countries in the world, is a major source of cheap animal protein to the growing human population, income to fishers, and employment to increasing number of youth and women. Likewise, the fisheries industry generates foreign currency to the country through exportation of fishery products. Hence, the socioeconomic importance of this sub-sector cannot be overemphasized. With time, however, the industry is experiencing a number of challenges threatening resource sustainability and the very sustainable livelihood of fishers and other stakeholders. Overcapacity, overfishing, illegal fishing and environmental degradation vices are gaining momentum. Fishers continue fishing harder reducing numerous fish populations to extremely low levels, destabilizing marine ecosystems and impoverishing many coastal communities.

In view of the current situation, there is only one option left, and that is to strengthen fisheries resource management practices, especially effective development and implementation of Fisheries Management Plans (FMPs). With regard to management plans, fisheries authorities in mainland Tanzania and Zanzibar recognize the crucial role of FMP as an indispensable tool in resource management. Hence, efforts have been made to develop and implement FMPs in a number of fisheries. The FMPs are being developed through users' participation in planning and implementation of FMPs. However, due to financial constraints and other technical reasons several fisheries are yet to be covered. Generally, the FMPs in Tanzania are structured based on basic guidelines provided by the Food and Agriculture Organization of the United Nations (FAO). The major components are coastal zone/fisheries management issues, ecological description of respective fishery, economics and social dimensions, and zoning. Also, the FMPs outline stakeholders or partners with their specific roles in management of respective fishery, management objectives, strategies to be used, and measures including access rights, regulations, co-management arrangement, and decision-making processes as well as data collection protocol.

Given the importance of having effective FMPs, as important tool for effective fishery resource management, the ECOFISH program of the Indian Ocean Commission, commissioned a regional study to assess the efficacy of existing management plans in supporting the overall goal of sustainable fisheries resource utilization. The assessment took into consideration integrated nature of the main functions of fisheries resource management. It included review of information gathering and analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities. And more importantly to assess whether the FMPs are achieving resource management objectives. Detailed Terms of Reference (ToR) for this study is provided under Section 3 of this report.

2.0 BACKGROUND INFORMATION

The United Republic of Tanzania (URT) comprises Mainland Tanzania and Zanzibar. The later retains semi-autonomous status including management of coastal fisheries under Zanzibar's jurisdiction. There are five administrative regions situated along the mainland coast covering distance of 1424 squares kilometers from Tanga Region to Lindi: Tanga, Coast, Dar es Salaam, Lindi and Mtwara. These regions are further subdivided into districts. The islands of Unguja and Pemba make up Zanzibar, the other part of the Union of Tanzania. The fisheries industry in Tanzania is essentially small-scale, with the sub-sector generating over 98% of about 500,000 tons of annual fish landing from both marine (20%) and inland (80%) water fisheries. This figure, however, does not include catches from industrial fishing in the Exclusive Economic Zone (EEZ) because the associated catch is transshipped at sea to the international market. With regard to coastal fisheries, fishing operation is dominated by small scale fishers though there is a small fleet of about 6-10 semi-industrial prawn trawlers (size below 150 GRT). Besides the fleet of shrimp trawlers, fishing for high value fishery products such as Octopus, Shrimp, Lobster and others is done by small-scale fishers who sell most of their catches to fish processing plants for processing and marketing to high-end markets such as tourist hotels and export markets. The coastal fishery is multispecies with different sub-chains such as reef fishery, small pelagic fishery, large pelagic fishery, prawn fishery, octopus' fishery and others. Species being caught include mackerels, king fish, scavengers, parrot fish, sardines, rabbit fish, rays, sharks, and crustaceans. However, the main commercial coastal species are Prawns, Octopus, Lobster, Crabs, Tuna and tuna like species. In relation to fishing operation, coastal fishers in the country use a variety of fishing gears and methods such as gill netting, purse-seining/ring net fishing, long lining, hand lining, and trap fishing.

The most recent fisheries frame survey enumerated 53,035 small-scale primary fishers on mainland coastal fisheries. Specifically, 11,436 (21.56%) of them own fishing crafts, whereas 33,040 (62.30%) are crew members. They use 9,242 fishing crafts with sizes ranging between 2.5 metres to 10 metres with majority of the crafts, 6,476 (70%), falling between 2.5 – 5 metres category. Likewise, Mainland Tanzania has a total of 274 landing sites where fishers land their catch. In relation to fishers' organization, there are 174 landing sites with Breach Management Units (BMUs) though only 75 (43%) of them are registered by the Ministry of Livestock and Fisheries (MLF, Frame Survey 2018).

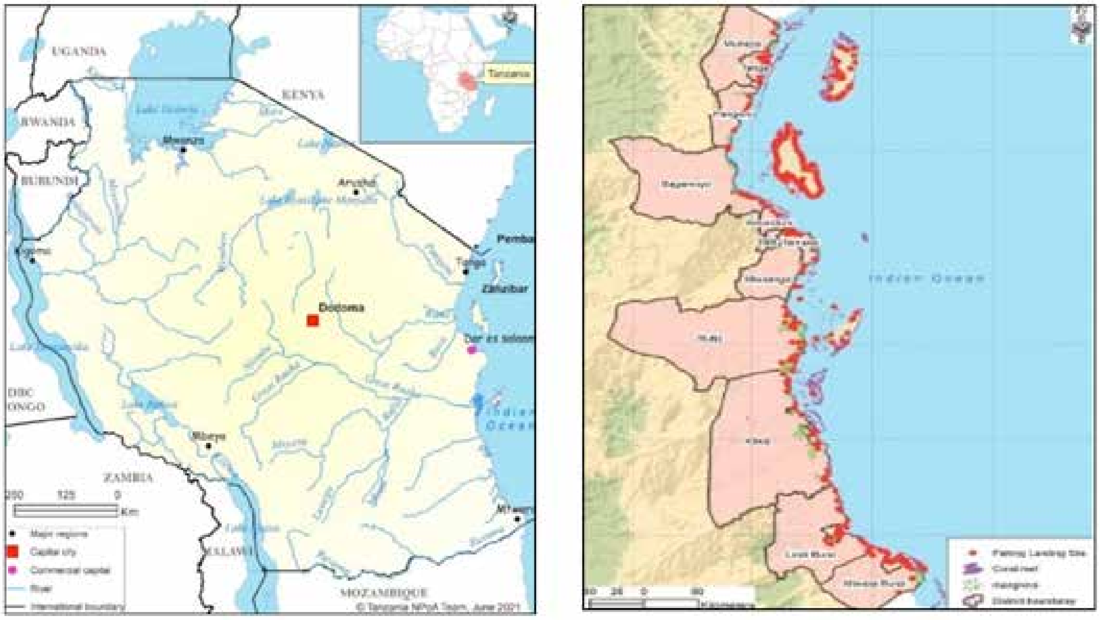
On the other hand, there are 50,218 primary fishers in Zanzibar (31,328 in Unguja and 18,890 in Pemba). This number includes both male and female fishers (43,080 males and 4,394 female). Zanzibar has a total of 235 formal landing sites of which 109 (49%) are in Unguja and 126 (57%) in Pemba districts. Most of the landing sites 199 (85%) are within Marine Conservation Areas (MCAs), whereas only 36 (15%) are located outside MCAs system (RGZ-ZFFS 2020). In this context, landing sites situated within MCA are covered by GMPs of respective MCAs, and thus Zanzibar remains with only 36 areas that still operating under open access regime.

In general terms, the coastal fisheries in Tanzania are characterized by overcapacity, overfishing, illegal fishing and environmental degradation. Similarly, the fishery is associated with high post-harvest losses, mainly caused by perishable nature of fishery products and inadequate preservation facilities in dispersed remote fishing ground. In relation to social aspects, fishers face a number of challenges such as low level of technology, inadequate capital associated with limited credit facilities and population growth. The rapid population growth in coastal zone, mainly driven by migration of people from inland places of the country to the coast, exerts increasing pressure on finite fishery resources through joining fishing and thus increasing fishing effort or by expanding the market.

Furthermore, high price tag on some of these species have fueled overfishing of certain species including prawn and sea cucumber species. The situation forced the government to impose moratorium on semi-industrial prawn fishing between 2007 and 2017, and on Sea cucumber fishing from mid 2000s to date. With new development taking place in marine and coastal environment, such as growth in blue economy, concerted efforts are needed in improving effective and efficiency of fisheries resource management if the finite fishery resource is to be sustained to sustain life in communities. It was for this reason that the government embarked on development and implementation of Fisheries Management Plans (FMPs).

The main objective of FMPs intervention is to complement traditional approach of using the relatively generalized Fisheries Policies, Fisheries Act, and Fisheries Regulations as the only tools for guiding fisheries resource management. These core instruments are just too broad to capture variability of an expansive fishing areas of the entire country (fig. 1 & fig. 2 below). The FMPs, in this regard, have comparative advantage that of being specific to a particular fishery.

The following sections provide a review with regard to development and implementation of FMPs in The United Republic of Tanzania.



Fisheries profile of Tanzania   Spatial distribution of landing

Figure 1: Coastal of Tanzania showing sites observed in 2024 fisheries frame survey.

3.0 LITERATURE REVIEW PN ARTISANAL FISHERIES

The artisanal fishery implied as traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amount of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, mainly for local consumption. Artisanal fisheries are those that use a relatively low level of technology: small canoes or boats instead of larger, more powerful vessels; no engines or very simple low-power engines; and traditional fishing gear such as spears or hand reels. It is a strategic objective sector that significantly contributes to millions of livelihoods (FAO, 2020b, 2022). The sector is in control of about half of the global annual marine catches. More than 120 million people worldwide hang on artisanal fisheries and fisheries activities like processing and trading (FAO, 2020c). About 90% of artisanal fishers reside in developing countries particularly Asian and African countries that include Bangladesh, Philippines, Thailand, Sri-Lanka, Vietnam, Senegal, Ghana, Tanzania, Madagascar and Malawi (Chuenpagdee & Jentoft, 2019).

In developing countries, about 47 million people are supported by artisanal fisheries (Cohen et al., 2019). Artisanal fishers, who account for more than half of all fishery output in the world, continue to be among the most marginalized groups (Spencer, 2021). The households of artisanal fishers in developing countries are characterized by persistent poverty and food insecurity (FAO, 2020c). Also, artisanal fisheries are underestimated, uncounted, lack the required recognition in policies and plans and, in some places, they are even hidden in national fisheries statistics (FAO, 2020a; Zelasney et al., 2020; UN, 2012; Teh et al., 2020). As such, in many developing countries, there is inadequate empirical information concerning the challenges of artisanal fisheries towards sustainable blue economy transformation (Béné & Friend, 2011; Teh et al., 2020). Thus, it is crucial to guarantee artisanal fisheries an equal economic, political and physical involvement in the emerging blue economy. An obvious expectation is that artisanal fisheries would contribute to fishers' livelihoods.

It is estimates Tanzania's current fish production capacity to be around 376 thousand tons per year. Similar to all agricultural activities, approximately 97 % of Tanzanian fish comes from artisanal fisheries (FAO, 2020c). The government reports that these artisanal fisheries contribute to over 90 % of the total annual fish landings in Tanzania. However, despite their significant production, artisanal fisheries remain at the lower end of the economy's income spectrum due to their informal activities The Tanzanian fishing sector, which contributed 1.8 % to the GDP last year (2022/2023), experienced a growth rate of at least 2.5 %. Despite its substantial potential for job creation and economic vitality, this primary sector grapples with a myriad of challenges.

The demand for fish goes up as tourist hotels and restaurants require high value species like squid, swordfish, crab, marlin, octopus, snappers and prawns. These coastal area's household poverty is more prevalent in rural coastal areas than in urban areas where the majority (50.8%) of the population lives (RoGZ, 2020b). According to Kessy and Omar (2017), 40.2% of people in rural areas live in poverty, compared to 17.9% who reside in urban areas. The costal area's artisanal fisheries could potentially play an important role in the coastal livelihoods if their management and governance are well organized (Mfamau, 2019). Albeit the existence of some empirical studies on fisheries in Coastal area of Tanzania Mainland (Colbert-Sangree, 2012; Jiddawi, 2012; O'Neill, 2018; Rehren et al., 2020, 2018), there is a dearth of empirical data on the challenges of artisanal fisheries towards the ongoing blue economy transformation in. Therefore, this study examined the challenges that artisanal fisheries face with a particular focus on the sustainability of the prioritized blue economy.

5.0 METHODOLOGY OF THE STUDY

5.1 Location: The study was done in Coastal Area of Tanzania Mainland namely Kigamboni, Kilwa, Mafia Island Bagamoyo and Pangani is a part of the United Republic of Tanzania (URT)

5.2 Study Design

A cross-sectional research design coupled with qualitative and quantitative approaches were employed to generate data at a single point in time (Sekaran & Bougie, 2016). The design provided a comprehensive analysis of the research problem by examining the challenges of artisanal fisheries in the study area (Kumar, 2011).

5.3 Population and Sample Size

The study based from five districts drawn from coastal area in Mainland namely Mafia, Kilwa, Kigamboni, Pangani and Bagamoyo; A sample of 500 of artisanal fishers of five fishing districts was determined through Yamane's formula of 1967 (as cited in Sarmah et al., 2013). Thereafter, the stratified proportional allocation method was applied to obtain an equal representation of the 500 artisanal fishers from each district (stratum) under study and the proportionated samples of 100 sampled population from each district were taken.

5.4 Data Collection

Data were generated through interviews with key informants, questionnaire surveys, focus group discussions and direct observations. The triangulation method created accurate, comprehensive and enriched data. It helped to balance information and distinctly differentiated data regarding the challenges of artisanal fisheries. It also offered an opportunity to integrate data analysis and interpretation (Almalki, 2016).

5.5 Data Analysis

To examine the challenges of artisanal fisheries, open ended questions were asked to the respondents and thereafter responses with similar themes were thematically interpreted and summarized. After that, IBM SPSS, version 25 was employed to code and compute descriptive statistics of frequencies and percentages showing the challenges with the high and low frequencies and percentages.

6.0 FINDINGS AND DISCUSSIONS

The study assessed the challenges of artisanal fisheries in five selected fishing districts in coastal area that seemed to be possible stumbling blocks of artisanal fisheries and the blue economy transformation at large. The study came up with the following major challenges of artisanal fisheries namely lack of capital, traditional and ineffective fishing facilities, poor market systems, overfishing, decline of marine fish stock, absence of fishers' rescue facilities and weak enforcement of fisheries laws and regulations were the major challenges of artisanal fisheries in the study area.

6.1 Lack of Capital

The study found that lack of capital is among the major challenges contributing to ineffective artisanal fisheries in the study area. A majority of respondents (95.20%) responded to a lack of sufficient capital to invest in modern fishing technologies. The financial vulnerability of artisanal fishers in this study was manifested in various forms such as a lack of user-friendly soft loan facilities in the study area, lack of capital among artisanal fishers was a major challenge pushing artisanal fishing into a subsistent activity. It was indisputable that sustainable artisanal fisheries needed financial backup, modern fishing vessels and gears, engine boat vessels and storage equipment that all needed enough financial support. Similarly, a study done by Billah et al. (2018) observed that 78% of the fishers revealed inadequate credit to be the most critical problem for the initiatives in the area of the study.

Furthermore, interviews with key informants revealed that some artisanal fishers' cooperatives have started to be offered a loan of fibber boats enclosed with other fishing tools by the government through the Cooperative and Rural Development Bank (CRDB); other financing institutions together with like-minded organizations.

Based on the above study observations, artisanal fisheries were characterized by low capital that hinder their fishing practices. Therefore, more efforts are required to increase artisanal fish production, including the adoption of modern fishing technologies to replace traditional fishing techniques. According to the study findings, the majority of artisanal fishers frequently lacked savings to enable them to meet such heavy capital like high operating costs. For example, the study revealed that fuel cost was approximately 60,000 to 80,000 (TZS) for 20 to 30 litres respectively per fibber boat fishing trip using an outboard engine.

6.2 Traditional and Ineffective Fishing Facilities

Data in Fig. 1 show that a large majority of respondents; i.e., 93.39%, claimed to use traditional and ineffective fishing facilities in the study area. These include the use of traditional fishing vessels: outrigger canoes and canoes using sails, paddles and poles that affect the fishing outcomes. Additionally, results from focus group discussions and key informant interviews revealed that, the traditional fishing vessels that artisanal fishers use in their fishing activities are not capable to resist strong winds, especially during the southeast monsoon. During this time of the year, most of the artisanal fishers opt to remain at home.

Moreover, the lack of modern and effective fishing facilities makes the artisanal fishers to operate in inshore fishing grounds. This situation causes high degradation of the fish community by capturing immature fish which violate the fisheries laws and regulation. Again, traditional fishing vessels lack cooling facilities for storage, thus causing a majority of the catch are to be sold on the day of capture, which offers no protection against changing or low prices.

6.3 Poor Market Systems

As in the study findings 77.18% of the respondents revealed that there is a challenge of poor market systems in the study area. Observations made through this study revealed that there is a lack of important market facilities, including modern market infrastructures with ice-making plants and sanitary systems. Also, there were challenges of low prices for fish catches, limited opening hours for village markets and price fluctuation. During FGDs, members argued that fish is a perishable product that requires permanent modern markets with cooling systems to enable the fishers to sell their products at a reasonable price before they perish. The absence of such modern market infrastructures makes us sell our fish catches at low prices, particularly during high catch season. Again, study observations revealed that there was a deficiency of work facilities for BMU fisheries officials. Additionally, it was found that 3 Beach Management Unit officials of the five studied villages have no fish catch measurement instrument for taking daily records of the fish catches. This results in the submission of unrealistic data to the Department of Fisheries. The unrealistic and irregular error occurs in the daily catch statistical records. Interview with a senior fisheries official found that the Department of Fisheries in the respective local government at district level faces a number of challenges including the challenge of understaffing and lack of working facilities.

As the right information and data are in the right hands and time, better informed and reasonable decisions can be made. This will, in turn, preserve and manage the marine resources of coastal area as well as the livelihoods of countless people in the area. Fisheries data and information which are found at the market places, are at the core of decision-making and need to be comprehensive, reliable, representative and timely. Such data include data on fish catches, vessels and gears used by artisanal fisheries are at the core of artisanal fisheries development. They inform the authoritative reports and publications on all areas related to a fishery in the government and other partners to design and adopt the best solutions to preserve Tanzanian's vital fish stocks and marine ecosystems as well as develop sustainable artisanal fisheries. Therefore, effective market systems and reliable, comprehensive and timely fisheries data collection are very crucial to the development of artisanal fisheries in coastal area and the study areas in particular for the betterment of artisanal fishers' livelihoods.

6.4 Overfishing

Overfishing draws too many fish out of renewable natural capital (Halpern et al., 2015). The study findings in Fig. 1 show that 88.59% of the respondents responded to the challenge of over- exploitation of marine resource occurrences which cause threats to marine habitats and ecosystems. Artisanal fishers fish every day while some of them fish twice and more in a day to earn their living. Despite numerous efforts, studies conducted found that overfishing is a challenge which is further worsened through Illegal, Unreported and Unregulated (IUU) fishing (FAO, 2020c; Sumaila & Tai, 2020). Overfishing is a worldwide major cause of IUU fishing, particularly in the area of artisanal fishing practices and it is linked to food insecurity (Cohen et al., 2019; Song et al., 2020).

Furthermore, direct observation during data collection observed the domination of the small fishing vessels in size that are used by respondents which caused the fishing vulnerability. This is due to small size of vessels, fishing activities depending on seasonal wind pattern (north- and south- easterly winds) and short distance fishing activities. This puts pressure on inshore fishery resources. Also, the domination of overfishing in the study area was caused by the upsurge of unskilled artisanal fishers' population in fisheries and marine conservation. This squat was reported by most of the key informants during the interview sessions; i.e., senior fisheries officials, district fisheries officials, BMU officials. They additionally argued that over-exploitation of marine resources is also a result of low levels of entrepreneurship knowledge and skills of the fishers, without which sustainability through relieving pressure on the existing resources cannot be achieved.

6.5 Decline of Marine Fish Stock

Study findings in Fig. 1 show that, 85.29% of respondents claimed that there is a challenge of the decline of marine fish stock. It was further argued that overfishing is largely caused by employing illegal and destructive fishing practices and increased pressure in fishing. Illegal fishing practices (for instance dynamite fishing), as well as IUU (Illegal, Unreported and Unregulated) pose serious threats to the marine environment that include fish stocks and fish habitats (coral reefs) in the study area. Research shows that the chief reason for the fall of marine fish stock and deterioration of coral reefs is overfishing. Extensive illegal and destructive fishing gear generally target small-sized fish and juveniles. This compromises the sustainability of the growing population, fish stocks, intensive seaweed farming and indiscriminate mangrove cutting for tourism development. All these are a result of a lack of enforcement of fisheries regulation and environmental degradation (Benansio & Jiddawi, 2016; Sarah & Akpalu, 2020).

Overall, artisanal fishers play a great role to be the factors for the fall of fish catches in the study areas. Despite the government's efforts to rescue the situation, monitoring and regulations are weak to maintain sustainable harvest levels. Fishing and unsustainable practices have amplified from year to year, particularly in areas that lack alternative livelihoods. Factually, the increase in the decline of fish catches results in low livelihoods of the artisanal fishers.

6.6 Absence of Fishers' Rescue Facilities

The absence of fishers' rescue facilities challenge was responded to by 61.86% of the respondents (refer Fig. 1). These rescue facilities include rescue vessels, life jackets and first aid kits. Interviews with key informants and FGDs revealed that fishing is a high-risk activity. Fishers experienced several accidents due to poor fishing facilities which cannot manage strong winds during the southeast monsoon. Research by Shrestha et al. (2022) in developing countries found that vessel disasters severally caused deadly injuries, with 14.3% - 81% drownings. The incidence of non-fatal injuries was between 55% and 61%. These were mostly caused by falls on the deck or into the sea, punctures and cuts by fishhooks/fish rays, blows from objects/tools, fishing facilities and animal bites or attacks.

The absence of fishers' rescue facilities makes artisanal fishing the most dangerous activity. Worldwide, the available artisanal fisheries statistics accepted that fishing is a risky activity (Casey et al., 2018). Fishers are vulnerable to injuries, deaths and accidents (Luo & Shin, 2019). Injury and death of fishers occur at much higher rates all over the world than national averages; it was estimated that about 24,000 deaths occurred in fishing per year, and an estimation of 24 million non-fatal accidents occurred every year (FAO, 2018a; Zytoon, 2012).

6.7 Weak Enforcement of Fisheries Laws and Regulations

Weak enforcement of fisheries laws and regulations was among the environmental and legal-based challenges reported in the study area. The study findings in Fig. 1 reveal that, 64.86% claimed that there was weak execution of fisheries laws and regulations.

Weak enforcement of fisheries laws, regulations and marine conservation systems that include ineffective and irregular MCAs patrols and controls have been mentioned for the increasing incidences of IUU fishing since there is low obedience among fishers. Thus, the current regulations cannot guarantee bearable use of fishery resources; e.g., like restrictions on mesh size, gear, and the sale of premature fish. The use of fishing gears, such as dragging gill nets inshore, is known to substantially impact the structure and health of coral reef communities through the physical breakage of coral colonies. Similarly, research done by Sarah and Akpalu (2020) observed that Ghana did not have strong legal framework to enforce fisheries legislation; a weak regulatory framework attracts foreign industrial vessels. Illegal fishing activities are reported in most parts of the coastal region of the country. This has, consequently, contributed the overall decline of fish catches. Fig. 1 presents the findings of the challenges of artisanal fisheries found in the study area.

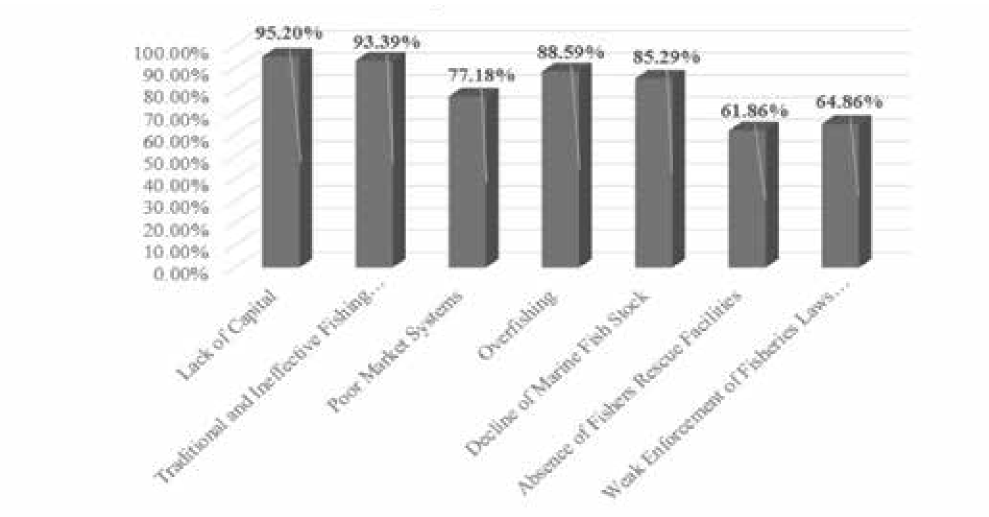


Figure 1: Challenges of Artisanal Fisheries in the study Area
Sources: Field Survey, November 2024

7.0 CONCLUSION AND FUTURE PROSPECTS

This study assessed the challenges of artisanal fisheries in the five selected districts in coastal area. The study revealed that artisanal fishing practices were faced with major challenges of lack of capital, traditional and ineffective fishing facilities, poor market systems, overfishing, decline of marine fish stock, absence of rescue facilities, and weak enforcement of fisheries laws and regulations. It is therefore recommended that fisheries decisions are taken to improve the livelihoods flexibility and involvement of artisanal fishers in decision making. These are important for sustainable artisanal fisheries that will spearhead the existing transformation of the Tanzania blue economy. In addition to that, to ensure the effective operationalization of artisanal fisheries, effective control of artisanal fisheries is a fundamental objective of the transformation of Tanzania's blue economy. It is important to advance fisheries to increase catches, reconstruct fishery stocks, and reinstate ecosystems to a productive and healthy state while controlling the exploited resources within ecosystem. This necessitates transformative changes to endorse governance and policy reforms, operative management frameworks, adequate social protection and innovations.

The Tanzanian government collaborates closely with international organizations such as the African Union Inter-African Bureau for Animal Resources (AU-IBAR), FAO, and the World-Wide Fund for Nature (WWF) to position Tanzania as a key player in Africa's agricultural market by 2030. Making Tanzania an essential agricultural market in Africa by 2030.

The President announces the forthcoming construction of fishing ports in Kilwa Masoko and Bagamoyo. The establishment of fishing ports will go hand in hand with the creation of modern fish markets. Currently, over 200 young Tanzanians have undergone specialized training, preparing them to seize opportunities in the fishing sector. Over the next year, an additional 300 individuals will be selected for similar training, fostering the development of enterprises utilizing aquatic resources.

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Analysing the Technical Efficiency of Ghana's Fishery Industry

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The fishery industry's contribution to national economic development as well as citizens' livelihood are immeasurable. Numerous studies have examined the sector's growth due to its significance to academics, researchers, and managers. This study is to statistically assess the technical efficiency of Ghana's fishery industry, test for returns to scale of the industry and investigate the impact of exogenous factors on the estimated technical efficiency. This study through a two-stage non-parametric Data Envelopment Analysis (DEA), investigates the efficiency of 20 Ghanaian registered fishery firms, which consist of 2 trawlers, 7 pole and line and 11 purseiners from 2008 to 2022 using convenience sampling. This makes up about 25% of registered industrial fishing vessels in Ghana's fishery sector. The study adopted two input, and two output variables accepted in fishery efficiency and productivity change studies.

In the first stage, the study assessed the technical efficiency of fishery firms to determine how effectively they are utilizing their resources. By conducting this analysis, benchmarks within the industry are identified, providing valuable insights into the performance of the fishery firms. In the second stage analysis, the study delves into the impact of various external factors on the technical efficiency of fishery firms using Pooled Ordinary Least Squares (POLS). These external factors include the age of the vessel, exchange rate, financial crises, vessel size (length overall), inflation rates, Gross Domestic Product (GDP), and the impact of the Covid-19 pandemic. The study quantifies the influence of the external factors on the technical efficiency estimates obtained in the first stage, thereby providing a comprehensive understanding of the broader economic and environmental context in which these firms operate.

Keywords: *Data Envelopment Analysis, Exogenous Factors, Fishery Industry, Technical Efficiency*

1. Introduction

The fishery resources of Ghana have been a pillar of the national economy, contributing significantly to socio-economic development (Adom, 2018). Fishing is the practice of pursuing and capturing fish, a tradition that spans centuries, and is a global phenomenon. This ancient activity has evolved significantly over time, particularly with advancements in modern technology. Fishing encompasses a range of techniques and methods, allowing for the effective gathering of fish. As fishing practices have improved, they have enabled fishers to employ various mechanisms and target a wider diversity of fish species, enhancing both the efficiency and scope of the fishing experience (Ewedji & Francis, 2019). Fishing is a heritage and culture in Ghana, much like it is in other countries with coastlines, due to the abundance of valuable and cherished fish stocks in its water resources. According to estimates, up to 10% of Ghana's population depends on the fishery industry for livelihood (OCEAN, 2015). The fishing industry plays a crucial role in promoting sustainable livelihoods and reducing poverty in numerous households and communities (Tietze, 2016). It has been estimated that the sector contributes approximately 1.5 percent to the nation's Gross Domestic Product (Asiedu, Okpei, Nunoo, & Failler, 2021) and 15 percent to the agricultural GDP (Eriksen, Akpalu, & Vondolia, 2018).

The fishery sector plays a critical role in ensuring food security and supporting the well-being of coastal communities (March & Failler, 2022). According to the Ministry of Fisheries and Aquaculture Development (MoFAD, 2015), Ghana's fishery industry generates an annual revenue exceeding $1 billion.

The classical theory of economic development provides a relevant theoretical framework for understanding the findings of the fishery sector research in Ghana. Central to this theory is the emphasis on the division of labour, capital accumulation, entrepreneurship, and market forces (Harris, 2007), all of which can be linked to the inefficiencies and challenges identified in the fishery sector. The division of labour is crucial in the fishery sector, as specialized roles within firms can boost productivity and efficiency. Classical theory highlights the importance of capital accumulation, advocating for investments in technology and management practices. Additionally, fostering entrepreneurship is essential, as innovation and risk-taking among fishery operators can lead to improved business models and practices. Regression analysis reveals that external shocks significantly affect technical efficiency, emphasizing the need for resilience in adapting to economic changes. Overall, classical theory provides a framework for understanding the fishery sector in Ghana, suggesting that specialization, capital investment, and competitive market forces are vital for enhancing performance and resilience.

Arita & Leung (2014) used Data Envelopment Analysis (DEA) to analyse the technical efficiency of Hawaii's Aquaculture Industry using 82 farms from 1997 to 2007. The study adopted multi- inputs (labor, land, machinery, and other expenses like sum of fertilizer, chemicals, seed stock, breeding, feed, gasoline, utilities, repairs, custom work, and other miscellaneous expenses) and one output (Total sale). The findings of the study show that for 2007, the average Technical Efficiency of all farms was 0.46, thus a decline from 0.73 in 1997. The result further showed that only 4 out of 33 farms in 2007 were efficient. It was deduced from the findings that Technical Efficiency was related to the size of farms, again full-time farms were significantly more efficient than small sized farms. The results also show that average excess real inputs for land and labour have slightly fallen over time, however, increases of factor costs may have hurt overall economic profitability.

With an objective to understand how changes in the amount of quota attributed to each vessel every year and how shifts in the quota regime affects vessel productivity, Oliveira, Camanho, & Gaspar (2013) researched 11 fleets in the northwest and 25 fleets in the southwest area of Portugal from 1999 to 2011 using bootstrapped Malmquist and DEA and did a two-factor decomposition into Efficiency Change (EC) and Technological Change (TC). The inputs and outputs considered are vessel overall length, gross tonnage, engine power, fishing days and fuel consumption per week, and landings (tons per year). The outcome of the study showed that the implementation of a weekly quota, as opposed to a daily quota, led to a significant improvement in productivity.

Rust et al. (2017) investigated the dynamic behaviour of both excess capacity and efficiency in an industrialized fleet after the introduction of quota management. The study used DEA to assess 234 active vessels between 2000 and 2013 in Southern Australia. The analysis revealed weak evidence for a prolonged adjustment in the fishery following the introduction of an ITQ system.

Cao et al. (2021) employed DEA to investigate whether economic measures are vital or whether capacity efficiency is sufficiently well reflected solely using physical measures on Vietnamese purse seine fishery industry with a sample of 52 purse seiners from 2016- 2017. The study considered vessel size, fishing time, number of fishers, and fuel consumption as input variables while revenue, cost, and profit were considered as the output variables. The results show that economic measures give a lower capacity utilization than those obtained by physical measures.

It is worthy to know that the results of a study by Ceyhan & Gene (2014) suggests that substantial decreases in inputs or gains in outputs could be attained by improving and better utilizing the existing technology in fishery activities.

Ghana's fishing industry serves as a significant source of livelihood and employment for millions of people throughout the country, accounting for around 15 percent of Ghana's agricultural GDP and providing 60 percent of the nation's animal protein supply (Eriksen, Akpalu, & Vondolia, 2018). The 30.8 million people that live in Ghana have a high demand for fish (Agyei, 2022). The purpose of the study is to assess the technical efficiency of Ghana's fishery industry, test for returns to scale of the industry and investigate the impact of exogenous factors on the estimated technical efficiency.

2. Methodology

A quantitative approach was utilized, involving the collection of numerical data that can undergo thorough analysis in a structured and systematic way. There is a growing interest among individuals, groups, and organizations in evaluating their performance to identify opportunities for improvement and efficiency. This enables better resource management and conservation by guiding necessary adjustments. The increasing emphasis on performance evaluation has spurred significant advancements in academic research, particularly in the field of performance management practices. Among these, Data Envelopment Analysis (DEA) emerged as a prominent methodology, rooted in the pioneering work of Charnes et al (1978), a deterministic, non- parametric approach based on mathematical programming. It measures the relative efficiency of Decision-Making Units (DMUs) by analysing their inputs and outputs, even when they are not proportionate. Their groundbreaking research introduced methods to evaluate the efficiency of decision-making units to identify the most efficient firm, whether it exists within the dataset or a combination of multiple efficient firms (Mizala, Romaguera, & Farren, 2002).

To define the efficient frontier, the inefficiency of a DMU is assessed based on its distance from the enveloping hull, which indicates the potential for efficiency enhancement. The frontier illustrates the maximum output that can be achieved with various combinations of inputs, while also representing the minimum input requirements for different output levels. DMUs positioned below the frontier are classified as inefficient, whereas those on the frontier are considered efficient (Constantin, Martin, Rivera, & De, 2009). Data Envelopment Analysis (DEA) relies on extreme observations, making it particularly sensitive to outliers (Cooper, Seiford, & Tone, 2007; Scippacercola & D'Ambra, 2013). DEA aims to establish an efficient frontier through a piecewise linear surface that "floats" above the observations, enabling it to reveal relationships that may not be apparent through other analytical methods.

Available literature shows that some scholars have adopted DEA in various sectors, yet quite a number of studies have been completed in the fishery sector (Al-Siyabi, Amin, Bose, & Al- Masroor, 2019; Reid & Squires, 2006; Vázquez-Rowe & Tyedmers, 2013). Data Envelopment Analysis has been widely utilized which spans numerous industries, including banking (Stewart, Matousek, & Nguyen, 2016), insurance (Grmanová & Strunz, 2017), agriculture (Toma, Dobre, Dona, & Cofas, 2015), oil and gas (Borodin & Mityushina, 2020), and fisheries (Liu, Sun, Lyu, Chu, & Zhang, 2021). DEA is renowned for its ability to assess the relative efficiency of decision- making units without requiring a predefined functional form, offering substantial flexibility and applicability in diverse contexts.

3. Results and Discussion

In the first stage analysis, two inputs are used to produce two outputs, and the technical efficiency score of fishery firms in Ghana from 2008 to 2022 are estimated to assess how Ghanaian fishery firms judiciously utilize their resources for economic efficiency of the given resources.

Table 1: Summary Statistics of first stage variables (Pooled, 2008-2022)

		Labour (Number of Crew onboard In '000s)	Operating cost (in USD$)	Carton of fish (in '000)	Profit (in USD$)
		X1	X2	Y1	Y2
Pooled	Count(N)	300	300	300	300
	Mean	32.68	260220.94	19415.75	521940.39
	SD	11.39	872513.18	5530.45	468501.36
	Min	13	3871.1	6890.5	6078
	Max	67	4570886.8	34679.7	2897891
	Time F-Statistic	0.278	72.85***	36.34***	218.5***

This observation is substantiated by the relatively higher standard deviation values compared to the mean values of both input and output variables. The elevated standard deviations highlight greater dispersion or variability within the dataset, further emphasizing the differences in the sizes of the fishery firms under analysis. On average, the input variables reveal that approximately, 33 crew members are employed per vessel, while the operational cost is approximately $260,220.94 million USD. Regarding the output variables, the data shows about 19415.75 (in thousands) cartons of fish are produced, while the approximated profit generated amounts to $521940.39 USD. This variability underscores the diverse scales of operations and outcomes among the examined entities.

Technical Efficiency Assessment from 2008 to 2022

The study assessed the technical efficiency of fishery firms in Ghana from 2008 to 2022 using R and R Studio software. The analysis aimed to evaluate how effectively Ghanaian fishery firms are utilizing their resources to achieve economic efficiency.

Table 2: Technical Efficiency estimates of all firms: 2008-2022

vessel name	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average
MENG XIN 6	7.96	2.52	2.52	2.52	2.52	1.00	1.00	1.73	2.84	2.21	2.94	6.01	3.19	2.46	1.87	2.88
MENG XIN 5	6.99	1.09	1.09	1.09	1.09	5.07	5.80	8.95	15.16	2.24	5.16	1.55	2.10	1.80	1.00	4.01
AP 703	12.04	1.08	1.08	1.08	1.08	1.18	66.88	1.90	1.00	2.53	2.23	2.16	2.76	2.94	1.21	6.74
LU RONG YUANGYU 222	8.09	1.08	1.08	1.08	1.08	4.91	1.49	1.79	5.62	1.13	4.92	2.13	5.02	3.66	2.49	3.04
MARINE 707	9.15	1.00	1.00	1.00	1.00	4.22	3.38	7.66	9.30	4.91	1.41	1.28	3.31	2.97	1.00	3.51
MARINE 711	1.00	1.13	1.13	1.13	1.13	4.96	10.00	14.82	34.67	2.30	1.00	1.48	2.09	1.78	5.65	5.62
RICO SIETE	18.65	1.95	1.95	1.95	1.95	9.12	4.62	19.77	63.60	2.00	1.69	1.46	3.56	2.97	2.14	9.16
SEA PLUS 87	16.98	1.08	1.08	1.08	1.08	8.68	6.12	8.42	12.53	5.39	1.20	1.00	2.07	1.45	1.46	4.64
SEA PLUS 89	17.55	1.08	1.08	1.08	1.08	6.49	1.63	1.18	2.40	1.15	1.47	1.55	2.14	1.42	4.26	3.04
AFRICA STAR	9.50	1.07	1.07	1.07	1.07	8.66	2.13	1.00	2.11	1.00	1.45	1.59	2.41	2.44	1.73	2.55
AGNES 1	1.00	1.00	1.00	1.00	1.00	3.04	1.91	1.95	3.03	1.00	1.00	1.29	2.20	1.86	1.14	1.56
ATLANTIC PRINCESS	4.87	1.05	1.05	1.05	1.05	1.00	64.19	1.00	1.00	2.00	4.49	2.20	5.10	3.38	2.08	6.37
ATLANTIC QUEEN	3.29	1.05	1.05	1.05	1.05	6.52	2.94	2.17	3.49	1.50	2.28	1.30	3.52	3.06	1.46	2.38
IRIS-J	7.60	1.08	1.08	1.08	1.08	1.05	54.15	1.36	23.33	1.33	1.25	1.51	1.00	1.00	4.27	6.81
LONG TAI 1	14.55	1.00	1.00	1.00	1.00	3.36	63.80	1.00	35.19	1.00	1.00	1.00	1.00	1.00	1.48	8.56
LONG TAI 2	9.99	1.03	1.03	1.03	1.03	3.09	2.56	1.97	2.09	1.82	1.93	2.19	3.52	2.86	1.91	2.54
PANOFI DISCOVERER	2.09	1.65	1.65	1.65	1.65	4.45	5.69	4.20	9.88	1.06	1.47	1.43	4.50	3.93	1.87	3.14
PANOFI FORERUNNER	5.82	1.01	1.01	1.01	1.01	4.26	5.33	1.25	2.26	6.59	1.82	2.16	2.34	1.90	1.00	2.59
PANOFI MASTER	2.24	1.72	1.72	1.72	1.72	4.14	3.12	1.00	2.20	2.06	1.13	1.00	3.04	1.56	4.28	2.18
PANOFI PATHFINDER	8.36	19.85	19.85	19.85	19.85	1.36	1.00	1.18	2.14	1.27	2.97	1.50	2.58	1.00	1.48	6.95
GEOMEAN	**6.327**	**1.38**	**1.38**	**1.38**	**1.38**	**3.5**	**5.47**	**2.49**	**5.48**	**1.87**	**1.85**	**1.6**	**2.65**	**2.09**	**1.9**	

Values greater than 1 shows inefficiency while a score of 1 show that the state was fully efficient in the respective year.

Source: Author's Construct

The table above shows clearly that although there were inefficiencies in the fishery sector's efficiency, on average, 2008, 2009, 2010, 2011 were the most efficient with a Geometric Average of 1.38 while 2008 was the most inefficient year with a score of 6.33. On the firm level throughout the entire period, AGNES 1 was adjudged the best firm among the 20 firms with respect to the average performance with an efficiency score of 1.56, which means that the firm was 56% inefficient. In summarizing the outcome of this objective, it can be said that all the firms are inefficient.

Test for Returns to scale

If an industry fails to assess the Returns To Scale (RTS) technology before evaluating its performance, the generated results may be biased and misleading Simar & Wilson (2002). To identify the appropriate RTS model for describing Ghana's fishery sector, this study employs three distinct tests based on the return to scale framework proposed by Simar & Wilson (2002) and Simar & Wilson (2011). One assumption underlying the use of DEA is that either Constant Returns

to Scale (CRS) or Variable Returns to Scale (VRS) technology can be employed to support the industry being evaluated. The choice between CRS and VRS has an impact on outcome of the efficiency. Therefore, to determine the appropriate scale elasticity attribute in Ghana's fishery industry, Simar and Wilson's test (2002) was utilized. In their test, the alternative hypothesis (VRS) was compared to the null hypothesis (CRS), and if the p-value is less than the significance level of 1%, the null hypothesis is rejected.

Table 3: Test of Returns to Scale

Ho: μ is CRS CRS	**Significance level**	**Mean of ratios (S1)**	**Ratio of means (S2)**	**Mean of ratios minus 1 (S3)**	**Conclusion**
Test Static		0.8136221**	0.5771565	-0.1879334**	Reject Ho
Critical Level	5%	0.9328545	0.6272319	-0.05797773	Reject Ho
Critical Level	1%	0.9050479	0.4941933	-0.0670718	Reject Ho

***p<0.1%, **p<1% and *p<5%

Following the significant differences observed for all variables, the returns to scale of the industry is tested. Table 3 above presents the test statistic (mean of ratios, ratio of means and mean of ratios minus 1), critical value, p-value and the ultimate decision, the null hypothesis (CRS). The null hypothesis is rejected on the basis that the p-value is less than the significance level of 1%, hence, Ghana's fishery industry operates under Variable Returns to Scale (VRS).

Second stage Analysis (Fishery Technical Efficiency and exogenous factors)

The second stage used the estimated technical efficiency scores from the first stage analysis to conduct a Pooled Ordinary Least Squares (POLS) regression on the impact of some environmental covariates in order to establish the influence of those regressors on the regressand. This two-stage analysis is well documented in the DEA and stochastic frontier analysis literature Daraio and Simar (2007) and Simar & Wilson (2011).

Descriptive statistics of second stage variables

Based on fishery efficiency literature, the following variables were selected as exogenous determinants that can influence the efficiency of Ghanaian fishery firms: age of the vessel (AGE), exchange rate (EXC), financial crises (FIN), length overall of the ship (LOA), inflation (INF), Gross Domestic Product (GDP), and Covid-19.

Table 4: Descriptive statistics of second stage variables

	TEVRS	**AGE**	**EXC**	**FIN**	**LOA**	**INF**	**GDP**	**Covid**
Count	300	300	300	300	300	300	300	300
Mean	4.41	23.38	1.24	0.26	57.2	2.24	1.45	0.25
SD	8.88	16.58	0.62	0.44	9.98	0.67	0.76	0.44
Min	1	0	0.34	0	39.96	0.17	0.09	0
Max	66.88	48	2.3	1	72.5	2.96	2.64	1

Note: AGE=age, EXC= exchange rate, FIN= financial crises, LOA= length overall of the ship, INF= inflation, GDP=Gross Domestic Product, and Covid=Covid-19

Regression analysis

The regression analysis provides crucial empirical insights into how various exogenous factors influence technical efficiency in Ghana's fishery industry, offering valuable implications for both policy and practice. The model's statistical significance (F-statistic: 5.43059, p-value: 7.1321e-06) confirms its validity for empirical interpretation, though the modest R-squared value of 0.11519 suggests that additional factors beyond those studied may influence technical efficiency in this sector.

General Pooled Ordinary Least Squares Regression Model

$$= \beta_0 + \sum_{=1} \beta \qquad + \varepsilon$$

Where Y_{it} is Dependent variable for entity i at time t, X_{it} is independent variable(s), ϵ_t is Error term and β_0, β_1 are the Coefficients to be estimated.

Pooled Ordinary Least Squares Model Used

$$Y = \beta_0 + \sum_{=1}^{7} \beta$$

Where Y is Eff, X_1 is AGE, X_2 is EXC, X_3 is FIN, X_4 is LOA, X_5 is INF, X_6 is GPD, X_7 is COVID

Table 5: Pooled Ordinary Least Squares Regression table

	Estimates	**STD Error**	**t-value**	**Pr (>ltl)**	**VIF**
Intercept	11.399550	3.879860	2.9381	0.0035652 **	
AGE	-0.016489	0.030444	-0.5416	0.5884924	1.065760
EXC	2.045389	1.083353	1.8880	0.0600149.	1.869397
FIN	-3.956680	1.319553	-2.9985	0.0029466**	1.418062
LOA	-0.040221	0.049847	-0.8069	0.4203879	1.035392
INF	0.191573	0.859103	0.2230	0.8236976	1.371126
GDP	-2.958307	0.762314	-3.8807	0.0001288 ***	1.405691
COVID	-7.628597	1.633358	-4.6705	0.0035652 ***	2.118586
Observations	300				
R-squared	0.11519				
F statistics	5.43059				
p-value	0.00				

****p<0.1%, **p<1% and *p<5%*

Regarding vessel-specific characteristics, the empirical evidence challenges conventional assumptions about the importance of physical assets in operational efficiency. Neither vessel age nor size demonstrates statistically significant impacts on technical efficiency. This finding aligns with research by Oliveira et al (2013), who found that physical vessel characteristics were less crucial to efficiency than operational and management factors in Portuguese fisheries. This suggests that modernization efforts focused solely on vessel upgrades may not yield the expected efficiency improvements. The analysis reveals complex relationships between macroeconomic factors and fishery efficiency. The marginally significant positive relationship with exchange rates (coefficient: 2.045389, p=0.0600149) supports findings by Cao et al (2021) regarding the

importance of economic measures in assessing fishing fleet efficiency. The significant negative relationship with GDP (coefficient: -2.958307, p=0.0001288) provides an interesting contrast to previous studies and suggests that economic growth may create competitive pressures that challenge fishing operations. This finding particularly resonates with research by Rust et al (2017), who identified complex adjustment patterns in fishery efficiency during periods of economic change.

The most compelling empirical findings relate to external shocks. Financial crises significantly impair technical efficiency (coefficient: -3.956680, p=0.0029466), while the COVID-19 pandemic shows the largest negative impact (coefficient: -7.628597, p=4.589e-06). These results align with and extend the work of Arita & Leung (2014), who found that external economic factors significantly influenced efficiency in aquaculture operations. The magnitude of these effects empirically demonstrates the vulnerability of fishing operations to systemic disruptions, particularly in developing economies like Ghana. The robustness of these findings is supported by acceptable variance inflation factors (all VIF values below 2.12), indicating reliable distinction between variables. This methodological strength allows for confident interpretation of the individual effects, similar to the approach used by Ceyhan & Gene (2014) in their analysis of Turkish fishermen. These empirical findings have significant implications for policy and industry practice in Ghana's fishery sector. First, the finding suggest that policy initiatives should prioritize building systemic resilience over vessel modernization programs. Second, there is a need for targeted support mechanisms during periods of broader economic growth to help fishing operations maintain efficiency. Third, the study highlights the critical importance of developing robust crisis response frameworks for the sector. These insights are particularly relevant given Ghana's position as a developing maritime economy and the sector's importance to national food security and employment. Future research could build on these findings by investigating the specific mechanisms through which economic growth challenges fishing efficiency, and by examining additional variables that might explain more of the variation in technical efficiency. Such work would further enhance our understanding of fishery economics in developing nations and contribute to more effective policy development.

4. Conclusion

The analysis of the fishery sector in Ghana reveals a pervasive issue of inefficiency, as evidenced by the findings from both the first and second stages of the study. While the years 2008, 2009, 2010, and 2011 were identified as the most efficient, with a Geometric Average Efficiency Score of 1.38, the year 2008 also marked the highest inefficiency, scoring 6.33. This temporal variability suggests that external factors such as the credit crunch of USA may have significantly influenced operational performance during these years. At the firm level, AGNES 1 emerged as the best performer among the 20 firms analysed, achieving an efficiency score of 1.56, indicating that even the top firm operates at 56% inefficiency. The subsequent regression analysis further elucidates the factors influencing technical efficiency, revealing that neither vessel age nor size significantly impacts efficiency, challenging conventional assumptions about physical assets. Instead, macroeconomic factors, such as exchange rates and GDP, play a crucial role, with the analysis indicating a marginally significant positive relationship with exchange rates and a significant negative relationship with GDP. Notably, external shocks, particularly financial crises and the COVID-19 pandemic, were found to have substantial negative impacts on technical efficiency.

These findings underscore the need for targeted policy interventions to address systemic inefficiencies across the sector, including investments in technology and management practices. Furthermore, the results highlight the importance of understanding the specific factors contributing to inefficiencies, which could inform more effective strategies for enhancing operational efficiency and resilience in the face of external shocks. Overall, the study emphasizes the critical need for comprehensive approaches to improve the performance of Ghana's fishery sector, which is vital for national food security and economic stability.

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Blue Economy CSR Initiatives and Employee Environmental Citizenship Behaviour: Examining the Mediating Effects of Employee Ocean Stewardship Passion and Environmental Empathy

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ABSTRACT

Acknowledging the critical role of employee environmental behaviour in advancing organizational sustainability, this study explores the influence of blue economy corporate social responsibility (CSR) initiatives on fostering employee environmental citizenship behaviours. By examining this relationship, the study highlights the potential of blue economy-driven CSR practices in promoting sustainable organizational development and contributing to environmental stewardship. Through the lens of the stimulus-organism-response (S-O-R) theory, the study investigates the mediating roles of employee ocean stewardship passion and environmental empathy in this relationship. With a quantitative, cross-sectional survey design and convenience sampling, data was gathered from 440 employees in maritime institutions implementing blue economy CSR programmes. The hypothesized mediation model was tested through structural equation modelling (SEM) with SPSS AMOS. The findings highlighted how blue economy CSR initiatives (stimulus) influence employee ocean stewardship passion and environmental empathy (organism), which further drive employee environmental citizenship behaviour (response). According to the study, employees who exhibit a stronger emotional connection to marine ecosystems engage in pro-environmental actions that support the blue economy. This research contributes to the growing body of knowledge on the blue economy, corporate social responsibility (CSR), and employee environmental behaviors, addressing the gaps in understanding the interplay between these concepts. Findings give insights to organizations seeking to foster employee engagement in corporate sustainability efforts. The study also has practical implications for the utilization of blue economy CSR programmes by organizations to cultivate employee passion for ocean stewardship and environmental empathy and encourage their participation in environmentally responsible behaviours that support the sustainable use of marine resources.

Keywords: *Blue Economy, Corporate Social Responsibility, Environmental Citizenship, Ocean Stewardship Passion, Environmental Empathy, Structural Equation Modeling*

INTRODUCTION

The global economic landscape increasingly recognizes the critical importance of sustainable ocean-based economic development, a concept encapsulated by the emerging paradigm of the Blue Economy (Pauli, 2010). As marine ecosystems face unprecedented challenges from climate change, pollution, overfishing, and other unsustainable practices, corporations are called upon to assume pivotal roles in marine conservation and sustainable development (United Nations, 2017). Corporate Social Responsibility (CSR) initiatives within the context of the Blue Economy have emerged as critical mechanisms for businesses to address marine environmental challenges and foster sustainable practices (Porter & Kramer, 2011).

Despite the growing emphasis on the Blue Economy, there remains a significant gap in understanding how corporate ocean-related initiatives translate into meaningful employee engagement and ocean stewardship (Ones & Dilchert, 2012; Pharm et al., 2024). While many organizations implement Blue Economy CSR programmes, the internal psychological processes that transform these initiatives into genuine employee ocean stewardship passion and environmental citizenship behaviour remain underexplored (Daily et al., 2009; McKinley et al., 2023). The interrelationship between organizational strategies, individual psychological factors, and employee commitment to marine sustainability presents a sophisticated challenge for researchers and practitioners alike. A substantial body of research attests to the efficacy of CSR in fostering environmentally conscious behaviour among employees (Wells et al., 2015). Evidence suggests that CSR initiatives influence employee pro-environmental behaviours through various psychological mechanisms, including organizational identification (Shah et al., 2020), environmental commitment (Afsar & Umrani, 2020), employee well-being (Ahmed et al., 2020), environmental orientation fit (Cheema et al., 2020b), employee-corporate relationships (Su & Swanson, 2019), and green practices (Suganthi, 2019). However, while CSR's external benefits, such as business competitiveness, corporate reputation, and environmental performance, are well-documented (Chuang & Huang, 2018; Khojastehpour & Johns, 2014), fewer studies have examined how CSR initiatives directed at marine ecosystems affect employees' psychological and emotional connections to ocean sustainability.

Promoting ocean stewardship passion, a deep emotional commitment to protecting and sustainably managing marine resources, is essential to fostering environmental citizenship behaviour among employees. Ocean stewardship passion emerges when employees internalize the importance of ocean sustainability through participation in CSR initiatives targeting marine conservation (Markóczy & Goldberg, 2020). Similarly, environmental empathy, an individual's capacity to emotionally connect with environmental issues, complements ocean stewardship passion by deepening employees' understanding and motivation to act in support of ocean sustainability (Musitu-Ferrer et al., 2019).

Existing literature has largely focused on the external impacts of CSR initiatives, with limited attention to these internal psychological mechanisms (Daily et al., 2012). Specifically, the mediating roles of ocean stewardship passion and environmental empathy in translating CSR initiatives into voluntary, proactive, and non-compulsory environmental citizenship behaviours remain under-explored (Moon & Deleon, 2007; Bennett et al., 2022; Buchan et al, 2023; Buchan et al, 2024). Therefore this research explores the mediation role of employees' ocean stewardship passion and environmental empathy on the relationship between blue economy CSR and environmental citizenship behaviour.

To address this gap, the present research employs the Stimulus-Organism-Response (S–O–R) theory to examine the psychological mechanisms linking Blue Economy CSR initiatives to environmental citizenship behaviour. Within this framework, CSR initiatives targeting ocean sustainability serve as the stimulus (S), ocean stewardship passion and environmental empathy represent the organism (O), and environmental citizenship behaviour acts as the response (R). This approach highlights the critical role of internal emotional and psychological processes in shaping employee engagement with marine conservation efforts.

Subsequently, the researchers gathered data from employees of marine-based companies via a survey questionnaire, to test proposed hypotheses. The structural equation results demonstrated that environmental CSR exerted a direct and indirect (through ocean stewardship passion and environmental empathy) influence on environmental citizenship behaviour. This study contributes to the literature in several ways by focusing on the individual-level impacts of Blue Economy CSR. The study enriches the body of knowledge on micro-CSR and environmental management. In summary, this research illuminates the psychological processes underlying the relationship between CSR initiatives and employee environmental citizenship behaviour in the context of the Blue Economy, emphasizing the pivotal roles of ocean stewardship passion and environmental empathy.

THEORETICAL BACKGROUND

Stimulus-organism-response model

The Stimulus-Organism-Response (S-O-R) model, rooted in environmental psychology, posits that environmental stimuli (S) influence an individual's internal state (O), leading to behavioural responses (R) (Mehrabian & Russell, 1974). In organizational contexts, factors such as management policies and daily operations serve as stimuli affecting employees' cognitive and emotional states, including perceptions and psychological experiences (Jiang et al., 2010). These internal states shape responses, such as attitudes and behaviours exhibited within and beyond the organization.

This study adopts the S-O-R model for two main reasons. First, as a framework from environmental psychology, the S-O-R model aligns with the study's focus on Blue Economy Corporate Social Responsibility (CSR) and its role in fostering environmental citizenship behaviours. It has been applied in prior studies to explain organizational environments' effects, such as Jani and Han's (2015) exploration of how hotel environments influence guest loyalty.

Second, the S-O-R model provides an integrated explanation of the psychological processes through which Blue Economy CSR shapes pro-ocean behaviours, filling gaps left by other theories such as the Theory of Planned Behavior or motivation theories (Heung & Gu, 2012). It enables a comprehensive analysis of how organizational practices inspire employee engagement in ocean stewardship initiatives.

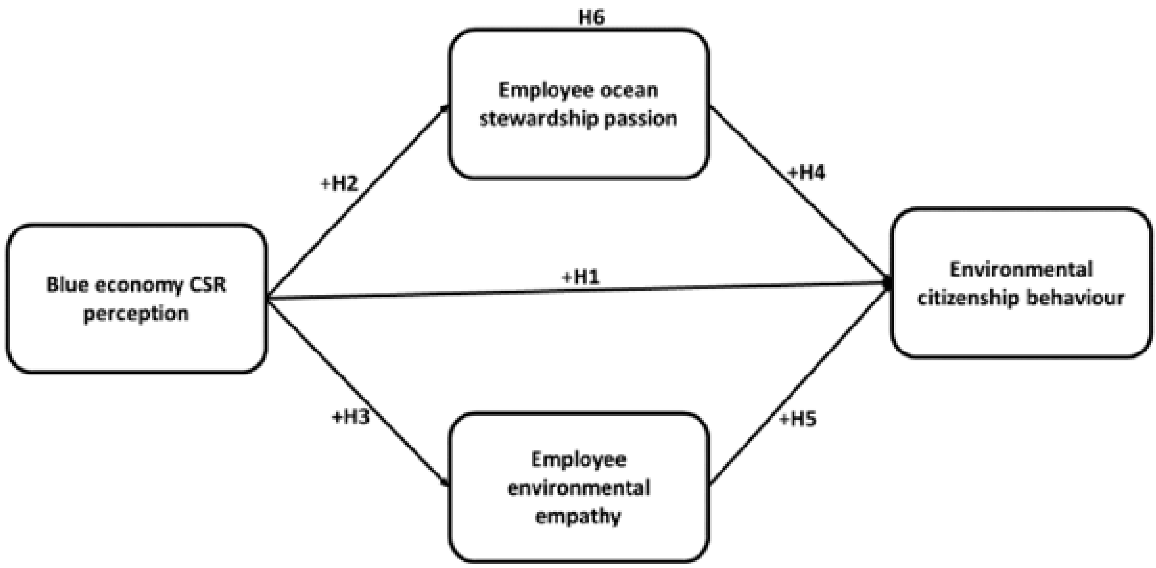

Fig 1 Conceptual model

Blue economy CSR perception and employee environmental citizenship behaviour

The convergence of Blue Economy CSR and employee environmental citizenship behaviour represents a critical paradigm in sustainable organizational development. The Blue Economy, which emphasizes sustainable marine and coastal resource management, offers a framework for integrating environmental stewardship into business strategies (Pauli, 2010). CSR links organizational environmental commitments to employee behaviours, with research showing that organizations demonstrating a genuine commitment to sustainability inspire employees to internalize these values and engage in proactive environmental citizenship behaviours (Ones & Dilchert, 2012). Blue Economy-focused CSR initiatives can foster a normative environment, triggering intrinsic motivation and encouraging employees to undertake environmentally responsible actions beyond their formal job roles (Ones & Dilchert, 2012). The study hypothesised accordingly:
Hypothesis 1. Environmental CSR perception positively relates to employee environmental citizenship behaviour.

Blue Economy CSR Perception and Ocean Stewardship Passion

The concept of ocean stewardship emphasizes intrinsic motivation for protecting marine ecosystems, aligning with Blue Economy goals (De Bernardi & Pedrini, 2020). Research shows that corporate social responsibility (CSR) initiatives focusing on marine sustainability can positively shape employees' attitudes towards the ocean, fostering emotional connections and a passion for ocean stewardship (Junot et al., 2017). Participation in activities promoting ocean sustainability further enhances emotional engagement and passion for conservation (Onkila, 2009). CSR initiatives offer employees direct involvement in marine preservation, cultivating positive experiences and strengthening their commitment to marine conservation (Gousse-Lessard et al., 2013). In light of the above evidence, the following hypothesis is proposed:

Hypothesis 2: Blue Economy CSR perception positively relates to ocean stewardship passion.

Blue economy CSR perception and environmental empathy

Blue economy corporate social responsibility (CSR) significantly influences employees' environmental empathy through several mechanisms. First, employees' perceptions of environmental CSR deepen their understanding of how environmental protection impacts the Earth's development, fostering stronger environmental values and emotional connections (Berenguer, 2007). Second, environmental CSR as a management strategy conveys environmental protection values to employees, increasing their concern and inspiring empathy (Dolby, 2019). Additionally, engaging in conservation activities enhances perceptions of the natural environment, strengthening employees' empathy for it (Dono et al., 2010). These factors collectively promote environmental empathy among employees, leading to the formulation of the following hypothesis.

Hypothesis 3. Blue economy CSR perception is positively associated with environmental empathy.

Ocean Stewardship Passion and Environmental Citizenship Behaviors

Ocean stewardship passion is a key predictor of environmentally responsible behaviours, particularly in marine conservation contexts (Robertson & Barling, 2013; Ardoin et al., 2020). This passion transforms individuals' emotional connections to the ocean into actionable conservation behaviours, such as voluntary contributions to marine protection (Vallerand et al., 2007). It also fosters a positive emotional connection, enhancing employees' sense of purpose and inspiring engagement in environmental citizenship behaviours (Fineman, 1996). Furthermore, ocean stewardship passion aligns employees' values with organizational conservation goals, motivating ethical environmental behaviours (Stern, 2000). Positive affect, including stewardship passion, further influences employees' environmental conduct (Williamson et al., 2006; Li et al., 2020), leading to the formulation of the following hypothesis.

Hypothesis 4: Ocean stewardship passion is positively associated with environmental citizenship behavior.

Environmental empathy and environmental citizenship behaviours

Environmental empathy is a key driver of environmental citizenship behaviour (Swim & Bloodhart, 2015). The altruistic and pro-social behaviour model (Batson et al., 1991) suggests that inducing empathy improves attitudes toward the environment, promoting citizenship behaviour. Schultz (2000) highlights that environmental empathy fosters tolerance, which supports positive environmental behaviours. Additionally, Berenguer (2007) found that nurturing environmental empathy encourages responsible environmental attitudes, while Dolby (2019) noted a positive correlation between empathy and environmental concern. Empathetic individuals are more likely to engage in eco-conscious behaviours (Musitu-Ferrer et al., 2019), making environmental empathy a catalyst for environmental citizenship (Kim & Cooke, 2020). Therefore, the study hypothesises as follows:

Hypothesis 5. Environmental empathy positively relates to environmental citizenship behaviour.

The Mediating Role of Ocean Stewardship Passion and Environmental Empathy

Blue Economy CSR practices, while essential, may not alone drive employees to adopt ocean-conscious behaviours. Psychological incentives, such as intrinsic motivation, awareness of ocean ecosystems, and the belief in contributing to marine sustainability, are crucial in fostering such behaviours (Afsar et al., 2016). Ocean stewardship passion and environmental empathy are key predictors of ocean-conscious citizenship behaviours (Ardoin et al., 2020; Shahbaz et al., 2013). Ocean stewardship passion involves a deep emotional commitment to marine conservation, while environmental empathy enhances awareness of the interconnectedness of marine ecosystems (Shen & Benson, 2016). Thus, Blue Economy CSR influences ocean-conscious citizenship behaviours through the mediating roles of these positive employee attitudes:

Hypothesis 6: Blue Economy CSR will indirectly affect ocean-conscious citizenship behaviour through the mediation of ocean stewardship passion.

Hypothesis 7: Environmental CSR will indirectly affect environmental citizenship behaviour through the mediation of environmental empathy.

RESEARCH METHODS

Sample and procedure

This study employed a quantitative methodology to test the proposed hypotheses. The researchers collaborated with several marine-based institutions to identify suitable respondents. Managers from five marine-focused organizations agreed to distribute questionnaires among selected employees. To minimize the risk of common method biases, data collection occurred in multiple phases over two months. A total of 600 questionnaires were distributed, and 440 valid responses were collected. The respondents were predominantly male (70%), with a median age range of 25-35 years (68.9%). The majority (88.9%) had been employed at their current organization for over five years. Descriptive statistics summarizing the respondents' profiles are presented in Table 1. Responses were rated on a 5-point Likert scale ranging from 1 (strong disagreement) to 5 (strong agreement).

Definition of Variables

Perception of Blue Economy Corporate Social Responsibility (CSR): The perception of CSR in relation to marine environments was measured using a modified version of the scale developed by Turker (2009). Four items reflecting CSR's relevance to marine sustainability and stewardship were used, including the statement: "*Our company actively engages in programmes that protect marine biodiversity and reduce environmental harm*."

Ocean Stewardship Passion: Ocean stewardship passion refers to a strong, enduring commitment to protecting and preserving marine environments. The researchers adapted the Environmental Passion Measure by Robertson and Barling (2013) to align with ocean stewardship. The scale consisted of ten items, including the statement: "I am deeply inspired to contribute to marine conservation efforts through my actions."
Environmental empathy: The three environmental empathy measure items were adapted from Kim and Cooke (2020), including the item "To what extent do you feel compassion for the marine environment?"

Environmental citizenship behaviour is defined as the actions of individuals that contribute to the preservation and enhancement of the natural marine environment. Environmental citizenship behaviour was assessed using a scale developed by Raineri and Paillé (2016). The scale comprised seven items, including "I suggest new practices that could improve the marine environmental performance of my company."

Control variables. Previous research has demonstrated that demographic characteristics may partially explain differences in the conduct of environmental citizenship behaviours, which may affect the hypothesized relationships in this study (Andersson & Bateman, 2000). Therefore, this study introduced gender, age and working years of the employee into the analytical model as control variables. Gender (1 = female, 2 = male), age (1 = 18-25, 2 = 26–35, 3 = 36–45, 4 = above 45), working years (1 = 0-5, 2 = 6–10, 3 = 11–15, 4 = Above 15).

Table 1
Characteristics of the sample (N = 450)

Demographic profile	Categories	Frequency	Percent (%)
Gender	Male	315	70.
	Female	135	30
Age	18-25	30	6.7
	26-35	310	68.9
	36-45	100	22.2
	Above 45	10	2.2
Working years	0-5	50	11.1
	6-10	200	44.4
	11-15	155	34.5
	Above 15	45	10

Measurement model test

The reliability and validity of the scales were assessed using principal component analysis (PCA) in SPSS 20.0 and confirmatory factor analysis (CFA) in AMOS 23.0. Cronbach's alpha values exceeded 0.75, surpassing the 0.7 threshold (Nunnally, 1978), confirming acceptable reliability. The composite reliabilities (CRs) ranged from 0.83 to 0.91, all above the recommended 0.7, indicating good reliability (Chin et al., 1997). For convergent validity, factor loadings exceeded 0.7 (Table 3) and average variance extracted (AVE) values were greater than 0.5, with most exceeding 0.6, demonstrating adequate convergent validity. Discriminant validity was confirmed as the square root of the AVE for each construct was higher than its correlations with other variables (Table 2).

Common method bias

To address potential common method bias due to the single-source sample, the authors took steps to minimize this risk. Reverse-coded questions were included in the questionnaire to assess response efficacy and identify significant discrepancies. Additionally, Harman's single-factor test was conducted, revealing that the most significant factor accounted for only 39.516% of the total variance. These results suggest minimal influence from common method bias in the study.

RESULTS

Descriptive analysis

Table 2 presents the means, standard deviations, and correlations between the variables. The results presented in the table indicate a significant positive relationship between blue economy CSR and ocean stewardship passion ($r = 0.57$, $p < 0.01$), as well as a significant positive relationship between blue economy CSR and environmental empathy ($r = 0.56$, $p < 0.01$). Therefore, Hypotheses 1 and 2 were initially supported. Additionally, a significant positive relationship was observed between blue economy CSR and environmental citizenship behaviour ($r = 0.60$, $p < 0.01$). Furthermore, ocean stewardship passion was found to be significantly and positively correlated with environmental citizenship behaviour ($r = 0.56$, $p < 0.01$), and environmental empathy was also significantly and positively correlated with environmental citizenship behaviour ($r = 0.53$, $p < 0.01$). Consequently, Hypotheses 3 and 4 were also initially supported.

Table 2

Means, SDs, correlations, and the square root of AVE.

		M	SD	1	2	3	4	5	6	7	8
1	GD	1.73	0.44	1							
2	AG	2.21	0.89	-0.24**	1						
3	WY	1.95	0.46	-0.17**	0.19**	1					
4	WP	2.39	1.24	0.22**	0.24**	0.28**	1				
5	BECSR	4.99	0.90	-0.01	-0.09*	-0.01	0.01	(0.87)			
6	OSP	4.60	0.74	0.07	-0.08	-0.03	0.02	0.57**	(0.80)		
7	EE	4.86	0.93	0.02	-0.12**	-0.03	-0.01	0.56**	0.49**	(0.83)	
8	ECB	4.85	0.81	-0.01	-0.12*	-0.01	-0.05	0.60**	0.56**	0.53**	(0.87)

*Note: ***p < 0.001, **p < 0.01, *p < 0.05; The number in parentheses is the square root of the AVE. GD: gender; AG: age; WY: working years; WP: work position; ECSR: environmental CSR perception; OSP: ocean stewardship passion; EE: environmental empathy; ECB: environmental citizenship behaviour.*

Table 3
Measurement model evaluation result.

Construct	Items		AVE	CR	Cronbach
Blue environmental CSR perception	BECSR1	0.73	0.65	0.87	0.83
	BECSR2	0.72			
	BECSR3	0.81			
	BECSR4	0.73			
Ocean Stewardship Passion	OSP1	0.70	0.62	0.94	0.91
	OSP2	0.76			
	OSP3	0.74			
	OSP4	0.80			
	OSP5	0.83			
	OSP6	0.78			
	OSP7	0.74			
	OSP8	0.77			
	OSP9	0.82			
	OSP10	0.72			
Environmental Empathy	EE1	0.82	0.72	0.80	0.85
	EE2	0.74			
	EE3	0.72			
Environmental citizenship behaviour	ECB1	0.71	0.76	0.92	0.92
	ECB2	0.84			
	ECB3	0.79			
	ECB4	0.88			
	ECB5	0.72			
	ECB6	0.75			
	ECB7	0.86			

Examining the direct effect

The researchers tested the proposed hypotheses using AMOS (Version 23.0) and a structural model to assess direct effects. The model fit indices indicated strong explanatory power: chi-square/df ratio (2.221), the root mean square error of approximation (RMSEA = 0.049), CFI (0.952), the Tucker-Lewis index (TLI =0.943), the adjusted goodness of fit index (AGFI = 0.834), the normed fit index (NFI = 0.921), and the incremental fit index (IFI = 0.932) (Li et al., 2020). The model explained 54% of the variance in environmental citizenship behaviour. The results confirmed the hypotheses as follows: Hypothesis 1, with a significant path coefficient of 0.542 ($\beta = 0.542$, T = 11.343, $p < 0.01$), linking blue economy CSR perception to ocean stewardship passion. Hypothesis 2, with a coefficient of 0.561 ($\beta = 0.561$, $T = 11.312$, $p < 0.001$), confirms the relationship between blue economy CSR perception and ocean stewardship passion. Hypothesis 3, with a coefficient of 0.620 ($\beta = 0.612$, $T = 11.364$, $p < 0.001$), supports the link between blue economy CSR perception and environmental empathy. Hypothesis 4, with a coefficient of 0.382 ($\beta = 0.382$, $T = 6.787$, $p < 0.05$), validates the relationship between ocean stewardship passion and environmental citizenship behaviour. Hypothesis 5, with a coefficient of 0.216 ($\beta = 0.216$, $T = 4.151$, $p < 0.01$), confirms the positive relationship between environmental empathy and environmental citizenship behaviour. These results support the direct effects as hypothesized.

Table 4 Results of the structural equation tests.

Structural path	Estimates	T-value	P-Value	Results
H1: Blue economy CSR perception - Environmental citizenship behaviour	0.542**	11. 343	0.01	Supported
H2: Environmental CSR perception - Ocean stewardship passion	0.561***	11.312	0.001	Supported
H3: Environmental CSR perception - Environmental empathy	0.612***	11.364	0.001	Supported
H4: Ocean stewardship passion - Environmental citizenship behavior	0.382*	6.787	0.05	Supported
H5: Environmental empathy - Environmental citizenship behavior	0.216**	4.151	0.01	Supported

Examining the mediating effects

The sixth hypothesis proposed that environmental CSR perception indirectly influences environmental citizenship behaviour through ocean stewardship passion. Initial results showed a significant direct effect of blue economy CSR perception on environmental citizenship behaviour ($\beta = 0.623$, $T = 12.123$, $p < 0.001$). After including ocean stewardship passion as a mediator, the path coefficient reduced to 0.437 ($\beta = 0.467$, $T = 7.847$, $p < 0.001$), confirming a partial mediating effect. The Sobel test ($Z = 5.6$, $p < 0.05$) and bootstrap analysis (95% CI = 0.121–0.291) further validated the mediating effect, supporting hypothesis 6.

For hypothesis 7, the direct effect of blue economy CSR perception on environmental citizenship behaviour was significant ($\beta = 0.645$, $T = 12.442$, $p < 0.001$). With environmental empathy as a mediator, the path coefficient decreased to 0.467 ($\beta = 0.458$, $T = 7.837$, $p < 0.001$), indicating a partial mediating effect. The Sobel test ($Z = 4.38$, $p < 0.001$) and bootstrap analysis (95% CI = 0.110–0.313) confirmed the significant indirect effect, supporting hypothesis 7.

THEORETICAL IMPLICATIONS

This study contributes to the theoretical foundation of corporate social responsibility (CSR) by addressing a critical gap in the literature on the relationship between Blue Economy CSR and employees' environmental citizenship behaviour (ECB). While prior research has focused broadly on CSR's impact on environmental conduct (Afsar & Umrani, 2020), limited attention has been given to how Blue Economy CSR influences employee behaviours. The study finds that Blue Economy CSR exerts both direct and indirect effects on ECB, mediated by employees' ocean stewardship passion and environmental empathy. By integrating micro-CSR perspectives, the study sheds light on the psychological and social processes that translate Blue Economy CSR into ECB. Blue Economy CSR, as a significant organizational environmental policy, relies on voluntary employee participation for its success (Gattiker & Carter, 2010). ECB, a discretionary behaviour driven by personal volition (Deci & Ryan, 2000), can be stimulated by fostering positive intrinsic factors like stewardship passion and empathy.

This research expands our understanding of the antecedents of ECB and offers empirical evidence of the mechanisms through which CSR initiatives in marine sustainability promote employee-driven environmental actions. It provides valuable insights for advancing sustainable development management practices within organizations.

MANAGERIAL IMPLICATIONS

This study confirms that Blue Economy CSR positively influences employees' environmental citizenship behaviour (ECB), offering actionable strategies for organizations. To encourage marine environmentally-conscious behaviours, organizations must actively cultivate a strong CSR image. This includes enhancing the visibility and frequency of Blue Economy CSR activities in marine conservation, thereby strengthening employees' perceptions of these initiatives. Regular monitoring of employee perceptions, as recommended by Afsar et al. (2018), is critical. Any gaps identified should be addressed through communication forums, internal reports, training, and other strategies to align perceptions with organizational goals.

Additionally, fostering positive environmental emotions, such as ocean stewardship passion and environmental empathy, is key to bridging Blue Economy CSR and ECB. Managers should clearly communicate the organization's marine environmental attitudes and the tangible impacts of its CSR activities on ecosystems and coastal communities. Integrating Blue Economy CSR into broader sustainability strategies and emphasizing contributions to human well-being, societal progress, and marine preservation will deepen employees' emotional connections to marine sustainability. This holistic approach not only enhances employee engagement but also builds a collective culture of environmental responsibility and stewardship, advancing both organizational and ecological goals.

LIMITATIONS AND FUTURE RESEARCH

This study is limited by its focus on marine-based institutions, potentially restricting the generalizability of findings to other industries. Additionally, the cross-sectional design used to test hypotheses could benefit from alternative methods such as experimental or mixed-method approaches. Future research should explore positive environmental emotions among a broader employee base to deepen understanding of the psychological mechanisms driving voluntary environmental behaviour.

CONCLUSION

This study advances understanding of the emerging nexus between Blue Economy Corporate Social Responsibility (CSR) and employees' environmental citizenship behaviour, addressing a critical gap in the literature. It confirms that effective implementation of Blue Economy CSR strategies fosters environmental citizenship behaviour among employees. Notably, the research highlights the mediating roles of positive environmental emotions, specifically ocean stewardship passion and environmental empathy, as pivotal mechanisms for transforming Blue Economy CSR into proactive, voluntary environmental actions. By demonstrating these connections, the study not only contributes to theoretical knowledge on CSR and marine environmental management but also underscores the importance of cultivating employee engagement through emotional and psychological pathways to drive organizational sustainability goals.

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Ocean Governance and Policy: The Case of the Management of the Exclusive Economic Zone (EEZ).

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Abstract
Oceans are full of potential. They contain valuable resources like minerals, hydrocarbons, fish and a variety of other living and non-living resources. Oceans and seas also serve as means of transportation and communication. It is, for these reasons, among many, that the international community during the 20th century sought to establish a set of laws to manage and govern oceans and seas as well as resolve conflicts that may arise from the use of oceans and the exploitation, conservation and distribution of resources therein. An international treaty to manage oceans and seas was negotiated for 30 years: from 1952 to 1982 culminating in the adoption of the International Convention on the Law of the Sea, 1982 (UNCLOS). The UNCLOS is the constitution of the sea and has been ratified by 169 member States as of the year 2024. The longevity of the negotiation period and the issues canvassed during those negotiations are indicative of the complexities involved in the exploitation, use and management of the oceans. This paper envisions to analyse the governance and management of a specific part of the sea covered by the UNCLOS: The Exclusive Economic Zone (EEZ). Specifically, it reviews the law, the practice, and the opportunities and challenges that have emerged in the governance, use and management of the EEZ and the resources thereon and the dispute resolution mechanisms in the convention to redress such challenges in order to foster maritime security and sustainable development since the adoption of UNCLOS in 1982 to present day. Data for this paper were mainly collected through comprehensive literature review on the subject matter and about 15 in-depth interviews were administered with key stakeholders in the field, particularly, members of academic staff at DMI and practitioners in maritime security and management in Tanzania. A content analysis has been used for this paper.

Key Words: *Ocean Governance, Exclusive Economic Zone (EEZ), Treaty, Convention, Dispute Resolution.*

1.0 Introduction

For a long time, man and the international community have recognized that seas and water masses are critical in several respects. Seas have been used for transportation and communication even before airplanes were discovered. Seas are also known to be large reservoirs of resources like minerals, oil and gas, aquaculture, fish and others. They also serve as attractive centers of recreation and tourism and in many cases, seas are strategic areas as far as security is concerned. To be more precise, history is rich in information that even early forerunners of colonialism like missionaries, traders and explorers used to travel by seas. In the 15th and 16th centuries, for instance, famous figures like Christopher Columbus and Vaco da Gama as well as traders from Portugal, England, Dutch and Spain used seas. In the process, some of these trades and travelers were involved in accumulation of resources as pirates while others paved the way for what would become respective colonies for their home governments. Moreover, during the 17th century, for instance, states like Portugal started proclaiming large portions of, even, high seas as part of their territories (Shaw, 2008; Scott, 2010). Even in contemporary times when the world has achieved enormous levels of technological development in almost all fields including transportation and communication where you even have aircrafts, sea transportation is still crucial and it is reported that merchant shipping still constitutes 80 per cent of world trade volume (Aust, 2010).

These experiences, no doubt, present both opportunities and challenges to mankind. They compel man to ponder ways and rules through which seas and resources in them could be exploited and distributed to various sections of the society. More importantly, the illegal use of seas and some actions of some states of proclaiming portions of the sea as part of their sovereign territory generate competition among states and actors and lead to the emergence of conflicts. It is also, therefore, necessary for the international community to design rules and procedures that can be used to resolve conflicts that emerge due to the use of seas for various purposes.

2.0 The Evolution of the Development of the Law of the Sea and the Management and Governance of Oceans

In 1958 the United Nations organized four conferences which led to the adoption of four conventions: The Territorial Sea and Contiguous Zone Convention, Convention on the High Seas, Convention on Fishing and Conservation of Living Resources on the High Seas and; Convention on the Continental Shelf. These conventions are commonly called the UN Conventions on the Law of the Sea of 1958 and they marked the first efforts to codify the law of the sea (Aust, 2010; Shaw, 2008; Evans, 2009). It is remarked that of the four conventions, the Convention on the High Seas simply declared principles that had existed while the other three contained both old and new principles. Arguably, therefore, what is now known as the Law of the sea is basically a combination of customary international law and treaties that were concluded by members of the international community (Shaw, 2008, Aust, 2010). Among the customary laws that are common and have formed the basis for the modern law of the sea include the freedom of the high seas that was advanced by the famous Dutch jurist; Hugo Grotius; also coined as 'The father of International Law' (Shaw, 2008).

Following the four conventions of the law of the sea of 1958 there were attempts and efforts to come up with The Law of the Sea. It is posited that the efforts to come up with the law of the sea were protracted and the conference itself lasted sometimes between 1974 and 1982. Countries from various parts of the world had concerns that all, contributed to the long time taken before the Law of the Sea could be forged. The conference is said to have been attended by Civil Society Organizations, various movements as well as developing and developed states. Critical disagreements between developed and developing countries emerged over particular interests. Among others, it is reported that developing countries wished to advance an idea of exclusive economic zone to allow coastal state to claim up to 200 miles as part of their territorial sea, control seabed and be able to limit developed countries from exploiting resources in such area while, developed countries were defensive of navigation rights and wanted to oppose any attempt to limit freedom of passage (Shaw, 2008).

After managing to iron out some of the difference, in 1982, the Convention on the Law of the Sea came into being. The conditions for it to be a treaty required 60 ratifications. The sixtieth ratification was reached in 1993 and as such, the treaty entered into force in July 1994. By now, there are 169 state parties. Plainly stated, the Law of the Sea Convention is very extensive as it covers 300 Articles and several annexes.

2.1 The Coverage of the UNCLOS

As broad as it is with several annexes attached to it, the UNCLOS covers a wide range of issues in relation to the management of oceans and seas. To be certain, among the issues and areas that are regulated by this body of law include: the management of the territorial sea and contiguous zone; regulation of merchant ships; warships and government ships; the management of straits that are used for international navigation as well transit and innocent passages in the Exclusive Economic Zone. Moreover, the Convention spells the rights and duties of others areas of the sea and the rights and duties of different categories of states. Other aspects covered, therefore, include, the rights and duties of archipelagic states, land locked countries, neighboring land locked states as well as geographically disadvantaged states. Besides, the UNCLOS details the management of the continental shelf, the Area, enclosed and semi-enclosed seas, Islands and High Seas. It also spells how the preservation, exploitation and conservation of marine resources and the rights for installation of various communication and scientific equipment as well as enforcement and dispute resolutions can be undertaken with regards to the sea. The convention also details various aspects with regards to organs for conflict resolution and their powers like the Authority, The Council and the Enterprise. This paper, as earlier hindered, entirely focuses on the management of the Exclusive Economic Zone (EEZ). Before embarking on this task, a glance on the evolution of the EEZ is worth an attention.

3.0 The Evolution and Development of the Exclusive Economic Zone

It is agreed by scholars that what came to be known as the Economic Exclusive Zone (EEZ) was a result of the attempt by newly independent countries to reclaim their resources in high seas. Following their political independence, coastal states, especially, those in the developing world claimed the right to have jurisdiction and control in areas adjacent and beyond their Territorial Sea (TS). Such efforts, later, culminated into the adoption of the 'special interests of coastal states' with regards to the management of living resources in high seas adjacent to the TS. Their demands led to the adoption of the Exclusive Fisheries Zone (EFZ) and this informed the practice of both national and international community with regards to high seas and resources found therein until the 1970s (Andreone, 2015). In a nutshell, therefore, the Exclusive Economic Zone resulted from the codification of the EFZ and what is known as the 'patrimonial sea'. It should also be noted that before the entry into force of the Law of the Sea Convention, the EEZ was regarded a part of customary international law.

3.1 The Concept of the Exclusive Economic Zone (EEZ)

The United Nations Law od the Sea Convention Article 55 states that the 'Exclusive Economic Zone is an are beyond and adjacent to the territorial sea'. The breadth of the EEZ is limited within 200 nautical miles from the baseline from which the breadth of the territorial sea is measured (UNCLOS, Art. 57). This is to say, the breadth of the EEZ shall not exceed this measure. For smooth management of the EEZ, Article 56 of the UNCLOS confers certain rights, jurisdiction and duties onto coastal states. Coastal states have sovereign rights over exploration, exploitation, conservation and management of natural resources in this part of the sea. Besides, coastal states have jurisdiction over the establishment and use of artificial islands, installations and structures as well as over marine scientific research and the protection and preservation of marine environment. While exercising such rights and jurisdictions, coastal states are obliged to take into regard the rights of other states and ensure that they act in a manner that does not contradict other provisions set forth in the UNCLOS. To be certain, the provisions relating to the EEZ are covered from Article 55 to 75 of the law of the sea. When, thoroughly, examined, these provisions of the law spark serious discussions and form part of the conflict in reference to the management of the EEZ. It is also imperative to note that the establishment and acceptance of the EEZ in International Law subjected about more than a third of ocean resources including continental resources and most fisheries in the control of coastal states (Hoel, 2005). The next section shades light on this argument.

Moreover, it is increasingly important to examine how the EEZ is managed because if it is not well handled, conflict may not only happen because of the need to exploit resources and benefit from them but also because this is an area that is subject to many activities which cause vices in the world. The EEZ is subject to problems like: illegal fishing of territorial waters, incursion of mineral exploitation across legal boundaries, maritime terrorism, narcotics smuggling, pollution as a result of shipping accidents or malpractice, trafficking of illegal immigrants and; avoidance of tax duties through smuggling (COHORT, 2005).

4.0 The Management and Governance of the Exclusive Economic Zone and Associated Challenges.

The management of different aspects in the ozone layer is actually done by coastal states with respect to various provisions of the law of the sea. In this section, a cross examination of various such aspects is discussed to unpack the implications of such conduct. To be very specific, to be able to comprehend how the EEZ is managed, one ought to have a comprehension of 20 Article of the UNCLOS, that is, article 55 to 75 of the law read together with other provisions of the same law. Specific details on issues and how they are managed and governed in the EEZ are as stipulated here below.

4.1 Environmental protection in the EEZ

Whereas, Article 56 of the UNCLOS confers jurisdiction over the protection of the environment in the EEZ it should be noted that these powers are only limited to specific types of pollutants. Certain kinds of pollution like that from ship pollution cannot be subject to domestic laws on environmental protection. Coastal states can exercise jurisdiction in case pollutants are caused by activities in the seabed, installation of devices or dumping and those that are directly from vessels. The jurisdiction of this nature is not exclusive and extensive to guarantee environmental protection. Apart from this limitation, the problem is further complicated as not all coastal states are capable of exercising jurisdiction on the issues that are covered by the treaty. Coastal states like those found in the developing world and Africa, in particular, are overburdened by cases domestically and one would wonder if they really manage to deal with cases happening in seas even when have they have mandate guaranteed.

4.2 The rights over marine scientific research

The UNCLOS under article 56 (b) grants coastal states with the rights over marine scientific research. That is, coastal states have the rights to undertake marine scientific research and are entitled to grant consent/permission to other states to undertake marine scientific research in the EEZ. As good as this provision may appear, it remains problematic as it does not explicitly define the meaning of 'scientific' research. It does not even say whether such research should be pure or applied research or be meant for business, intelligence or any other purpose (Andreone, 2015). This has been a source of disputes among states.

4.3 Coastal States' Right to establish and use Artificial Islands and Installations

Coastal states have the right to construct and use artificial islands and install various equipment in the EEZ (UNCLOS Art. 60). The coastal state is also given the right to regulate the activities of other states that wish to construct artificial islands, install certain equipment and enact different structures. This provision essentially confers exclusive right and jurisdiction onto the coastal state. Thus, the management of this aspect is, entirely into the hands of the coastal state. Article 60 (2) further adds that the coastal state shall have jurisdictional rights over such matters as customs, fiscal, health, safety, immigration laws and regulation. This is demanding. For many developing countries that cannot even administer these aspects on land space, undertaking these responsibilities and exercising these rights appear to be untenable.

4.4 The Management of non-living resources and other economic resources.

The other important aspect with respect to the management of the EEZ concerns the governance of non-ling resources and all other economic resources. The UN Law of the Sea Convention under Article 56 (1) empowers coastal states to exploit and conserve all resources found in the seabed and subsoil of the EEZ. The provision gives exclusive rights to the coastal states with regards to this aspect. This provision of the law does not, however, prescribe specific powers of coastal states and the extent or means of enforcement in case of any dispute between coastal states and other states. This has also been a source of conflict and disputes among states in the international community.

4.5 The Enforcement Powers of Coastal States in the EEZ

As coastal states are granted jurisdictional powers in the EEZ, Article 73 (1) of the UNCLOS stipulates some enforcement mechanisms with regards to activities related to exploitation and conservation of resources in the zone. The specific enforcement mechanisms that can be used by coastal states in case of violation or breach of the law according to the above article include: boarding, inspection, arrest and judicial action. This is a crucial provision as far as the management of resources in the EEZ is concerned. Questions, however, arise on the competence of states to enforce these provisions as even when they try to, they end up losing cases and pay dearly. A case in point is in 2009 when Tanzania arrested a ship named Tawaqil 1and confiscated the resources (fish) weighing about 293 tones that had been boarded in it. After the proceedings, Tanzania was ordered to pay in compensation, a total of 3.3 billion Tanzanian shillings. This is not the only case as the country has lost a lot of other cases in international tribunals like in the cases involving the Tanzania Electricity Company Limited versus IPTL. This is just one case among many where the country has lost cases in international tribunals and incurred serious financial and other resources costs.

4.6 The Management of Highly Migratory Species

With an understanding that just as in land, in water there are species of living organisms that move from one locality to another at a quick pace, hereby, referred to as 'Highly Migratory Species'. The UNCLOS is not silent on how such species should be managed in the EEZ. Article 64 (1) of the law provides coastal states or any other states whose citizens or nationals harvest fish in zones that contain highly migratory species shall be required to cooperate directly or through International Organization to ensure such species are conserved and preserved in order to guarantee their maximum utilization. Albeit, the law also provides that in cases where such International Organizations are non-existent, the responsible states required to establish them. Not many countries have lived up to this provision and requirement of the law. Examples of highly migratory species include sharks, pacific tunas, swordfish and bill fish. A good example of an organization working to manage such species is the NOAA Fisheries in the West Coast.

5.0 Some Conflict Resolutions Mechanisms enshrined in the Convention

With a clear understanding that disputes and conflicts with regards to the use of resource found in the EEZ are bound to happen, the international community through the UNCLOS has set mechanisms to resolve such conflicts. Article 59 of the Law of the Sea provides for the basis for resolution of conflicts regarding the attribution of rights and jurisdiction in the EEZ. To be categorical, the article emphasizes that if a conflict arises between the interests of a coastal state and those of any other state or states, it should be resolved on the 'basis of equity and in the light of all the relevant circumstances, taking into account the respective importance of the interests involved to the parties as well as to the international community as a whole'. Specifically, conflicts that happen in seas where the EEZ is also a part are resolved primarily through negotiation between the parties or through other pacific means of settlements of disputes as enshrined in the United Nation Charter, Chapter six which include: inquiry, negotiation, mediation, use of good office, arbitration and judicial settlements (UN Charter, 1945). The UNCLOS also establishes the International Tribunal for the Law of the Sea (ITLOS) purposely meant do address marine related disputes. The court is responsible for disputes related to the interpretation and application of the UNCLOS. In some cases, ad hoc mechanisms/courts may be established to deal with specific conflicts. The world court, The International Court of Justice (ICJ) also resolves conflicts that happen in the world, including those that occur in seas and water bodies.

6.0 Conclusions

This paper has noted that seas present a great potential to mankind and that different actors have, since time immemorial, had a lust to benefit from the resources found therein. Most importantly, it has been noted that whereas, almost, all parts of oceans and seas have valuable resources, the EEZ is highly contested because coastal states have continuously claimed sovereign rights over this part of the sea. The enactment of a regime of the EEZ that confers rights and jurisdictional powers on coastal states and puts more than a third of ocean resources under the control of coastal states, to be sincere, limits the chances of other categories od states to make use of such resources. As such, it is convincing to argue that as it stands, the EEZ and its resources shall persistently represent an area of conflicting interests in the international community. It is a zone that it is fragile and prone to conflicts. Rethinking better ways to manage it should never end if peace and security as well as sustainable use of marine resources and development are to be realized. It has also been hinted that there are mechanisms in place to resolve disputes that may arise to the use of the EEZ like the Authority, the Assembly and the Council as well as the tribunal. These are important institutions and need to be further strengthened to be able to handle issues related to the overall use of the seas and oceans given the increase number of problems associated with this particular part of the Earth.

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Environmental Protection and Sustainability: Exploration for the Strategies of Environmental Stewardship and Community Engagement

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Abstract

The sustainable development of the blue economy is critical for preserving biodiversity, promoting economic growth, and ensuring human well-being. This study investigates how environmental stewardship aligns with key Sustainable Development Goals (SDGs), focusing on SDG 13 (Climate Action) and SDG 14 (Life Below Water), while also exploring its broader impact on SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). Through an in-depth analysis of international agreements such as the United Nations Convention on the Law of the Sea (UNCLOS) 1982, the Convention on Biological Diversity (CBD) 1992, the OSPAR Convention 1992, the Barcelona Convention, and the Marine Pollution Convention (MARPOL) 1973 (Annexes I, IV, and VI), this research evaluates the effectiveness of these frameworks in supporting sustainable blue economy strategies. Additionally, national policies on fishing practices, pollution control, and habitat conservation are reviewed to assess their role in fostering environmental sustainability.

Methodology: This study adopts a mixed-method approach. A document review of key international conventions, policies, and strategies forms the foundation for evaluating global and national environmental governance. Data is further collected through interviews and questionnaires targeting coastal communities in Mtwara, Mbeya, Zanzibar, and Dar es Salaam, as well as maritime professionals, to capture insights on policy effectiveness and community involvement.

Analysis Technique: The gathered data is subjected to qualitative content analysis to identify key themes, patterns, and relationships, providing a deeper understanding of policy implementation, governance effectiveness, and community engagement.
The study aims to offer practical strategies for improving community participation in environmental stewardship and advancing sustainability within the blue economy, contributing to the global goals of sustainable development.

Keywords: *Blue economy, SDGs, environmental stewardship, community engagement, sustainability, policy, governance, pollution control.*

INTRODUCTION

The sustainability of blue economy is vital in many scopes. The world at whole depends on Ocean and water bodies to sustain the livelihood in the matter of economic, social and biodiversity. This makes a call upon humans to invade the strategies for Environmental Stewardship basically the Blue Environments together with communities around coastal and lake shores to be engaged on the all strategies for environmental sustainability.
However, Sustainable practices on the context of Ocean, are not merely the responsibility of governments and organizations; they require the collective effort of individuals and communities. Engaging local populations in environmental decision-making fosters a sense of ownership and accountability, which can lead to more effective and everlasting outcomes. By examining case studies and current initiatives that exemplify successful community engagement in environmental protection and stewardship, this paper highlights innovative strategies for environmental stewardship and how the community can be engaged into those strategies so as to empower residents, promote resilience, and contribute to the creation of sustainable environment stewardship.

BACKGROUND

Environmental issues in Tanzania have been a challenge for a while. Around 1980s – 1990s We used to engage in environmental destruction, such as cutting down trees for cleaning purposes, as the community fought tsetse flies, collected firewood and charcoal for domestic use, and cut mangroves for building houses and making fishing boats. The villages and towns were not properly planned, resulting in poor sewage systems that led to the discharge of wastewater into the ocean and other water resources.

Environmental stewardship in the context of marine resources has evolved further with environmental movements that particularly focused on ocean environments. Several key events have taken place within these movements, such as Early Awareness (early 1900s), marine conservation movements in the mid-20th century (1950s-60s), international focus on oceans (1970s-1980s), and Sustainable Development. Several policies have been formulated to ensure the sustainable use of the ocean, such as the MARPOL Convention, 1973 and the OSPAR Convention. Along with the Sustainable Development Goals, these have been established to guide future efforts.

MAIN OBJECTIVES

The objective of this study focused on exploring the strategies for environmental stewardship and how those strategies can be devoted to the community engagement. The specific objectives typically includes

i. Strategies for environmental stewardship; presenting the reliable innovative strategies for the environmental stewardship to ensure the sustainable use and sustainable life for the marine environments and water bodies
ii. Approaches for community engagement for environmental stewardship; presenting approaches that shows how the community can be engaged in Marine environmental stewardship.

LITERATURE REVIEW

In spite of having different Maritime Conventions the matter of Environmental protection still a crucial issue. This is because all policies and conventions are including more marine professionals and stakeholders while the communities are not exactly directed to the implementation of such policies and conventions and goals.

Strategies for environmental stewardship Especially in Tanzania has highly based on protecting the Land environments where by all Strategies and community engagement has focused on land protection mostly.

Communities are seen as the lowest implementers of the policies and conventions while involving local communities in decision-making processes regarding marine resource management. Lack of trainings and capacity-building programs which can help enhance their skills in sustainable practices has led to the partial participation of community in the implementation of the imposed policies.

METHODOLOGY

Data on this study were collected through mixed-method approach where by it involved

i. Documents review on the international conventions, policies and strategies for Environmental Governance.
Document review is referred as process of collecting relevant documents, analyzing them, and extracting information that adds to understanding of the research topic (Harry F. Wolcott, 1994). In this paper document review approach was applied so as to provide deep background information and offers the valuable data that has been helpful in the completion of this paper. This method therefore, involved the selection of Documents where by the selected documents were adhere to meet the information that were needed due the accessibility and credibility. The Documents selected were Maritime Conventions, SDG 2015 and books.

ii. Questionnaires
Questionnaire is one of the most commonly used methods for collecting data in both quantitative and mixed-methods research (John W. Creswell 2014). In this paper Questionnaires used as the tool to collect primary information from the targeted coastal communities from different regions Mtwara, Mbeya and Zanzibar and marine professionals. The Questions provided were open questions where by individual were given the opportunities to express themselves.

iii. Interviews targeted to coastal communities in Mtwara, Zanzibar, Mbeya and Marine professionals.
Interviews also were applied to get more secondary information from targeted coastal communities in Mtwara, Mbeya and Zanzibar, together with the Marine professionals

DISCUSSION

This part represents the all findings including the interpretation and explanation, comparison, implications of the study done.

1. INTERPRETATION OF THE FINDINGS

1.1. The problem is due to the increase of population along coastal areas has led to the unsustainable use of water resources which threatens the ocean ecosystem. For instance, over fishing where by 70% of the world's fish stock has already been exploited which is beyond the sustainable boundary.

1.2. Cumulative impacts of land-based activities; the study finds that land based human activities are sources of environmental destructions for instance the destruction of wetlands, mangrove damages, damage of watersheds and impounding of water supplies to support development activities in coastal and lake shore areas such as constructions and recreational places

1.3. People consider ocean as the ultimate sink for discharges of waste of all kinds; communities and buildings especially hotels along the coastal areas tends to empty their septic and discharge all sewages wastes to the sea, the wastes carry microbes like Coliforms which are harmful to human and fish. When accumulated at large number in fish tissues coliforms cause diseases such as CHOLERA when the fishes doesn't well cooked (McGeorge, H. D. (1998). Spillage of the oil, transport of hazardous wastes, and nuclear test.

1.4. Poor urban and village planning that allows the building of big hotels and industries along the coastal areas; findings reveal poor urban and villages planning disrupts marine habitat like mangroves, coral reefs, and sea grass, which serve as vital breeding grounds for marine ecosystem.

1.5. Lack of environmental education to the communities along the lake shores and coastal areas; the findings reveal that many communities live along the coastal areas and lake shore has no education on how to accumulate water resources sustainably, local fisher men still use wrong fishing tools like dynamites, uses wrong size of fishing nets which led to the exploiting of small fishes, destruction of mangroves for building boats and houses.

1.6. Lack of awareness concerning with the marine environmental conservations;
In spite the efforts and initiatives the world has taken such as having the world Ocean Day which is celebrated every year, establishment of different maritime conventions, environmental campaigns and documentaries. Communities seem not to be aware and taking it seriously for their roles on protecting and conserving marine environments. The policies, campaigns and documentaries are barely understandable to the communities which are the primary implementers in maintaining and protecting environments the communities are not aware of toxic pollutions, effluents discharge management. All

strategies, Goals and conventions are understandable only to marine professionals and environmental experts only.

RECOMENDATIONS

This study has found out the environmental stewardship in the context of includes different stakeholders from the national level to the community level . The findings has come up with the following Approaches to be implemented by the Nation and the community.

1. The inclusion of marine environmental issues in school curriculum

Children have to learn about the marine environmental issues from the early age from primary school level of education to secondary. This will ease the understanding of environmental issues in communities since it will reflect what they have learn from school to the society.

2. The Inclusion of community engagement in legislation

The legislation in protecting marine environment should address the communities and recognize the communities as the prior pioneers to sustainable environmental practice. The legislation also should include the penalties and fines that will be charged to whoever caught destructing marine environments.

3. Engaging the community in proper village and town planning

Community has to be engaged in planning of village and towns, thus will help more to create a sense of ownership and responsibilities to the community and hence will enable them to be fully responsible for environmental protection and conservation.

4. Creating awareness to the community

The findings show that majority of community is not aware on the importance of protecting Marine environments therefore, strategies like campaigns, use of community leaders to create awareness to the community they are leading, training and workshops, and participatory method on things that concerns with the marine environments.

5. Provision of Education to the community

For accomplishment of anything Education is highly needed so as to raise the further knowledge of something. The community has to be provided with education learning on the important of protecting and conserving the marine environments for the present and future generation. The community has to be educated about the climate change that will impact the marine environmental stewardship.

6. Engaging the community in technology advancements

Community needs a full engagement in the advancement and innovation of technology especially the management of waste the Use of effluent treatment plant. Like Fumba Town in Zanzibar, the Town is well planned along the sea shore and has been built with the effluent treatment plant which recycles all waste sewages and they are not discharged to the ocean

7. Engaging the communities in Aqua Agriculture like planting of sea weeds and mangroves

Community has to be empowered and given the facilities to engage themselves in Aqua Agriculture not only for economic benefits but also for environmental protection and sustainability, This can be practically implemented IMO week 20th-25th September every year to raise awareness to the community

8. Preparation of National Blue economy road map identifying the respective areas that needs to be protected

9. The Maritime Authority should focus on Maritime environment protection

The Maritime Authority should be adhere for the protection of Maritime environments not only focusing on ships but also the communities along shore and coastal areas.

10. Establishment of projects to empower shore side communities

Projects like the provision of advanced fishing tools to the fishing communities as loans from the Government, this will help in banning the use of illegal tools for fishing activities. Also the Advanced fishing tools can be provided as the grants from Maritime stakeholders especially in Maritime days.

11. Establishment for Ships reception facilities

Ships reception facilities will help to receive the spent oil (dirty oil) from ships and recycling them to be useful again in running industries machine.

CONCLUSION

We depend on Environments, and Environment depends on us , we should take the Efforts to protect the environment for the future generations. The Development activities have to go hand in hand with the protection of our environments. The community has to look on Marine Environmental stewardship approaches with the open Eyes. Oceans carry wealth and sustainable development for the future in scope of Climate change, economic benefits and social life.

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From theory to Practice: 12 Action Points to operationalise Model Regulations

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Abstract

Domestic ferry transport plays an essential role in the daily lives of populations residing in regions that rely on waterways such as rivers, islands, archipelagos, lakes and deltas where alternative transport modes are not feasible. The diversity of domestic ferry transportation complicates the establishment of uniform global standards for domestic ferry safety. Unlike regulation of international shipping which is governed by IMO conventions, regulation of domestic ferry operations is largely falling within national jurisdiction which is resulting in fragmented safety regulations and inconsistent enforcement of regulations. The study addresses these disparities by evaluating model regulations on domestic ferry safety and translating them into practical action points. The Action point have potential to enhance the safety performance of domestic ferry operations.

Through qualitative analysis and the insights gained from regional workshop which was conducted in Africa, the research identifies key regulatory and operational gaps which include inadequate safety culture, ageing vessels, insufficient crew training and challenges related to overloading and weather risks. Findings and insights gained from the workshop have given successful practices from various stakeholders which has informed the formulation of 12-point action plan. The proposed action plan focuses on enhancing domestic ferry safety by emphasising risk assessments, strengthened regulatory enforcement mechanisms, community awareness initiatives and advanced technologies for real-time monitoring and emergency response.

The paper contributes significantly to bridging the gap between theoretical safety models and actionable and localised strategies which offers a practical framework for policymakers, regulatory bodies, ferry operators and maritime safety advocates. By promoting a resilient safety culture and addressing specific regional needs, this approach seeks to reduce maritime accidents, build passenger trust and ensure that ferries remain a sustainable, safe and dependable mode of transport.

Keywords
Domestic ferry safety, model regulations, maritime safety, action plan, stakeholder collaboration

Introduction

Domestic ferry transport facilitates movement of approximately 4.27 billion passengers annually which underscores its scale as a critical component of global transportation infrastructure comparable to that of commercial aviation (Interferry, n.d.). For many regions especially those characterised by archipelagos and inland waterways, ferries serve as essential lifelines which provide not only economic connectivity but also cohesion. In Africa, domestic ferries play pivotal role in facilitating trade, easy access to services and community linkage especially in regions where alternative modes of transport are either unavailable or economically infeasible (Hebbar et al., 2022). Despite the importance of ferries, the safety of domestic ferries remains a persistent challenge, which is marked by high-profile accidents such as the MV Nyerere accident which underscore systemic vulnerabilities (Matano, 2018).

Unlike international shipping which is regulated by strong framework of SOLAS, 1974, as amended, domestic ferry safety falls under the jurisdiction of member states. The regulatory decision results in fragmented standards, inconsistent enforcement and gaps in oversight. IMO, recognising these challenges, has developed domestic ferry model regulations (resolution MSC.518(105)) to guide member states in enhancing ferry safety. However, the voluntary nature of the model regulations, coupled with resource constraints and localised challenges such as aging fleet and insufficient crew training often limits their implementation especially in developing states (Hebbar, 2024). As the result, accidents have continued to occur.

Furthermore, ferry safety challenges in Africa are acute and unique given the fact that countries in the region are developing states. The reliance on older vessels which many are operating beyond their intended lifespan combined with infrastructural deficits and cultural attitudes towards safety which creates a risky operational environment. For instance, studies reveal that over 70% of ferry related accidents in Africa are attributable to overloading, poor maintenance and bad weather preparedness (Hebbar et al., 2022). Additionally, absence of harmonised safety standards and expert sharing across the region increases the problem because operators and regulators sometimes lack the technical capacity to enforce stricter measures. However, issues are not unique to Africa but reflect broader global trends in other regions with similar socio-economic conditions (Schröder-Hinrichs et al., 2013).

Therefore, addressing challenges requires bridging the gap between theoretical standards and what is actually taking place on ground. However, there remains a critical need for a framework that translates model regulations into actionable strategies. Therefore, the study seeks to fill the gap by focusing on Africa as a case study to develop 12 point action plan that is informed by domestic ferry safety model regulations and tailored to the unique needs of the region.

By integrating insights from a regional workshop held in Gabon, the study not only addresses ferry safety challenges of Africa but also offers lessons which apply to other regions with similar safety challenges.

Methodology

The study employed qualitative research method which enabled in exploring the safety challenges which are being faced by the West African region. It enabled the participants to express their views and give recommendations which was key in coming up with Action plan. The data was collected using group discussions, panel discussions and presentations by the maritime experts during the regional workshop that was held in Gabon in July 2024. The approach allowed for in-depth understanding of the operational and regulatory contexts that influence domestic ferry safety from different countries which attended the workshop.

The workshops brought together maritime experts from Congo, the Democratic Republic of Congo, Gabon, Gambia, Guinea, Nigeria, Sierra Leone, MOWCA and IMRF and other stakeholders who included ferry operators, passengers and civil society representatives. The workshop was particularly effective in identifying key challenges and generating ideas for potential solutions.

The data collected was analysed using thematic analysis which involved three steps of coding, pattern recognition and validation. During the coding phase, recurring themes such as maintenance, regulatory fragmentation, search and rescue, ageing fleet, crew training deficiencies and cultural barriers were identified. Finally, findings from the workshops were cross referenced to ensure the reliability and robustness of the analysis.

Findings and Discussion

The findings from the regional workshop on enhancement of the safety of domestic ferry safety which was held in Libreville, Gabon revealed a complex interplay of regulatory, operational, cultural and technological challenges which undermine the safety of domestic ferry operations in Africa. The insights which are enriched by stakeholder input which highlight both systemic weaknesses and opportunities for transformative change.

Fragmentation of regulatory frameworks

The workshops underscored the detrimental impact of fragmented regulatory frameworks across West and Central Africa. Participants repeatedly cited the absence of harmonised safety regulations as critical barrier to effective oversight and enforcement. While the IMO's model regulations provide valuable guidance, their voluntary limits their adoption at national level.

One participant emphasised that "inconsistent regulatory practices among neighbouring countries lead to discrepancies in safety standards, enabling non-compliant operators to exploit regulatory gaps" (Participant K, 2024). The regulatory vacuum often results in inconsistent enforcement of safety measures and limited oversight of ferry operations. The workshop called for harmonised safety regulations aligned with the Model regulations on Domestic ferry safety, underscoring their voluntary but important role in guiding safety improvements. This points to the necessity of including the guidelines into enforceable

national laws which are supported by consistent enforcement mechanisms.
Comparative examples from Southeast Asia reveal the success of regional frameworks such as the ASEAN Transport Strategic Plan in harmonising maritime regulations. Africa can draw lessons from these models to develop a regional mechanism under MOWCA. However, achieving this requires significant political will and capacity-building initiatives.

Safety culture

Lack of safety culture among ferry operators emerged as a recurrent theme. Reactive approaches dominate with operators addressing safety only after incidents have occurred. Workshop discussions highlighted reluctance among operators to conduct regular drills, report near misses and incidents, carry out maintenance or invest in crew training. Experts noted that absence of mandatory accident investigations further perpetuates this reactive mindset.

However, one of the maritime safety experts stated that "……… building a strong safety culture requires not only regulatory enforcement but also public awareness and engagement. Crew members must see safety as integral to their day to day operations rather than compliance exercise……."

Presentations by experts highlighted the need for operators and crew to adopt proactive safety practices such as regular drills and reporting of near misses and administrations carrying out accident investigations in time and sharing lessons learnt. As noted by one of the experts that "investigating marine incidents and communicating lessons learnt to all stakeholders" was essential for building strong safety culture. Therefore, by including safety culture into day to day operations, ferry operators can transition from reactive to preventive strategies.

Operational and Technical Challenges

Operational deficiencies especially reliance on ageing vessels have represented big risk to ferry safety. Participants highlighted that many ferries in the region exceed their lifespan which leads to frequent mechanical failures and heightened vulnerability during bad weather conditions. Furthermore, maintenance practices are often inadequate due to resource constraints and lack of skilled technicians (Participant H, 2024).

Overloading, which is driven by economic pressures and weak enforcement creates a fertile ground for the safety risks to keep happening. One of the participants recounted incidents where "operators were driven by making profits motives and ignored passenger lines which lead to tragic consequences during capsise event" (Participant M, 2024).

Technological solutions integration also plays an important role in mitigating operational risks. The workshop recommended "encouraging MOWCA member states to establish digital identification of passengers and put in place accreditation mechanisms for ship inspectors," which can play real-time monitoring systems for overloading and weather alerts. As noted by expert "weather updates should be issued and ferries should not be allowed to depart in the face of bad weather". However, implementing the systems requires collaboration among governments, ferry operators, masters and regional organisations. Furthermore, participants acknowledged barriers to the adoption of technological solutions, which included high costs and limited technical expertise. There is need to increase the capacity of the region through taking maritime training courses that will address the gap.

Environmental and navigational risks

The workshop highlighted bad weather and unregulated navigation routes as environmental and navigational risks. Participants stressed that ferries are ill-equipped to handle sudden changes in weather and operators lack access to real-time meteorological updates. Lack of designated navigation routes further complicates safety management because it increases the likelihood of collisions and grounding incidents. Workshop participants called for "establishment of clearly defined and enforceable navigation routes and should be supported by penalties for non compliance".

The 12-Point Action Plan

The findings informed the development of a 12-point action plan designed to address the identified challenges. The Action plan proposed by Prof. Hebber Anish as shown in (Figure 1) comprises of 12 goals and a set of 111 suggest tiered actions by Member states (45 actions), Company (28 actions) and Master (21 actions) for achieving each of the goals that was agreed by participants attending the Regional workshop on Safety of Inland Waterways and Passenger Ferries.

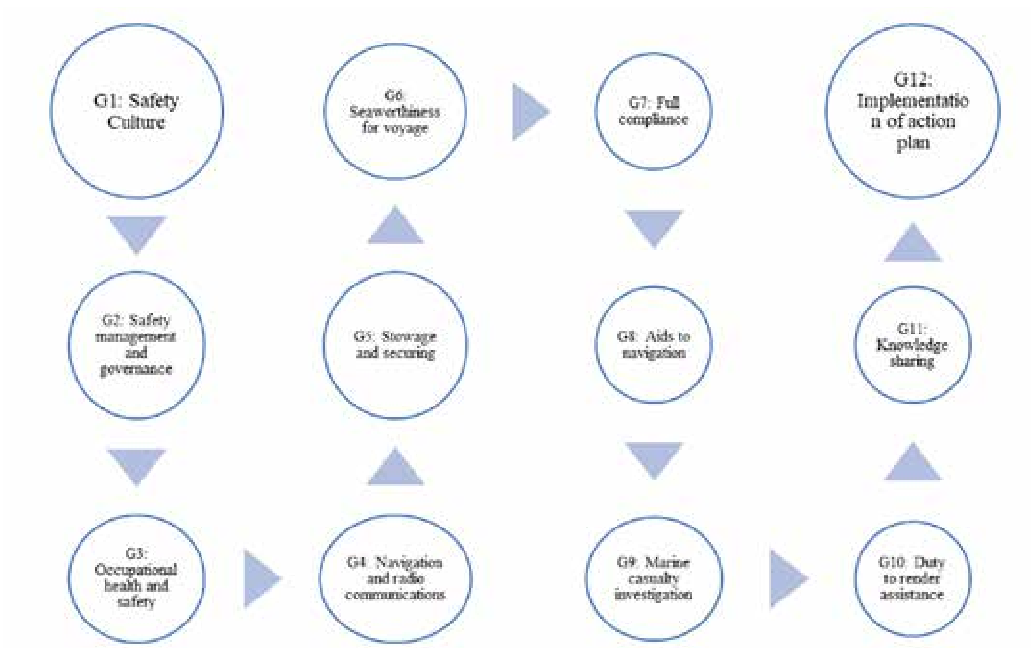

Figure 2: Proposed 12 goals (Source: Prof. Hebber Anish)

Member State	1. Adopt national policy for operational safety of domestic ferries 2. Establish a regime of inspections, tests and surveys by the competent authority or a recognized organization, an equivalent domestic entity or a nominated surveyor
Company	3. Adopt company safety policy and safety strategy 4. Define responsibilities for safety management 5. Identify and provide resources for safety management 6. Conduct safety awareness meetings 7. Conduct safety trainings of all company and ship personnel 8. Issue companywide safety bulletins 9. Encourage reporting of near misses and accidents 10. Maintain record of near misses and accidents 11. Investigate incidents and accidents and communicate lessons learnt to all stakeholders 12. Organize inspections, tests and surveys of ships in a timely manner
Master	13. Conduct regular safety meetings onboard ship 14. Conduct regular safety and fire drills

Figure 3: Goal 1: Safety culture

Figure 2 shows Goal no. 1 of the whole 12 Action Plan, which is safety culture and it focuses at putting in place effective mechanisms to promote and strengthen safety culture in all areas of domestic ferry operations. The action plan for Goal 1 is also presented, showing what Member State, company and Master need to do to achieve the main goal of safety culture. The 12-point action plan emphasises the need for a multi-tiered approach which involves member states, operators and ferry masters.

The study recommends that there should be;

- harmonising national regulations with IMO safety guidelines to address fragmentation;
- promoting fleet modernisation through using models of countries which have successfully secured funding;
- embedding proactive safety culture through mandatory training and regular safety audits;
- establishing enforceable navigation routes and integrating real-time weather monitoring systems; and
- strengthening community engagement to promote shared commitment to safety.

Therefore, the action plan prioritises interventions which address the most pressing challenges while laying the groundwork for long-term systemic improvements and is informed by the model regulations for domestic ferry safety.

Conclusion

The study bridges the gap between theoretical safety standards and practical implementation by operationalising IMO model regulations on domestic ferry safety into 12 point action plan which Is tailored to the unique challenges of domestic ferry operations in Africa. Through in-depth analysis of stakeholder insights and findings from regional workshops, the study identifies critical areas of intervention, which include regulatory harmonisation, fleet modernisation and integration of advanced technologies. The fragmented nature of domestic ferry safety regulations, which is coupled with cultural, operational and infrastructural deficiencies, has left many ferry systems vulnerable to preventable accidents. By emphasising safety culture, promoting community engagement and strengthening regional collaboration, the study provides clear roadmap for improving safety outcomes. The proposed action plan highlights the importance of tiered responsibilities among member states, operators and ferry masters by ensuring safety interventions are both practical and sustainable.

Beyond Africa, the findings and recommendations offer valuable lessons for other regions with similar socio-economic and infrastructural challenges. By leveraging international best practices and promoting partnerships between public and private stakeholders, the approach aims to create a resilient and dependable ferry system that reduces maritime accidents, enhances passenger confidence and supports economic growth.

Future research should focus on evaluating the quantitative impacts of the Action plan such as reductions in accident rates and economic benefits. Additionally, exploring the role of emerging technologies such as AI and real-time ferry monitoring could further enhance the safety and efficiency of domestic ferry systems. By building on the foundation laid in the study, stakeholders can work towards a safer and more sustainable future for ferry transportation worldwide.

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Leveraging on Ecotourism and conservation of blue economy Opportunities in Marine Protected MPA

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1. INTRODUCTION

The blue economy is represented by three interconnected pillars: economic social and environmental. Blue Economy is a key pillar in increasing economic benefits for developing countries sustainably. The Sustainable Development agenda recognizes marine resource elements such as fisheries, Aquaculture, and Tourism and by extension the Blue Economy as a key pillar in increasing economic benefits for developing countries, sustainably. Specifically, SDG 14 calls on all stakeholders to "conserve and sustainably use the oceans, seas and marine resources for sustainable development". Blue economy sectors such as tourism and travel, maritime transport, fisheries Resources and seafood production are heavily impacted by the climate change challenges. Planning to cope with climate change impacts requires the ability to predict how the oceans' ecosystems will respond. Coastal marine zones are especially vulnerable to this degradation as human activities are increasingly concentrated on the coast and exert great pressure on these ecosystems, severely affecting them. It has been difficult to determine how to re-establish the former ecosystems, what they should contain, and how they should function One management model is that of an ecosystem approach, which promotes conservation and sustainable use in an equitable manner (Pomeroy and Douvere, 2008; Lucrezi et al., 2019). Leveraging conservation efforts of marine protected areas (MPAs) is one way to sustain the changes in biodiversity.

Marine protected area (MPA) is an area of sea within the blue economy space dedicated to the protection and maintenance of biodiversity, and Natural and associated cultural resources, and managed through legal or other effective means. MPAs include marine parks, nature reserves, and locally managed marine areas that protect reefs, seagrass beds, shipwrecks, archaeological sites, tidal lagoons, mudflats, saltmarshes, mangroves, rock platforms, underwater areas on the coast and the seabed in deep water, as well as open water (the water column). Modern technology has increased the range of uses and access to the Blue economy within marine environments supporting industries such as fishing, tourism, aquaculture, and marine transport. Harnessing blue economy opportunities in the ecotourism sector introduces the need for a sustainable form of natural resource-based tourism. focusing primarily on experiencing and learning about nature. Marine ecotourism is a sector of sustainable tourism considered as a rapidly growing and profitable market that takes into account environmental conservation and promoting local communities' interests.

1.1 Ecotourism

Ecotourism is defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" Ecotourism is defined as a type of nature-based tourism that focuses on environmental sustainability and ecological preservation, aiming to protect natural landscapes and promote green growth in developing countries. Ecotourism is about uniting conservation, communities, and sustainable travel. ecotourism Provides financial benefits and empowerment for local people. Minimizes environmental impacts and builds environmental and cultural awareness and respect. Ecotourism Provides positive experiences for both visitors and hosts including direct financial benefits for conservation. Raise sensitivity to host countries' political, environmental, and social climate. Ecotourism only works when it yields economic benefits to local people, supports conservation, and reduces the human impact of travel. It requires the active and educated participation of tourists and the travel industry. Eco tourists are more likely to contribute to conservation financially through the revenue generated by larger numbers of tourists. While ecotourism is based on enabling people to experience the natural environment in a manner that is consistent with the principles of sustainable development, marine ecotourism is about attempting to establish and maintain a symbiotic relationship between tourism and the natural marine environment. Marine ecotourism activities may be water-based, land-based, or both. Marine ecotourism is an establishment for the maintenance of a symbiotic relationship between tourism and the natural marine environment. Marine ecotourism activities can be water-based, land- based, or both. Marine ecotourism includes: watching whales, dolphins, sharks, seals, and other marine animals, seabird ornithology, diving and snorkeling, nature-based sightseeing trips by surface boat or submarine, rock-pooling, coastal footpath, and beach walking and visiting seashore and sea life centers. Ecotourism within the blue economy can play a key role in supporting innovations by supporting the conservation of MPAS while contributing to improving the incomes of local communities and the involvement of stakeholders. This development in the Blue economy is strongly related to the Integrated Coastal Zone Management process.

Leveraging Conservation efforts of marine protected areas (MPAs) is one way that the changes in biodiversity can be sustained. Modern technology has increased the range of uses of, and access to, blue economy within marine environments supporting industries such as fishing, tourism, aquaculture, and marine transport. Ecotourism within the blue economy plays a key role in supporting innovations by financing the conservation of MPAS while contributing to improving the incomes of local communities and the involvement of stakeholders.

1.2 Marine Protected Areas (MPAS)

Marine protected areas (MPA) is 'any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment' (Agardy et al., 2003) Marine Protected Areas (MPAs) are spatially-delimited areas of the marine environment that are managed, at least in part, for conservation of biodiversity (MPAS) help to protect important habitats and representative samples of marine life and can assist in restoring the productivity of the oceans and avoid further degradation. 'MPAs are favorable areas for the development of environmental and ecotourism activities. Examples include protected areas around coral reefs, underwater sea mounts, and geothermal vents. MPAs are established to achieve specific conservation goals, usually a result of a dialogue among resource managers, scientists, local communities, and other stakeholders. Once these goals have been established, the management measures needed to achieve these goals must be evaluated. As a result, they are generally established only when management tools are determined to be the most appropriate ones available to achieve the set goals. MPAs are not just marine-based, they also include terrestrial protected areas that contain or border shorelines, estuaries, or wetlands; thus their boundaries encompass an oceanic shoreline, thereby providing coastal protection (Lucrezi et al., 2019). Additionally, the aquatic and shoreline environments of large freshwater lakes and rivers can also host MPAs.

Marine protected areas are also sites for scientific study and can generate income through tourism and sustainable fishing. MPAs provide a range of benefits for fisheries, local economies, and the marine environment including conservation of biodiversity and ecosystems. There are many types of MPAs, and they can vary in several aspects such as size, conservation goals, governance, and level of protection, among other factors.

MPAs are established to achieve specific conservation goals, usually after a dialogue among resource managers, scientists, local communities, and other stakeholders. Once these goals have been established management measures needed to achieve these goals must be evaluated However Marine reserves are the most highly protected type of MPA and they involve trade-offs with socioeconomic uses of an area.

2. OBJECTVTES

1. The purpose of marine ecotourism and conservation in blue economy
2. The role of marine protected areas in ecotourism within blue economy opportunities
3. Technology application in marine protected areas and climate change adaptation within blue economy sectors.

2.1 PURPOSE OF MARINE ECOTOURISM IN THE BLUE ECONOMY

Marine ecotourism in the blue economy aims to establish and maintain a symbiotic relationship between tourism and the natural marine environment. This is an existing opportunity within the Blue Economy sector. Marine ecotourism is interconnected and interdependent with other sectors of the blue economy as well as broader types of tourism activities, many of which are coastal. Developing marine ecotourism links to the blue economy directly by supporting government priorities for the tourism industry and also provides an economic incentive to improve ocean management. Marine ecotourism has gains in social, environmental, cultural, and economic imperatives as part of the overall tourism system. Ecotourism activities are water-based, land-based, or both. Marine ecotourism in marine protected areas generates positive outcomes for the natural environment. This is by way of propagating eco-awareness and the principles of sustainable development by providing economic alternatives to activities that degrade or deplete the natural environment. This takes place by way of raising funds that can be used for environmental protection. This is developed and marketed within a planning framework that ensures the practice of ecotourism is compatible with sustainability considerations. Marine ecotourism is also closely linked to marine tourism. Marketing marine protected areas for marine ecotourism encourages tourists to come close to nature. In Marine ecotourism visitors pay to interact with the fauna in these settings the revenue generated directly supports the conservation of marine areas by financing protection, contributing to conservation science, and aiding research activity (META- 2001)

2.2 ROLE OF MARINE PROTECTED AREAS IN ECOTOURISM

The role of marine protected areas (MPA) in ecotourism is to establish a framework for the development and marketing of a range of integrated marine ecotourism products, aimed at attracting a greater level of participation in marine ecotourism activities that exist in the blue economy sector. This also encourages coastal communities that are stewards of the ocean and coastal ecosystems to participate in the conservation of marine habitats. MPAs are established for general conservation reasons but expectations often include increased conservation of biodiversity, improvement of fishery catches, and sustainability of threatened species, also allowing for the recovery of species depleted by ecosystem changes. MPAs are also meant to protect activities like overfishing. biological diversity associated with ecosystems and protecting critical sites for reproduction and growth of species. Benefits of MPAS include protecting regions of oceans from human activities, supporting livelihoods, jobs creation, and providing food security opportunities. (Appendix 2)

MPAS provides focal points for education about marine ecosystems and human interactions and also provides sites for nature-based recreation and tourism. Scientific benefits relate to the use of MPAs as reference areas to assess the scale of human impacts on the environment, locations, and data collection. Generation of recreational and educational benefits. Also increased the abundance of threatened species and habitats and insurance against stock collapse.

Ecotourism within the blue economy plays a key role in supporting innovations by financing the conservation of MPAS while contributing to improving the incomes of local communities and the involvement of stakeholders. Transboundary MPAs are important in areas where a single marine ecological unit is shared by the jurisdictions of two or more countries. Where there is a history of rivalry or conflict between adjacent nations, the conservation of a shared resource can be an important step in building mutual understanding and cooperation.

3. MPAS CHALLAGES AND SOLUTIONS

3.1 Challenges

Maintaining marine protected areas within a marine ecosystem in their intact conditions and for them to be self-sustaining and able to adapt to climate changes in the ocean, is a prudent investment for the blue economy opportunities. MPA's basic requirements by the UN standards are to Protect and restore ecosystems and biodiversity, Develop a sustainable and equitable ocean economy, and Change humanity's relationship with the ocean. from open access to the ocean to protected sites and finally fully protected sites of protected MPAS (appedex1).

To address these challenges, management models of MPA's must find ways to value natural capital and at the same time, involve local communities and stakeholders in the governance processes of MPAS. The challenges to enhance the scientific basis for establishing, managing, and assessing the effectiveness of MPAs fall into four categories

I. Knowing and understanding the living resources of an MPA and how they interact,
II. Understanding how human activities affect marine systems,
III. Understanding the societies response to these changes,
IV. The quantity and extension of coastal and marine protected areas (MPAs)

Some MPAs have poor financial and human resources, thus lacking effectiveness. Such MPAs may frequently trigger conflicts with local communities, by imposing restrictions on their activities with no alternative or compensations, causing serious governance inefficiencies.

Governance of MPAS consists of interactions between structures, processes, and traditions, which determine how responsibilities are exercised, how decisions are taken, and how the views of citizens and stakeholders are integrated into the decision-making process within specific MPAs.

3.2 Solutions

The governance of marine spaces in MPAS is the management of stakeholder activities in these spaces. Optimizing this management and addressing stakeholder issues requires effective governance frameworks to be in place. This calls for Collaborative, cooperative, and integrative governance and improved frameworks for dealing with stakeholder issues within the MPAs.

Stakeholder involvement should be an ongoing process that includes the interested parties in assessing, planning, and implementing the MPAs and is widely known as an indicator of success for MPAs and marine conservation.

Multilevel governance processes are particularly important, regarding policies concerning economic and social cohesion and nature conservation, since MPAS are intrinsically connected to mutual relationships between regions and national states.

4.1 Technology and climate change adaptation in marine protected areas.

Marine protected areas (MPAs) are an essential tool in the recovery and protection of our ocean and the services it provides, MPAs primarily relate to biodiversity conservation of fisheries resources, research, and management tools. Modern technology has increased the range of uses and access to marine environments, supporting industries such as fishing, tourism, aquaculture, and the development of new forms of drugs from marine biodiversity. Leveraging on Conservation efforts of marine protected areas (MPAs) invites modern technologies and access to the blue economy within marine environments (appendix 3).

Technologies that are used include the ones used in testing in natural conditions such as antifouling designs and treatments, fish-finding equipment, benthic ecosystems mapping, in water calibration for satellite-based ocean and marine weather observing systems.

Near-pristine ecosystems in MPAS allow the developers of new technology to assess the performance of such systems within ecosystems that are behaving ‘normally’. Global Fishing Watch has for example partnered with Dona Bertarelli Philanthropy in developing Global Fishing Watch Marine Manager, as a new technology portal to support the effective design, management, and monitoring of MPAs. This technology provides dynamic and interactive data on human-use activity, ocean conditions, and biology for the near future. Marine protected areas help to ensure continuity and future options for protecting the health of marine ecosystems. MPAs are therefore an effective instrument to mitigate the effects of climate change. Planning to cope with climate change requires the ability to predict how the oceans’ ecosystems will respond. Measurements of long-term changes from researching MPAs are a way that the changes in biodiversity can be determined.

4.2 Conclusion

MPAS will in the future develop a sustainable and equitable blue economy and Change humanity’s relationship with the ocean. Ecotourism within the blue economy will play a key role in supporting innovations by financing the conservation of MPAS while contributing to improving the incomes of local communities and the involvement of stakeholders.

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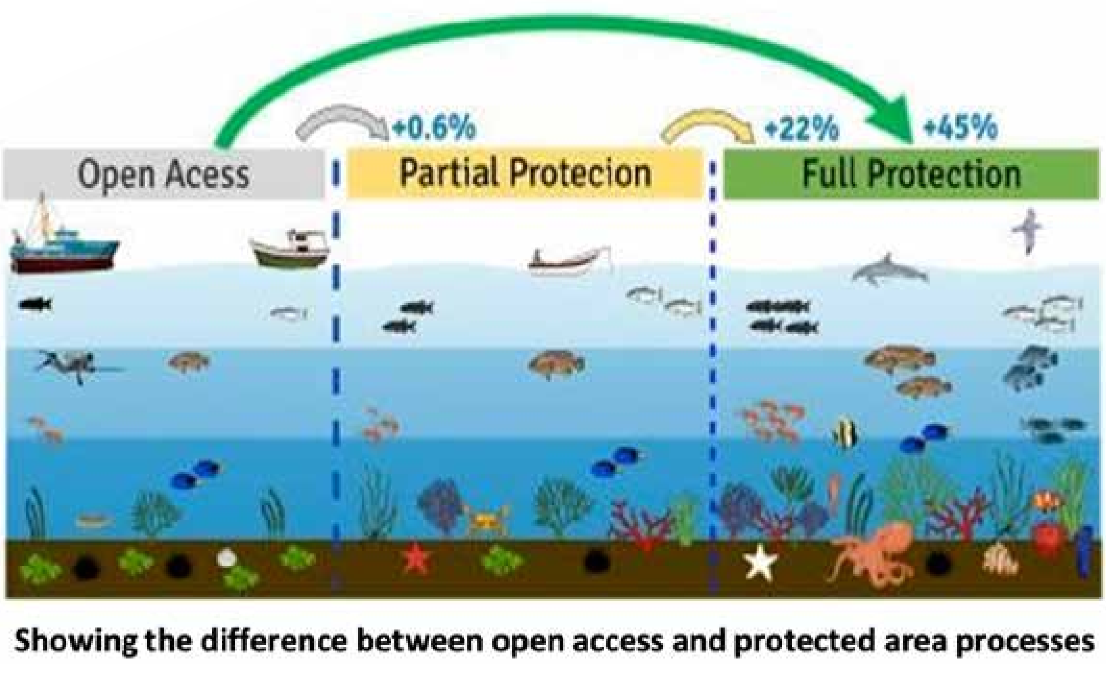
META - 2001 'Genuinely Sustainable Marine Ecotourism in the European Union Atlantic Area: A Blueprint for Responsible Marketing' :

APPENDICES

Appendix 1

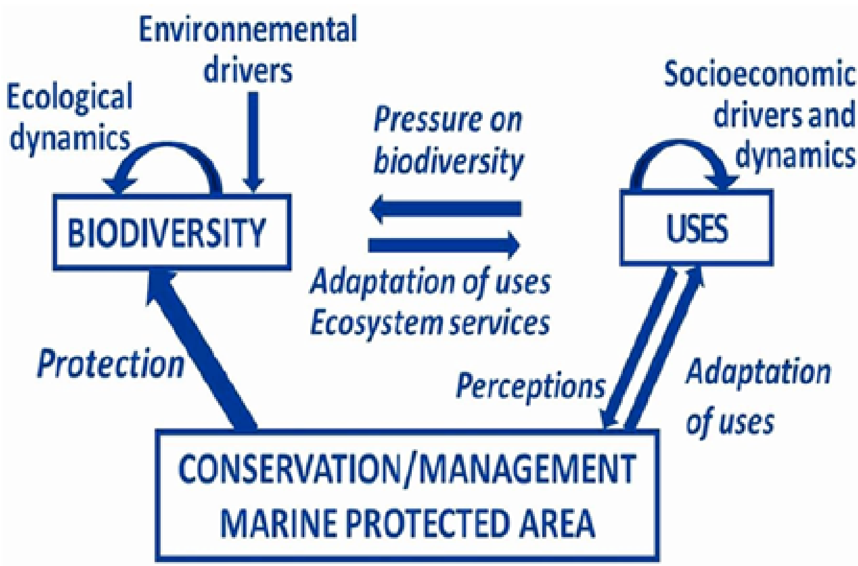


Showing the difference between open access and protected area processes

Appendix 2

Showing benefits of marine protected areas Appendix

Appendix 3



Showing the cycle of biodiversity in MPAS

First Report on the Occurrences of Microplastic Contamination in Mariculture

Eucheuma Cottonii from Lancang Island, Kepulauan Seribu National Park, Jakarta, Indonesia

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Abstract
Microplastics (MPs) contamination in marine environments in the blue economy significantly threatens marine ecosystems and human health. This study presents the first recorded occurrence of MP contamination in the macroalga Eucheuma cottonii Weber Bosse, 1913, specifically in samples collected from Lancang Island, Kepulauan Seribu National Park, Jakarta, Indonesia. Fibrous blue MPs, measuring approximately 400 µm, were identified in two samples, each weighing 15 g (wet weight). This finding aligns with previous studies reporting fibrous MPs as the global contaminants in macroalgal populations. Despite the similarity, our findings contrast with those from nearby regions, where fragment MPs were observed as the most abundant form. The interaction between MPs and macroalgae is influenced by factors such as surface texture, chemical composition, and the presence of mucilage. Additionally, MPs have been shown to impact macroalgal health, reducing growth rates and photosynthetic efficiency and increasing oxidative stress, destruction of marine resources in the blue economy highlighting the need for further research. Considering E. cottonii as an edible macroalga and a critical habitat provider in marine ecosystems, regular monitoring of MPs contamination is essential. This research contributes to a broader investigation of MP contamination of macroalgae with regards to the blue economy resources and underscoring the importance of sustainable practices in marine resource management for economic development.

Keywords: *Eucheuma cottonii, fibrous microplastics, Kepulauan Seribu National Park, marine macroalgae, microplastic contamination, blue economy*
Abbreviations: *KSNP: Kepulauan Seribu National Park, MPs: Microplastics*

INTRODUCTION

Indonesia is one of the world's largest producers of macroalgae, commonly known as seaweed, playing a pivotal role in meeting global demand and expanding export opportunities (Basyuni et al. 2024). The country is one of the leading exporters of macroalgae in Asia, with the primary cultivated species being Eucheuma cottonii Weber Bosse, 1913, Gracilaria sp., and Gelidium sp. (Gumilar et al. 2024). Nevertheless, Microplastics (MPs) pose a growing environmental challenge to marine ecosystems, including Indonesia's coastal waters, especially in aquaculture areas dominated by seaweed farming (Zhang et al. 2022). These tiny plastic particles (<5 mm), often less dense than water, tend to accumulate on the ocean's surface due to human activities (Xiang et al. 2022). In South Asia, MP pollution affects marine, terrestrial, and atmospheric environments, with species like fish, seaweed, and oysters being especially vulnerable, which raises concerns about human exposure through seafood consumption (Sin et al. 2023). While Indonesia's coastal macroalgae, consumed as sea vegetables, show differing levels of MP contamination compared to seawater and sediments, the broader impact on marine biodiversity is a global concern (Patria et al. 2023). In Indonesia, ocean currents mainly drive the presence of MPs in open seas, reflecting global averages. MPs concentrations are closely linked to population density. They are distributed through various human activities, including laundry, waste disposal, wastewater management, irrigation, organic fertilizers, coatings, and mulch (Setyaningsih et al. 2023). Water currents also play a role, with stronger currents able to transport larger quantities of MPs. These hazardous particles transpire through ecosystems due to domestic, industrial, and coastal activities, with domestic runoff containing microbeads and MPs fragments a significant contributor (Ahmad et al. 2020). Unmanaged domestic plastic waste disposal remains the principal source of MPs contamination in Indonesia's marine ecosystems, with fragments and fibers being the most frequently found forms (Sari et al. 2021). The ingestion or absorption of MPs has harmful effects on aquatic organisms. At the population level, MPs can reduce species diversity and biomass. In contrast, on an individual level, they can impair survival, reproduction, growth, feeding behavior, emergence, embryonic development, mobility, and even photosynthesis (Koelmans et al. 2022). Plastic is the most widespread form of marine debris globally, with MP pollution posing an increasing challenge for marine ecosystems. Although extensive research has been conducted on marine plastic waste, few studies focus on aquaculture in Southeast Asia, where MP regulations often overlook coastal aquaculture pollution (Albasri et al. 2024). A comprehensive approach is needed to analyze and assess MP pollution in aquaculture, including proper sampling, extraction, and qualitative and quantitative analyses (Xiang et al. 2022). Research on MP contamination in macroalgae remains limited globally, particularly in Indonesia (Purayil et al. 2024). Even Sari et al. (2021), who specifically addressed MP contamination in Indonesia's aquatic environments, did not report any MP contamination in macroalgae. Furthermore, a review by Lima et al. (2024) that assessed the density of MPs associated with macroalgae across different ecosystems and countries identified only ten articles; none focused on the macroalgae species E. cottonii. Given the importance of macroalgae as a substrate for MPs accumulation and the significant biomass of mariculture macroalgae alongside the abundance of MPs in Kepulauan Seribu National Park, Jakarta (Patria et al. 2023), this study aims to fill the information gap on the interactions between macroalgae and MPs. It focuses on detecting and characterizing the MPs found in E. cottonii seaweed samples collected from Lancang Island, Kepulauan Seribu National Park, Jakarta, including their color, size, and shape. This research is part of a more extensive investigation comparing the effects of floating and bottom cultivation techniques on seaweed growth, MPs contamination, and secondary metabolite content in Pramuka Island, Kepulauan Seribu National Park, Jakarta.

Impacts of microplastic contamination on seaweed and its implications on human health Microplastics on the other hand, pose a significant environmental concern in marine ecosystems. These are small plastic particles (<5mm) that have accumulated in the oceans due to human activities. Due to the increasing number of human population, there is a remarkable amount of microplastic waste according to the statistical analysis. The global production of plastic has reached 370 million tons by 2019. The infection of microplastic in the seaweed can lead to challenges such as stress, and contributes to the physiological processes of seaweed growth and development. The contamination of microplastic in seaweed biomass can affect the general growth and development of seaweeds and thereby affects the quality, quantity and economic value (Bayu & Handayani 2018).

Microplastics are emerging as one of the major factors not only affecting environment but also causing health related issues in human population. The toxic chemicals associated with microplastics can bioaccumulation in the food chain. As most of our marine coastal areas are contaminated with plastic pollution, there is high risk that human are consuming a good number of microplastics from sea food consumption. These findings reveal potential risk of MPs to human digestion and nutrient assimilation. Microplastics may cause changes in the intestinal micro biome, resulting in imbalance between beneficial and harmful bacteria, which can lead to various symptoms such as abdominal pain, bloating, death, inflammation, gastrointestinal issues, potential endocrine abruption and changes in bowel habits. Similarly, research studies had demonstrated the deposition of microplastic particles in lungs, especially in patients with respiratory diseases. The health risks associated with microplastics in edible macroalgae pose significant implications for food safety and security. By highlighting these risks, this research can inform policymakers, industry stakeholders, and the public about the need for monitoring and mitigating microplastic contamination. This proactive approach is essential for protecting public health, supporting sustainable food systems, and ensuring the long-term viability of macroalgae as a valuable resource in global diets (Mittal et al., 2023).

MATERIALS AND METHODS

Study area

Seaweed samples were from Lancang Island, Kepulauan Seribu National Park (KSNP), Jakarta, Indonesia (Figure 1). Samples preparation and MPs assessment were done at the Biology Department, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Indonesia. Figure 1. Original location of purchased seaweed samples in Lancang Island, Kepulauan Seribu National Park, Jakarta, Indonesia

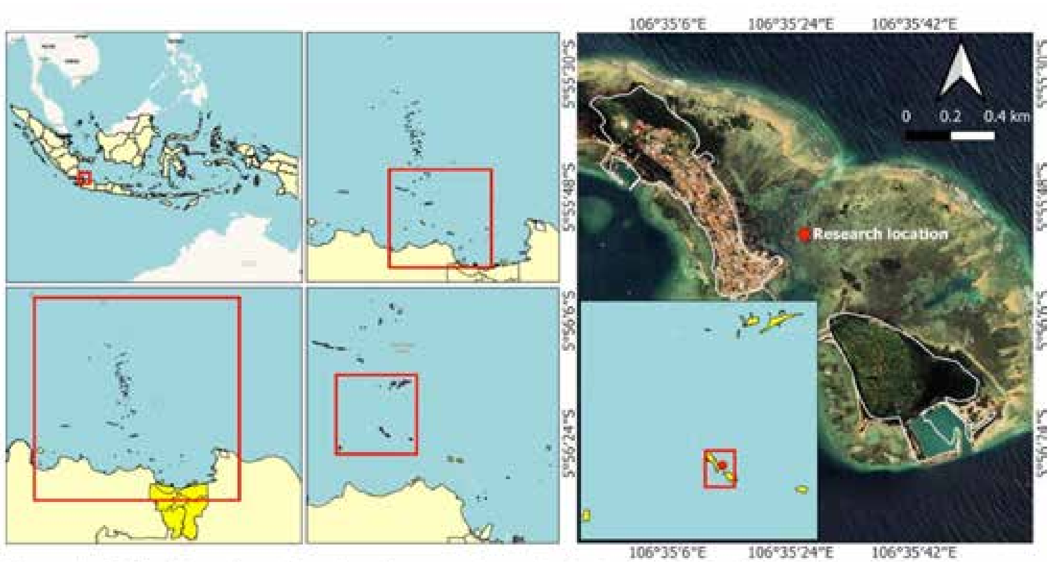

Figure 1. Original location of purchased seaweed samples in Lancang Island, Kepulauan Seribu National Park, Jakarta, Indonesia

Procedures

Sample origin

Seaweed samples (E. cottonii) (Figure 2) were purchased from a seaweed farmer. The samples were brought to the Biology Department, FMIPA, Universitas Indonesia, Indonesia, for a preliminary examination of MPs contamination.

Figure 2. Macroalgae of the species Eucheuma cottonii

MICROPLASTIC TECHNIQUE IN DENTIFICATION

A volume of 200 mL of distilled water was added to a 500 mL beaker and then placed on a magnetic stirrer. A stir bar was gently placed into the beaker using forceps, and a 15 g sample of seaweed was added. The magnetic stirrer was switched on, and the stir bar was set to a speed of 3 on the magnetic stirrer scale for 15 minutes. After the allotted time, the stir bar and the seaweed sample were removed from the beaker, and the water was poured into a separating funnel for MP isolation using filter paper. In the final stage, the filter paper was examined under a stereomicroscope for microplastic detection, using a 10× magnification lens to observe the MPs on the filter paper (Patria et al. 2023). The extraction process and analysis were conducted in a controlled investigation room, with gloves and lab coats worn throughout to prevent airborne contamination. Once isolated and detected, the MPs were counted, photographed, and measured, and their shape and size recorded. A laboratory technician and another postgraduate student then double-checked and confirmed the findings.

Data analysis

The collected data, encompassing the quantity, color, size, and shape of MPs, were recorded and described qualitatively. Additionally, secondary data on MP content in macroalgae were gathered by searching relevant literature in Google Scholar using the keywords "microplastic," "macroalgae," and "E. cottonii." All acquired data were then used for comparative analysis and further discussion.

RESULTS AND DISCUSSION

This study identified a blue, fibrous MP particle with an irregular shape, measuring 400 µm (Figure 3), in two samples of E. cottonii, each weighing 15g (wet weight). This discovery aligns with findings by Sari et al. (2021), Huang et al. (2023), Lima et al. (2024), and Purayil et al. (2024), marking the first documented occurrence of MP contamination in E. cottonii, both in Indonesia and globally.

This present research finding has directly aligned objectives and goals with Purayil et al. (2024), in their research, who has reported that fibrous MPs have become one of the most predominant contaminants in marine macroalgal populations. Additionally, in regards to fibrous MPs, Lima et al. (2024) in their study have also highlighted that blue fibers were the most investigated contaminant in various stranded marine macroalgae populations on estuarine beaches in Brazil. Blue is among the most ubiquitous and widespread MP colors found in marine environments (Rossi et al. 2024), notwithstanding certain transparent MPs being the most common type found in marine ecosystems. Various shades of blue have been detected in different macroalgae species (Seng et al. 2020; Esiukova et al. 2021; Li et al. 2022).

The results detected from this research has identified only fibrous MPs, which considerably defer from those of Patria et al. (2023), who reported in his study that fragment MPs as the most prevalent consisting of (34%), followed by fibrous MPs consisting of (31%) in Caulerpa racemosa (Forssk.) J.Agardh samples that were collected from Semak Daun

Island, Kepulauan Seribu National Park, Jakarta. According to extensive research from Purayil et al. (2024), nevertheless, the most common shapes of microplastics that were found in targeted marine macroalgae are fibers wand consisting of (50%), followed by beads of (29%), while fragments and other forms each account for only 7%.

Rossi et al. (2024) have made a distinction between MPs, which encompass various types such as fragments, films, and pellets, and Microfibers (MFs), which were defined as thin, elongated MPs with a high length-to-width ratio of 3:1 to 5:1. Their report highlighted that MFs are the most common type found in the marine sediments of the Vesuvian Coast, Southern Italy. They also suggested that marine sediments not only serve as a reservoir for MPs but also act as a source, supplying MPs to various marine organisms due to turbulence encountered during waves or other physical factors of seawater in the marine ecosystem.

Studies and research have discovered and quantified the numerous interactions between MPs and marine macroalgae and seagrasses in different marine settings (Feng et al. 2020a,b; Huang et al. 2020). An example of Macroalgae species, Ulva prolifera O.F.Mull., has been detected as a prospective bio-trapper for MPs as a result of its adequate trapping capacity, indicating its appropriateness as a bio- organic material for the recovery of MP-polluted seawater (Gao et al. 2020). The prolific connection of MPs to macroalgae is influenced by certain factors such as chemical composition, texture, and as well as the presence of mucilage. For instance, Peller et al. (2021) have observed in their study that senescent Cladophora spp. of macroalgae, which has experienced chemical changes in their cell walls, in less interaction with MPs as paralleled to younger individuals. Nevertheless, further examination and analysis are necessary, as the withholding of MPs by macroalgae has greatly depended on their morphological and physiological features regarding the polymeric composition and shape of the MPs (Feng et al. 2020a; Cozzolino et al. 2022).

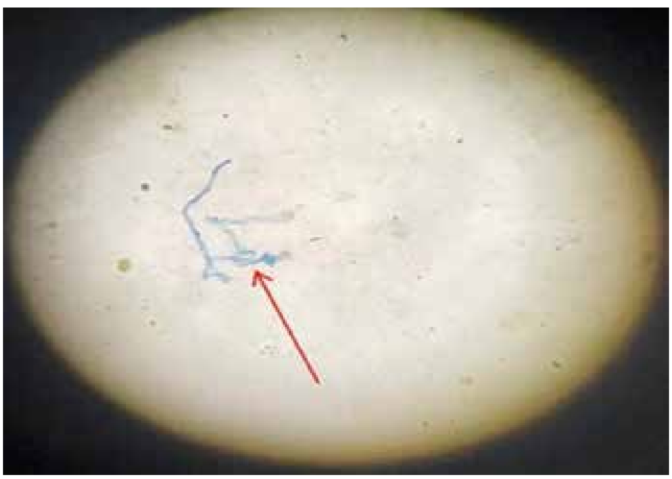

Figure 3. Microscopic image of the observed blue fibrous MPs (red arrow)

Vis-à-vis the observance capacity of macroalgae, MPs can still put forth toxic effects in a species-specific manner (Jung et al. 2023). Various research studies have highlighted that MPs can seriously hinder growth suppression and lead to a reduction of photosynthesis in certain macroalgal species in contaminated marine ecosystems. For example, declining factors include growth and Net Photosynthetic Rates (NPRs) in Chondrus sp. Moreover, U. prolifera significantly decreased when microalgae were exposed to higher concentrations of MPs (Feng et al. 2020a; Jung et al. 2023; Li et al. 2023). Similarly, polystyrene MPs inhibited photosynthetic oxygen evolution rates, increased Malondialdehyde (MDA) content, and reduction in Extracellular Polymeric Substance (EPS) levels in Caulerpa lentillifera J.Ag. and Gracilaria tenuistipitata C.F.Chang & B.M.Xia, 1976 (Feng et al. 2020a; Li et al. 2023). In U. pertusa and Gigartina sp., a dose-dependent reaction to MPs led to substantial rises in enzymatic antioxidant accomplishments and oxidative stress markers at concentrations of 50,000 MPs/mL (Post, 2021). Elevated levels of Reactive Oxygen Species (ROS) have also been investigated in Chondrus sp. when subjected to high levels of MPs (Jung et al. 2023). The interaction of MPs to the algal surface can lead to light blockage and impede the activity of photosynthetic reaction centers, acting against electron transfer rates (Jung et al. 2023). This interference can result in electron accumulation, increasing ROS production and the likelihood of oxidative stress in macroalgae. Advanced research study is required to address the current knowledge gap on the effects of MPs on macroalgae in marine ecosystems. The prevalence of MPs in macroalgae has pursuit some researchers to predict that these primary producers act as traps for MPs (Huang et al. 2020; Seng et al. 2020), with the possibility of generating MPs within their biomass (de Smit et al. 2021). MPs interact with various forms of macroalgae in various environments, whether attached to substrates like rocky shores (Khosravi et al. 2022), floating in the water column, or stranded on beaches (Feng et al. 2020a). Nevertheless, macroalgae generate and assist in the transportation of MPs throughout various marine ecosystems and food webs (Saley et al. 2019; Feng et al. 2020a; Gao et al. 2020; Li et al. 2020). Macroalgae serve as habitat builders, i.e., rendering shelter and nutritional nourishment to various organisms in the marine ecosystem, including macrofauna and benthic megafauna, as well as terrestrial invertebrates, fish, and birds (Schlacher et al. 2017; Gallardo et al. 2021). Subsequently, contamination of macroalgae due to MPs could significantly impact the species that rely on them for habitat and food, including humans who consume these species as a food source (Feng et al. 2020b; Patria et al. 2023). According to Giri et al. (2024), MPs entering the human body may lead to a range of harmful health effects, including oxidative imbalance that disrupts cellular metabolism, inflammatory responses, immune toxicity, increased cancer risk, neurotoxic effects, gut micro biome imbalance, and disruptions in the reproductive system, among others. Furthermore, it is essential to actively monitor the presence of MPs, more especially in various macroalgae edible species.

This study, focused on detecting blue fiber Microplastic (MP) contamination in E. cottonii, represents the first documented occurrence of MP contamination in this species in Indonesia and globally. However, certain limitations should be acknowledged. The geographic scope was limited to samples from Lancang Island in Kepulauan Seribu National Park, which may not fully represent MP contamination levels in E. cottonii across other regions or cultivation sites. Moreover, while blue fiber MPs were identified, we did not analyze other types of MPs or investigate their chemical compositions and potential toxicities. Additionally, environmental factors such as water quality, pollution proximity, and specific cultivation methods were not thoroughly assessed. The study also did not explore the broader ecological impact of MP contamination on E. cottonii or its potential effects on organisms that consume it.

Future research should address these limitations by expanding the sampling range to include multiple regions and various cultivation environments, enabling a more comprehensive understanding of MP contamination in E. cottonii across Indonesia and beyond. More detailed MP analysis, covering diverse shapes, colors, chemical compositions, and toxicity, would provide further insight into contamination sources and risks. Additionally, studies on the impact of different cultivation techniques, such as floating versus bottom methods, could clarify their relationship to contamination levels. Ecotoxicological studies exploring MP effects on E. cottonii physiology and potential bioaccumulation in marine organisms consuming this macroalgae are also crucial for assessing ecological and food safety implications. Long-term monitoring of MPs in E. cottonii would help reveal trends and understand MP persistence and seasonal variations, enhancing our knowledge of the contamination's scope and impacts. Together, these future directions could yield a more holistic perspective on MP contamination and inform sustainable practices for E. cottonii cultivation and broader marine ecosystem health. In conclusion, this research study represents the first ultimate recorded discovery of MP contamination in E. cottonii macroalgae, both in Indonesia and globally. The most common fibrous blue MPs observed aligns with findings from other studies, emphasizing broadly the extensive nature of fibrous MPs in marine environments. The results also highlight a contrast in MP types across different macroalgal species and locations, featuring the species-specific nature of MP interactions. MPs adhere to macroalgae based on various factors, including chemical composition, surface texture, and mucilage presence. While some macroalgae show latent as bio-trappers, MPs can still prevail toxic impacts on macroalgae, resulting to growth suppression, reduced photosynthesis, and increased oxidative stress. These effects emphasize the need for further investigation into the mechanisms of MP retention and the ecological impacts on macroalgae and associated marine species which leads to their loss of life. Given the role of macroalgae as habitat providers and food sources, monitoring MP contamination in edible species is very crucial to enhance protection to marine ecosystems and human health as a whole.

How monitoring and mitigating MPs in macroalgae align with sustainable marine resource management and economic growth, key components of the Blue Economy

A Blue Economy framework could promote sustainable fishery practices, ecotourism, marine transportation, and trade to reduce plastic pollution. Fishing nets are a major source of plastic waste, and a sustainable industry can reduce waste and promote environmental conservation. Ecotourism can provide a sustainable revenue stream for coastal communities and promote sustainable management. Marine transportation and trade can benefit from microplastics as fuel additives, while alternative packaging solutions can reduce plastic waste. Education and awareness raising initiatives can also help reduce plastic use. Implementing a Blue Economy framework in Africa requires significant investments, collaborations, and partnerships across industries, governmental agencies, and civil society organizations (Nwafor 2024).

The dominance of microplastics contamination in macroalgae poses significant threats to marine ecosystems and human health. However, addressing this issue is crucial for sustainable marine resource management and aligns with the principles of the Blue Economy, which emphasizes the sustainable use of ocean resources for economic growth, improved livelihoods, and preserves marine and aquatic resources. For marine ecosystems to remain healthy and to preserve biodiversity and ecosystem services, microplastics (MPs) found in macroalgae are essential. We can improve public health, increase food safety, and foster confidence in marine food products by lowering microplastic contamination. Monitoring programs offer useful information on the prevalence of MP, which informs management plans and regulations. This promotes ecotourism, local economies, and sustainable fishing. Reducing microplastic pollution promotes the creation of green technologies and creative solutions, which boosts the economy and lessens its negative effects on the marine resources. Addressing microplastic issues and maximizing the potential of healthy marine resources need cooperation between governments, scientists, and local populations.

According to the study, waste management and plastic consumption might be greatly impacted by microplastic contamination in macroalgae. It implies that best practices for harvesting and processing macroalgae can be developed, and that stronger laws on the disposal of plastic waste and recycling programs can be put into place. According to the research, training programs and educational materials for seaweed producers and fishers may also aid in lowering pollution. The study also highlighted that fostering a sense of ownership and promoting sustainable practices can be achieved through community involvement and cooperation with nearby companies. In order to lessen microplastic contamination, it also recommends that businesses spend money on the study and creation of substitute materials and technologies. Additionally, the study backs funding for programs aimed at cleaning up the ocean and coastal communities

RECOMMENDATIONS

A good number of the marine species are lost as a result of microplastic contamination and this has post a threat to our marine biodiversity. With sudden increase in population, civilization as well as climate change impacts, sustainable measures needs to be develop to mitigate the impacts of plastics and its effects in the marine ecosystem in the long-run. In order to lessen the pollution caused by plastic, it is necessary to enhance waste management systems, cut down on single-use plastics, raise public awareness, impose regulations, fund research, encourage sustainable practices, plan community clean-ups, encourage cooperation between public and private sectors, invest in technology and innovation, and restrict the amount of microplastics that are present in consumer goods.

Plastic waste can be decreased by putting in place recycling systems, using safe disposal techniques, and outlawing single-use plastics. Campaigns for public awareness, laws, studies, and environmentally friendly activities can all be beneficial. Governments, non-governmental organizations, and the commercial sector working together can combat marine plastic pollution. It is directly tied to overall plastic pollution. Nevertheless, a multidisciplinary strategy is required to address the complex nature of microplastic contamination, as these measures alone are insufficient

ACKNOWLEDGEMENTS

This research was funded by Hibah Riset Universitas Indonesia for the year 2024 with grant number NKB- 114/UN2.RST/HKP.05.00/2024. The project is titled "Assessing the Influence of Two Different Techniques of Seaweed Farming with Regard to Growth, Secondary Metabolite Profiles, and Microplastic Content".

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GREEN HRM PRACTICES AND SUSTAINABLE DEVELOPMENT GOALS IN THE HOSPITALITY INDUSTRY OF GHANA

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Abstract

This study explores the impact of Green Human Resource Management (GHRM) practices on achieving the Sustainable Development Goals (SDGs) within the hospitality industry of Ghana. Specifically, this study evaluated the impact of various GHRM practices (green recruitment and selection, green performance management and appraisal, green training and development, and green reward and compensation) on SDGs 6, 11, 12, and 14 and identified the challenges faced by hospitality organizations in achieving the SDGs in the hospitality industry with emphasis on the coastal establishments. The study population comprised 105 hospitality establishments within the coastal communities in Accra. A multi-stage sampling technique, which integrates convenience and lottery sampling was employed to select 105 respondents. The study employed a quantitative approach and adopted the explanatory research design. The data gathered was analysed using Smart PLS-SEM 4. The findings indicated that the relationship between green recruitment and selection, green reward and compensation, and green training and development on the SDGs are statistically insignificant. However, it is worth noting that the relationship between green performance management and appraisal and the SDGs is statistically significant in the hospitality industry of Ghana. The study concluded that to harness the potential of GHRM fully, the industry must adopt a holistic and transformative approach to recruitment and selection strategies that need to prioritize eco-conscious candidates and strengthen green employer branding, while reward systems must be realigned to incentivize and recognize contributions to environmental objectives. Training programs must move beyond superficial exercises to instil deep-seated sustainability values and proactive environmental behaviours among employees. The study recommends hospitality establishments highlight the effectiveness of green performance management and appraisal practices in driving progress toward SDGs 6, 11, 12, and 14, demonstrating that embedding environmental metrics into performance evaluations fosters accountability and aligns employee efforts with sustainability objectives. This success provides a model for leveraging GHRM practices to address critical environmental challenges toward the blue economy.

Keywords: *Environmental Sustainability, Green Human Resource Management, Hospitality Industry, Marine Ecosystem, and Sustainable Development Goals.*

Introduction

The hospitality industry in Ghana, as highlighted by the Ghana Statistical Service (GSS, 2022), has emerged as a dynamic and essential sector, significantly contributing to the country's economic growth and employment through its diverse offerings such as hotels, resorts, restaurants, and tourism services (Otoo, 2019). The GSS (2023) estimates that the industry contributes approximately 5.5% to Ghana's GDP, underscoring its critical role in the nation's economic landscape. However, despite these positive contributions, Mensah (2019) asserts that the sector faces numerous challenges that threaten its sustainability and environmental impact. For instance, a report by the Environmental Protection Agency (EPA) of Ghana, as noted by Milla-Amekor (2024), reveals that many hospitality establishments exhibit limited compliance with environmental regulations, resulting in issues such as poor waste management, high energy consumption, and water pollution. The hospitality industry in Ghana, particularly in Accra, faces significant environmental challenges linked to rapid urbanization, population growth, and inadequate waste management infrastructure (Arthur et al., 2023; Hart, 2022). Inefficient waste collection and disposal practices, such as open dumping and burning, contribute to soil and water contamination, air pollution, and degraded ecosystems, including water bodies like the Sea, Korle Lagoon, and Odaw River (Anokye et al., 2024; Ntajal et al., 2022; Clottey et al., 2022). These issues are exacerbated during rainy seasons when clogged drainage systems lead to flooding, worsening sanitation conditions, and spreading waterborne diseases like cholera and dysentery (Owusu & Obour, 2021; Yeboah et al., 2024). This study integrates the resource-based view (RBV) and the theory of planned behaviour (TPB) to address these sustainability challenges. The RBV focuses on strategically managing internal resources, such as green-skilled employees, for competitive advantage, while the TPB explains how these resources can be motivated to exhibit behaviours that support organizational sustainability goals (Conner & Armitage, 1998; Madhani, 2010). This integration, particularly relevant to Ghana's hospitality sector, highlights how Green Human Resource Management (GHRM) practices can foster pro-environmental behaviours and align human capital with Sustainable Development Goals (SDGs). As underscored by Sakshi et al. (2020) and Legrand et al. (2022), the hospitality industry plays a critical role in addressing sustainability challenges due to its significant environmental impact. GHRM has emerged as a key strategy to integrate sustainability into workforce management, including practices like green recruitment, training, performance management, and reward systems (Roscoe et al., 2019; Joshi et al., 2023). By improving employees' skills, motivation, and opportunities to support sustainability, GHRM aligns operational efficiency with broader environmental goals (Molina-Azorin et al., 2021; Schroeder et al., 2019).

Green recruitment and selection are key elements of GHRM, focusing on hiring individuals with relevant skills who share a commitment to environmental sustainability (Jamil et al., 2023; Pham & Paillé, 2020). In Ghana's resource-intensive hospitality industry, green recruitment aligns new hires with sustainability values, supporting Sustainable Development Goals through reduced carbon emissions and sustainable practices. Green performance management and appraisal systems are equally important, as they assess and enhance employee contributions to sustainability by using green performance indicators like waste reduction, energy efficiency, and resource conservation (Ardiza et al., 2021; Fernandez & Ganesan, 2023). These systems promote accountability and continuous improvement, driving initiatives aligning with the hospitality sector's SDGs. Green training and development equip employees with skills and knowledge to adopt eco-friendly behaviours, such as water conservation and energy-efficient operations (Yusoff, 2015; He & Zaman, 2024). These programs reduce ecological footprints and create a sustainability-focused culture that supports SDGs. Lastly, green reward and compensation strategies motivate employees by linking rewards to environmental performance and sustainable contributions (Ahmed et al., 2021; Pham et al., 2019). By recognizing and reinforcing eco-friendly behaviours, these strategies align personal and organizational goals, fostering a culture of sustainability and advancing sustainable development across multiple dimensions.

Efforts to address Accra's environmental challenges have largely been ineffective due to inadequate funding, poor coordination, and limited community participation (Zhou et al., 2021; Oduro, 2019; Deku, 2020). Despite public education campaigns and the National Sanitation Campaign, improper waste disposal methods like open dumping and burning persist, exacerbated by weak regulatory enforcement and insufficient infrastructure (Anokye et al., 2024; Mensah, 2019; Lartey et al., 2023). Private waste management companies have also struggled due to operational challenges, ineffective contracts, and inadequate recycling systems (Aning-Agyei, 2020; Seah et al., 2021). Achieving lasting environmental cleanliness in Accra requires coordinated efforts, enhanced GHRM practices, improved policy implementation, and community engagement (Debrah et al., 2022). The hospitality industry in Ghana, a significant contributor to economic growth and employment (GSS, 2022), faces challenges aligning with Sustainable Development Goals due to its environmental impact, including greenhouse gas emissions and unsustainable resource use (Geoffrey et al., 2021; Ali et al., 2021). While GHRM practices can help align industry operations with SDGs like clean energy and responsible consumption (Roscoe et al., 2019), only 30% of establishments have adopted sustainable practices, limiting the sector's contribution to sustainability (GTA, 2022). Moreover, over 60% of hospitality establishments fail to comply with waste disposal regulations, harming public health and ecosystems (EPA, 2022). The limited adoption of GHRM practices such as training employees in sustainable practices and incentivizing green behaviours further undermines progress (Suleman et al., 2022). Existing research highlights gaps in the literature on GHRM's role in fostering sustainability within Ghana's hospitality industry, emphasizing the need for focused studies to address the sector's unique environmental impacts and potential for sustainable development (Ali et al., 2021; Baffoe et al., 2021; Kissi et al., 2024).

Moreover, several studies from other geographical contexts, such as India (Mishra, 2017) and Pakistan (Ghani et al., 2024), employ methodologies like PLS-SEM and SWOT analysis, yet there is a need for more in-depth empirical research using a quantitative approach to capture the nuances of GHRM's impact on sustainability within the Ghanaian hospitality industry. Additionally, although prior research has examined the relationship between

GHRM and SDGs broadly, few studies have explored this relationship through the lens of employee behaviour and organizational practices specific to the hospitality industry. This gap presents an opportunity to investigate the impact of GHRM practices on achieving the Sustainable Development Goals 6, (Clean Water and Sanitation), 11, (Sustainable Cities and Communities), 12, (Responsible Consumption and Production), and 14, (Life Below Water) within the Ghanaian hospitality industry along the coastal communities in Accra. Consequently, this study aims to evaluate the impact of various GHRM practices on SDGs while identifying the challenges and barriers faced by hospitality organizations in implementing GHRM practices in Ghana's hospitality sector.

Literature Review

Theoretical Review

The resource-based view (RBV) Theory, introduced by Jay Barney in 1991, highlights that an organization's competitive advantage stems from internal resources that are valuable, rare, inimitable, and non-substitutable (VRIN) (Chacha, 2010). These resources, including technology, infrastructure, skills, and organizational culture, significantly influence organizational performance and success (Rantanen, 2021). In Green Human Resource Management (GHRM), RBV underscores human resources as critical assets for driving sustainability initiatives (Jamil et al., 2023). Practices like green recruitment, training, and performance management align workforces with environmental sustainability, enabling organizations to achieve sustainability goals. However, RBV faces criticism for focusing primarily on internal resources while overlooking external factors such as market dynamics and competition. Despite this, RBV is pivotal in linking GHRM to Sustainable Development Goals (SDGs) by leveraging human capital for sustainable development. Furthermore, the theory of planned behaviour (TPB), developed by Icek Ajzen in 1985, explains individual actions through three components: attitude toward behaviour, subjective norms, and perceived behavioral control (Hagger, 2019). These elements shape behavioral intention, which predicts actual behaviour (Ajzen, 2011). Within GHRM, TPB demonstrates how green initiatives, such as training and performance management, influence employee attitudes and behaviours toward sustainability. These practices foster pro-environmental behaviours and enhance employees' perceptions of their ability to support environmental goals. Although TPB has been criticized for emphasizing intention over unconscious behaviours or external constraints, it remains a valuable tool for structuring GHRM practices to influence employee behaviours toward achieving sustainability objectives. The RBV and TPB theories complement each other by integrating internal resource management with employee behavioural perspectives (Madhani, 2010). RBV focuses on leveraging green-skilled employees for competitive advantage, while TPB explains how these employees can be motivated to exhibit behaviours supporting sustainability goals (Conner & Armitage, 1998). This integration is particularly relevant in Ghana's hospitality industry, where GHRM practices (RBV) and pro-environmental behaviours (TPB) can collectively advance SDGs. Together, these theories provide a strategic and behavioural framework for examining the impact of GHRM on sustainable development.

Conceptual Review

Concept of Green Human Resource Management Practices

According to Podgorodnichenko et al. (2020), modern organizations emphasize environmental protection alongside achieving success. Human resources play a vital role in embedding environmental initiatives within HR management processes, referred to as Green Human Resource Management (GHRM) (Molina-Azorin et al., 2021). This approach supports organizations in achieving environmental objectives and adhering to regulations. GHRM integrates environmental management principles into HR practices such as recruitment and selection, performance management and appraisal, training and development, and reward and compensation (Amjad et al., 2021). Green recruitment and selection focus on environmental awareness and criteria that attract eco-conscious candidates. Environmental training enhances employees' knowledge, skills, and proactive efforts in reducing waste and upholding environmental standards. Performance management and appraisal in this context involve aligning employee evaluation goals with green job descriptions. To motivate employees to meet environmental objectives, organizations align rewards and incentives with their green strategies. Additionally, empowering employees to engage in environmental activities strengthens their commitment to sustainability.

Adopting a holistic approach to GHRM practices is essential for achieving effective and long-term environmental sustainability. According to Anlesinya and Susomrith (2020), using a GHRM bundle rather than isolated practices enhances environmental performance. A comprehensive approach fosters a loop of positive environmental behaviours. For example, hiring environmentally conscious individuals enables targeted training on both job-specific tasks and broader environmental impacts. This knowledge can be applied collectively, reinforced through performance reviews, and rewarded to sustain green initiatives. Such integrated practices are particularly relevant in industries with significant environmental impacts, such as hospitality, and in economies prioritizing sustainability. HRM practices such as green recruitment and selection, training and development, performance management and appraisal, and reward and compensation remain foundational to supporting these green initiatives.

Green Recruitment and Selection

Recruitment refers to the process of attracting a large pool of candidates from which the most suitable individual can be chosen by an organization (Aliyu, 2021). To adopt a green approach in recruitment, organizations have two main strategies. First, organizations can design recruitment strategies aimed at attracting candidates who are knowledgeable about and concerned for the environment. Alternatively, organizations can position themselves as "green employers," appealing to individuals who value environmental protection. The most effective approach is to recruit talent committed to environmental causes in the long term. Additionally, HR departments can utilize electronic platforms to convey their green message and accept applications, reducing the environmental impact. Following recruitment, the selection process identifies the most suitable candidate for a specific role. A green selection process could include evaluating candidates based on their responses to environmentally focused questions, allowing the organization to assess their alignment with green objectives (Adjei-Bamfo et al., 2020). Additionally, minimizing the use of paper in selection tests is a simple yet effective way to integrate environmental considerations into the selection process.

Green Performance Management and Appraisal

Bayo-Moriones et al. (2020) posit that the performance management and appraisal aspect of HRM focuses on assessing how well individuals contribute to achieving organizational objectives. In the context of Green HRM, this involves evaluating an employee's contributions toward the organization's environmental goals. Some scholars suggest incorporating specific environmental performance criteria into appraisal systems to ensure these contributions are formally recognized (Hameed et al., 2020; Ren et al., 2021). To make this process effective, it is essential that employees are fully aware of the environmental standards being assessed and that appraisals are conducted fairly and transparently.

Green Training and Development

Training and development are crucial once an employee joins an organization. It becomes the organization's responsibility to invest in its workforce, aligning their growth with the organization's goals (Mahapatro, 2021). This commitment reflects how much the organization values the importance of training and development. Green training and development emphasize educating employees about eco-friendly practices, the significance of environmental management initiatives, and methods to reduce waste and conserve energy (Gull & Idrees, 2022). Such programs should aim to enhance employees' knowledge, skills, and abilities in addressing environmental challenges while fostering their sense of responsibility as global citizens. Additionally, HRM should prioritize cultivating a sustainable organizational culture to ensure lasting environmental and social impacts.

Green Reward and Compensation

Das et al. (2021) postulate that compensation is a critical and complex component of HRM, encompassing all forms of payment and benefits provided to employees in exchange for their work. Its primary purpose is to attract, retain, and motivate the workforce. In the context of Green HRM, organizations can integrate environmental goals into their compensation strategies by offering rewards tied to the achievement of green objectives identified during performance appraisals (Martins et al., 2021). For example, some companies recognize and incentivize environmentally responsible behaviours. Additionally, employees can be rewarded for obtaining green certifications or completing specialized training programs that align with the organization's sustainability goals.

The Role of Green HRM in Sustainable Development Goals

The study of sustainability within HRM emerged to address the growing demand for sustainable development. Roorda (2020) emphasises sustainable development as meeting current needs without hindering future generations' ability to meet theirs.

Achieving sustainability requires a deep cultural and societal transformation that fosters new collective values and beliefs (Hammond, 2021). According to Wijaya and Mursitama (2023), Elkington's concept of the Triple Bottom Line emphasizes a balanced approach to sustainable development, urging businesses to consider social, environmental, and economic impacts. This approach reflects a paradigm shift that prioritizes social and environmental performance alongside economic growth. Green HRM evolved as a response to traditional HRM practices to focus on addressing environmental challenges.

In line with the transformative 2030 Agenda for Sustainable Development, the United Nations established 17 Sustainable Development Goals (SDGs) and 169 associated targets, providing a framework for actionable and collaborative solutions to global sustainability challenges. Six out of the seventeen SDGs are directly crafted to achieve environmental sustainability. These six SDGs (SDGs 6, 7, 11, 12, 13, and 14) focused on clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action, and finally, life below water. Companies play a crucial role in achieving these goals, particularly SDG 6, 11, 12, and 14, which call for responsible consumption and production. This includes adopting sustainable practices and integrating sustainability into GHRM practices. Research highlights the critical role of HRM in tackling sustainability challenges, emphasizing the importance of employees as key agents of change (Podgorodnichenko et al., 2020; Podgorodnichenko et al., 2022). Unlike traditional HRM, Green HRM incorporates environmental management into all HRM functions and practices. By aligning HRM strategies with environmental objectives, employees can drive more sustainable production processes and product development, significantly contributing to achieving sustainable consumption and production patterns as outlined in SDG 6, 11, 12, and 14.

Hypotheses and Question

After an extensive review of existing scholarly works and the comprehensive theoretical framework, the following research hypotheses and question were posed to guide the study:

H1: There is a significant positive relationship between green recruitment and selection and Sustainable Development Goals in the hospitality industry of Ghana.

H2: There is a significant positive relationship between green performance management and appraisal and Sustainable Development Goals in the hospitality industry of Ghana.

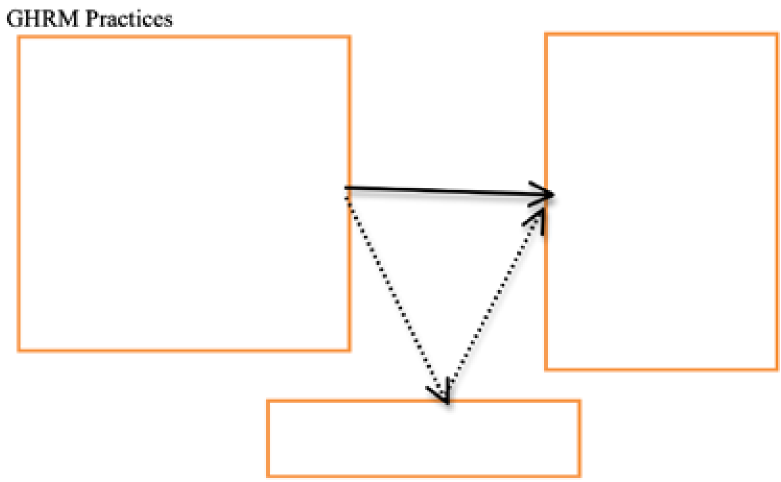
H3: There is a significant positive relationship between green training and development and Sustainable Development Goals in the hospitality industry of Ghana.

H4: There is a significant positive relationship between green rewards and compensation and Sustainable Development Goals in the hospitality industry of Ghana.

1. What are the challenges and barriers faced by hospitality organizations in implementing Green Human Resource Management (GHRM) practices in Ghana's hospitality sector?

Proposed Conceptual Framework

The figure below is the conceptual framework illustrating the impact of GHRM practices on SDG.



Source: Authors construct (2024)

Research Methods

Research Approach and Design

The research approach and design are fundamental for aligning the research paradigm with appropriate data collection and analysis methods (Rahi, 2017). Strijker et al. (2020) identify three primary research approaches: qualitative, quantitative, and mixed methods. Given the study's focus on examining the relationship between Green HRM practices and SDGs within Ghana's hospitality industry, a quantitative approach is most suitable as it allows for the empirical testing of hypotheses and the analysis of relationships between variables using statistical techniques (Kandel, 2020). This study prioritizes a quantitative approach to capture measurable data and validate findings that are generalizable across the industry. In terms of research design, Bell et al. (2022) describe it as the overall framework for conducting a study. An explanatory research design was appropriate for understanding how the implementation of Green HRM practices impacts the achievement of specific SDGs 6, 11, 12, and 14. Explanatory research enables a comprehensive examination of these causal relationships and the identification of key factors influencing sustainability outcomes (Pandey et al., 2021). Thus, the use of an explanatory design aligns well to assess the extent to which Green HRM practices contribute to achieving sustainability goals in Ghana's hospitality industry.

Population and Sampling Procedure

The population for this study was drawn from the hospitality industry in Ghana, specifically focusing on hotels, resorts, and recreational centers along the coastal communities in

Accra, as these establishments play a pivotal role in implementing GHRM practices and aligning operations with the SDGs. The study focused on mid to high-tier hospitality establishments that have the organizational structure and resources to support comprehensive GHRM practices. According to the Ghana Tourism Authority (GTA, 2023), there are over 150 licensed hospitality establishments across the coastal communities in Accra. The study targeted managerial employees working in these establishments, as they are directly involved in the implementation and operationalization of GHRM practices. This included managerial staff, HR professionals, and other key personnel who can provide valuable insights into how GHRM practices influence the organization's sustainability performance. Focusing on these establishments is crucial, as they contribute significantly to Ghana's tourism sector and are better positioned to adopt sustainable practices that align with SDGs.

The sampling procedure for this study was designed to incorporate practical methods that minimize potential sampling errors and ensure a representative selection of respondents. The sampling procedure according to Gupta et al., (2022) involves creating detailed procedures and practical methods for selecting samples to minimize potential errors. A multi-stage sampling technique, which integrates convenience sampling and lottery sampling, were employed to achieve a comprehensive sample that reflects the diverse perspectives within the hospitality industry in Ghana. Firstly, convenience sampling was used to identify and select hotels and resorts that are willing to participate in the research. Given the constraints related to access and the willingness of establishments to share information on GHRM practices, convenience sampling was appropriate for targeting establishments that have the organizational capacity and interest in sustainability initiatives. Within each establishment, the lottery sampling method was used to randomly select employees for participation in the study.

Data Processing and Analysis

The data collected from respondents in this study was analysed using a combination of descriptive and inferential statistics. Prior to conducting the analysis, the data were carefully coded to minimize the risk of errors during the entry process. To further ensure the accuracy of the data, the researchers implement a double-entry method, which involves entering the same data twice and comparing the two sets to identify and correct any discrepancies. Although this approach can be time-consuming, it guarantees precision in data handling. Once the data has been properly processed, it was analysed using descriptive statistics, such as percentages and frequencies, to provide an overview of key characteristics of the respondents, such as age, gender, educational background, and other relevant factors using SPSS. Smart PLS-SEM was employed to analyse the research hypotheses. Smart PLS-SEM is particularly suited for this type of research because it excels in handling complex models with multiple variables and relationships.

Results

Table 1: Demographic Information of Respondent

Variables	Options	Frequency	Percentage (%)
Gender	Male	55	52.4
	Female	50	47.6
	Total	105	100.0
Highest qualification			
	Postgraduate	15	14.3
	First degree	46	43.8
	HND/ Diploma	16	15.2
	Professional certificate	25	23.8
	Others	3	2.9
	Total	**105**	**100.0**
Working experience	Less than 5 years	13	12.4
	5 - 10 years	33	31.4
	Over 10 years	59	56.2
	Total	**105**	**100.0**
Position	Owner	8	7.6
	Manager	65	61.9
	Senior staff	32	30.5
	Total	**105**	**100.0**

Source: Authors construct (2024)

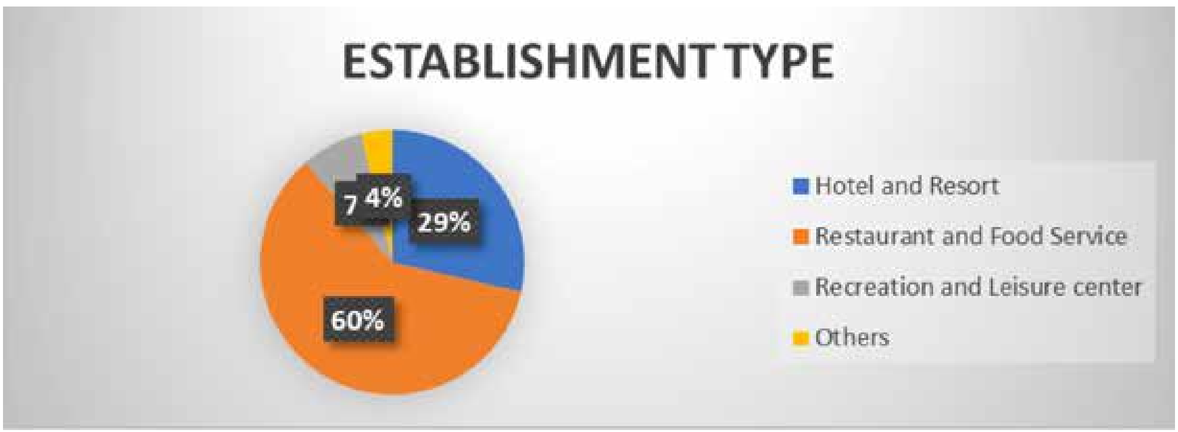


Figure 2: Hospitality Establishment Type
Source: Authors construct (2024)

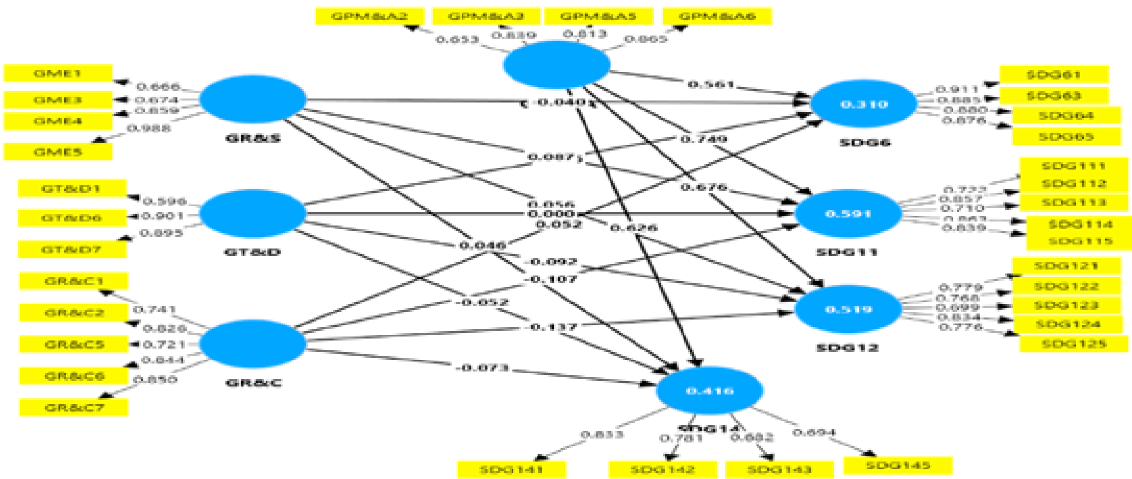


Figure 2: The Measurement Model

Table 2: Construct Reliability and Validity

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average variance extracted (AVE)
GPM&A	0.808	0.837	0.873	0.635
GR&C	0.860	0.884	0.897	0.637
GR&S	0.885	2.401	0.880	0.653
GT&D	0.726	0.798	0.847	0.656
SDG11	0.860	0.878	0.899	0.642
SDG12	0.830	0.837	0.880	0.596
SDG14	0.742	0.768	0.836	0.563
SDG6	0.911	0.923	0.937	0.789

Source: Authors construct (2024)

	GPM&A	GR&C	GR&S	GT&D	SDG11	SDG12	SDG14	SDG6
GPM&A								
GR&C	0.120							
GR&S	0.084	0.712						
GT&D	0.128	0.824	0.730					
SDG11	0.866	0.151	0.081	0.104				
SDG12	0.836	0.265	0.078	0.256	0.804			
SDG14	0.804	0.204	0.117	0.170	0.843	0.835		
SDG6	0.635	0.072	0.046	0.081	0.503	0.331	0.527	

Table 3: HTMT Ratio Result: Discriminant Validity
Source: Authors construct (2024)

The results of the study in Table 2 demonstrate that the constructs used have high internal consistency and reliability, as indicated by Cronbach's Alpha values exceeding 0.7 and good composite reliability. The AVE values are also relatively high (>0.5), indicating good validity. The study confirms the robustness of both convergent and discriminant validity of its constructs, with no issues found in Table 2 & 3

Table 4: Inner VIF Values

	VIP
GPM&A -> SDG11	1.025
GPM&A -> SDG12	1.025
GPM&A -> SDG14	1.025
GPM&A -> SDG6	1.025
GR&C -> SDG11	1.937
GR&C -> SDG12	1.937
GR&C -> SDG14	1.937
GR&C -> SDG6	1.937
GR&S -> SDG11	1.561
GR&S -> SDG12	1.561
GR&S -> SDG14	1.561
GR&S -> SDG6	1.561
GT&D -> SDG11	1.758
GT&D -> SDG12	1.758
GT&D -> SDG14	1.758
GT&D -> SDG6	1.758

Source: Authors construct (2024)

The VIF scores observed in Table 4 indicate that there is no prevalent method bias across all the constructs, as none of the VIF scores for the inner model exceeded 5, as reported by Oke et al. (2019).

Hypothesis Testing

The hypothesis testing in this study provides insights into the relationship between GHRM practices and SDGs within the hospitality industry in Ghana.

Table 5: Hypothesis Testing

Path	Original sample (O)	Sample mean (M)	STDEV	T statistics	P values	Hypothesis testing
GPM&A -> SDG11	0.749	0.748	0.081	9.208	0.000	Supported
GPM&A -> SDG12	0.676	0.669	0.071	9.470	0.000	Supported
GPM&A -> SDG14	0.626	0.627	0.073	8.569	0.000	Supported

GPM&A -> SDG6	0.561	0.563	0.086	6.556	0.000	Supported
GR&C -> SDG11	-0.107	-0.104	0.083	1.289	0.197	Not supported
GR&C -> SDG12	-0.137	-0.169	0.080	1.711	0.087	Not supported
GR&C -> SDG14	-0.073	-0.085	0.097	0.746	0.456	Not supported
GR&C -> SDG6	0.052	0.054	0.099	0.519	0.604	Not supported
GR&S -> SDG11	0.087	0.080	0.077	1.137	0.256	Not supported
GR&S -> SDG12	0.056	0.116	0.094	0.592	0.554	Not supported
GR&S -> SDG14	0.046	0.073	0.106	0.437	0.662	Not supported
GR&S -> SDG6	-0.040	-0.052	0.119	0.334	0.738	Not supported
GT&D -> SDG11	0.000	-0.009	0.065	0.001	0.999	Not supported
GT&D -> SDG12	-0.092	-0.120	0.086	1.079	0.281	Not supported
GT&D -> SDG14	-0.052	-0.074	0.103	0.510	0.610	Not supported
GT&D -> SDG6	0.056	0.059	0.088	0.634	0.526	Not supported

Source: Authors construct (2024)

The results in Table 5 provide insights into hypothesis testing for the relationships between the constructs: green performance management and appraisal (GPM&A), green recruitment and selection (GR&S), green rewards and compensation (GR&C), and green training and development (GT&D) and their contributions to SDGs 6, 11, 12, and 14. It evaluates the hypotheses using path coefficients, sample means, standard deviations, t-statistics, and p-values. The findings reveal that GPM&A has a significant and strong positive relationship with all four SDGs. The path coefficients range from 0.561 to 0.749, with high t-statistics (above the threshold of 1.96) and p-values of 0.000, indicating strong support for all four hypotheses. These results emphasize the critical role of effective green performance management and appraisal practices in driving progress toward sustainable cities (SDG11), responsible consumption (SDG12), life below water (SDG14), and clean water and sanitation (SDG6). The consistency between the original sample and the sample mean further reinforces the reliability of these relationships.

Conversely, GR&C demonstrates negative or negligible relationships with the SDGs, with path coefficients such as -0.107 for SDG11, -0.137 for SDG12, -0.073 for SDG14, and a minor positive value of 0.052 for SDG6. None of these relationships are statistically significant, as reflected by t-statistics below the critical value and p-values exceeding 0.05. These findings suggest that green reward and compensation strategies, as currently implemented, are not effectively contributing to sustainability goals, highlighting a potential area for re-evaluation and improvement. Similarly, GR&S exhibits weak and statistically insignificant relationships with the SDGs. Although the path coefficients are slightly positive for SDG11 (0.087), SDG12 (0.056), and SDG14 (0.046), and negative for SDG6 (-0.040), their t-statistics and high p-values indicate a lack of support for these hypotheses. This suggests that green recruitment and selection practices may have limited influence on achieving the targeted

SDGs and might require better alignment with sustainability objectives. GT&D, on the other hand, shows no significant relationships with the SDGs, with path coefficients close to zero or slightly negative for SDG11, SDG12, and SDG14, and a small positive coefficient of 0.056 for SDG6. The t-statistics and p-values reinforce the lack of statistical significance, indicating that current green training and development practices are not effective drivers of sustainability outcomes. The results point to the need for redesigning or enhancing training programs to ensure a meaningful impact on sustainability.

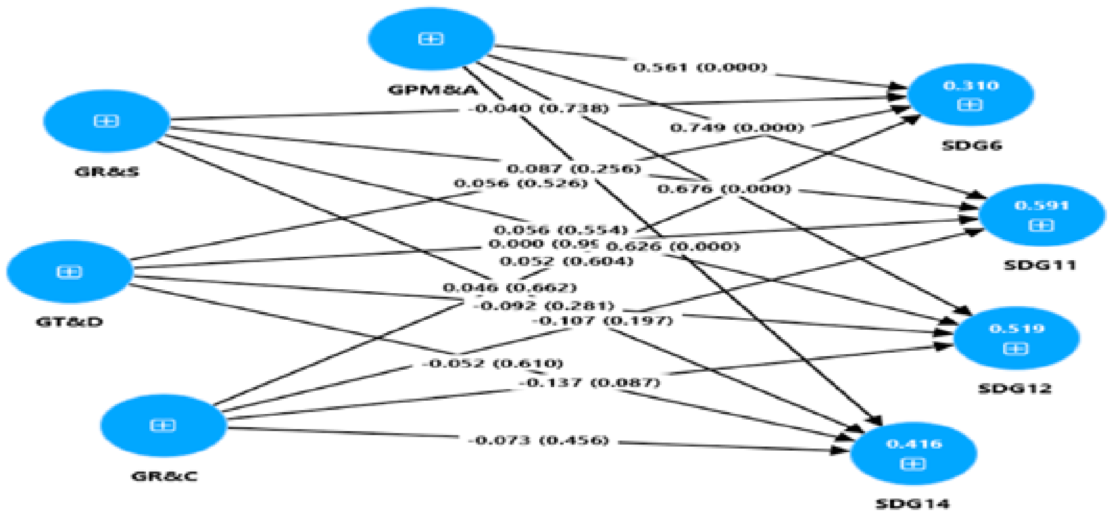


Figure 4: Structural model showing the effect of GHRM practices on SGD of hospitality employees.

Challenges and barriers faced by hospitality organizations in implementing GHRM practices and SDGs in Ghana's hospitality sector

Table 6: Challenges and barriers

Statements	N	Mean	Std. Deviation
Knowledge Gaps			
Management does not prioritize training on green practices and environmental sustainability.	105	3.43	1.307
Staff lacks sufficient knowledge of sustainable practices in this organization.	105	3.41	.948
This establishment does not have access to adequate information on Green Human Resource Management.	105	3.30	1.153
This organization offers workshops or forums for staff to improve environmental behaviour.	105	3.46	1.118
The importance of environmental sustainability is not well communicated within our organization.	105	3.44	1.117

Policy Barrier			
Government regulations on waste management are not effectively enforced in the hospitality sector.	105	3.61	1.061
This establishment does not receive incentives or tax benefits for adopting environmentally friendly practices.	105	3.77	1.040
There is a lack of clear government policies promoting sustainable practices in the hospitality industry.	105	3.78	.930
There is insufficient support from local authorities to promote sustainable tourism practices in this area.	105	3.76	.872
Inadequate regulatory support makes it difficult for this organization to implement green practices.	105	3.86	.848
Cultural Barrier			
There is resistance from staff to adopt new environmentally friendly methods due to long-standing habits.	105	3.64	1.048
There is a lack of cultural emphasis on environmental conservation within the local community.	105	3.86	.882
Traditional practices in our organization often conflict with the adoption of modern sustainable practices.	105	3.89	.954
Guests are not receptive to changes that promote sustainability, such as reducing water or energy usage during their stay.	105	3.77	.963
The belief that sustainability practices are foreign concepts creates resistance to their implementation in this establishment.	105	3.84	.878

Source: Authors construct (2024)

The findings in Table 6 highlight several challenges and barriers that hospitality organizations in Ghana face in implementing GHRM practices and achieving SDGs. These challenges are categorized into knowledge gaps, policy barriers, and cultural barriers, with mean scores indicating the perceived severity of each issue and standard deviations reflecting variations in responses. Under knowledge gaps, it is evident that a lack of adequate training and awareness impedes the adoption of green practices. The statement "Management does not prioritize training on green practices and environmental sustainability" has a mean of 3.43, indicating that many organizations do not view training as a critical priority. Similarly, staff members' insufficient knowledge of sustainable practices, with a mean of 3.41, suggests that the workforce is not adequately equipped to contribute to environmental sustainability. The relatively high mean of 3.46 for workshops or forums intended to improve environmental behaviour indicates a moderate presence of such initiatives, but this is likely insufficient given the broader context of limited organizational knowledge. Furthermore, the insufficient communication of environmental sustainability's importance within organizations (mean of 3.44) suggests a gap in leadership and strategic vision for sustainability.

Policy barriers present the most pronounced challenges, as evidenced by the high means across this category. The lack of clear government policies promoting sustainable practices in the hospitality industry (mean of 3.78) and inadequate regulatory support for implementing green practices (mean of 3.86) highlight systemic issues that hinder progress. Additionally, the absence of government incentives, such as tax benefits (mean of 3.77), and weak enforcement of waste management regulations (mean of 3.61) exacerbate the difficulty of adopting environmentally friendly practices. These findings indicate that the hospitality sector operates in a regulatory environment that does not sufficiently encourage or facilitate sustainable development. Cultural barriers also pose significant challenges, as seen in the resistance to change from both staff and guests. The mean score of 3.89 for the conflict between traditional practices and modern sustainable practices highlights how deeply rooted organizational habits and norms can act as obstacles. Similarly, resistance from guests to adopt sustainability-promoting changes, such as reducing water or energy use during their stay (mean of 3.77), underscores the difficulty of aligning customer expectations with environmental goals. The perception that sustainability is a foreign concept (mean of 3.84) and the lack of a cultural emphasis on environmental conservation within the local community (mean of 3.86) further complicate efforts to embed sustainable practices.

Discussions

The findings on the relationship between GHRM practices and SDGs highlight critical implications when analysed in light of the reviewed literature. The results support this framework by demonstrating that green performance management and appraisal practices have a strong and positive impact on all the 4 SDGs under consideration. High path coefficients and significant p-values affirm that aligning employee performance goals with environmental objectives effectively fosters sustainability in these critical areas. This finding aligns with Hameed et al. (2020) and Ren et al. (2021), who underscore the importance of integrating environmental metrics into performance appraisals to enhance accountability and engagement with sustainability and the blue economy goals. However, the study reveals significant gaps in the impact of other GHRM practices, such as green recruitment and selection, green rewards and compensation, and green training and development. For green recruitment and selection, the negligible path coefficients suggest a misalignment between recruitment strategies and the overarching goals of sustainability toward the blue economy. This supports Aliyu's (2021) assertion that recruitment processes must explicitly target eco-conscious candidates or emphasize the organization's green employer branding to attract individuals aligned with sustainability principles. The lack of significant outcomes in green rewards and compensation further emphasizes that organizations must redesign reward systems to recognize and incentivize employees' contributions to environmental objectives, as Das et al. (2021) highlight the importance of aligning compensation with green initiatives to motivate pro-environmental behaviour.

The ineffectiveness of green training and development in driving sustainability outcomes in achieving the blue economy, as evidenced by the lack of significant path coefficients, calls attention to deficiencies in current training programs. This finding resonates with Gull and Idrees (2022), who stress that training initiatives must not only enhance knowledge and skills related to eco-friendly practices but also cultivate a sense of responsibility and commitment among employees. The lack of meaningful impact implies that hospitality organizations may be treating green training as a superficial exercise rather than a transformative approach to instilling sustainable values. The strong results for green performance management and appraisal align with Ajzen's (2011) assertion that well-structured management practices enhance employees' intention and ability to adopt environmentally responsible behaviours. In contrast, the lackluster performance of green recruitment and selection, green rewards and compensation, and green training and development suggest that these practices fail to sufficiently influence the attitudes or perceived control necessary for behavioural change. This disconnect reinforces that achieving sustainability toward the blue economy requires a deep cultural transformation supported by effective GHRM practices.

Conclusions

The findings affirm that green performance management and appraisal practices serve as a cornerstone for achieving SDGs 6, 11, 12, and 14 by effectively integrating environmental objectives into employee performance metrics. This success reflects the strategic potential of aligning human capital with sustainability goals. However, the negative contributions of green recruitment and selection, green rewards and compensation, and green training and development reveal significant gaps in the current implementation of GHRM practices. To fully harness the potential of GHRM, the industry must adopt a holistic and transformative approach. Recruitment strategies need to prioritize eco-conscious candidates and strengthen green employer branding, while reward systems must be realigned to incentivize and recognize contributions to environmental objectives. Training programs must move beyond superficial exercises to instil deep-seated sustainability values and proactive environmental behaviours among employees.

Practical Implications

The hospitality industry required an urgent need to strategically implement Green HRM practices to achieve SDGs. The study highlights the effectiveness of green performance management and appraisal practices in driving progress toward SDGs 6, 11, 12, and 14, demonstrating that embedding environmental metrics into performance evaluations fosters accountability and aligns employee efforts with sustainability objectives. This success provides a model for leveraging GHRM practices to address critical environmental challenges. However, the gaps identified in green recruitment and selection, green rewards and compensation, and green training and development signal the need for a more targeted and integrated approach. Recruitment and selection strategies must focus on attracting candidates with eco-conscious values and enhancing green employer branding to build a workforce committed to sustainability. Reward systems should be restructured to explicitly recognize and incentivize employees' contributions to environmental goals, fostering motivation for pro-environmental behaviours. Additionally, training programs require a transformative overhaul to move beyond basic knowledge dissemination, aiming instead to embed sustainability as a core value and cultivate employees' commitment to environmental stewardship.

Limitations and Suggestions for Further Research

This study focused on four GHRM practices namely: green recruitment and selection, green training and development, green performance management and appraisal, and green reward and compensation on SDG 6, 11, 12, and 14 in the hospitality industry of Ghana. While many green HRM practices influence SDGs, this study focuses on these four practices because these areas are directly linked to the most pressing challenges in the Ghanaian hospitality industry. Hence, the study recommends that further research investigate the effect of other green HRM practices, such as employee participation, employee engagement initiatives, and talent management, on SDGs within the Ghanaian hospitality industry. Also, the study adopted the quantitative research approach to examine the relationship between variables, the study recommends future researchers complement quantitative research with qualitative studies to gain deeper insights into employees' perceptions and experiences related to GHRM practices and their influence on SDG 6, 11, 12, and 14 and if possible, conduct longitudinal studies to track changes in the SDGs over time in response to various GHRM practices within the hospitality industry to enhance the degree of generalizability.

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Challenges and ways forward toward ballast water management (BWM) in Ghana

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Abstract
This paper aims to discuss the challenges facing the maritime sector of Ghana in preventing the potential spread of harmful aquatic species through ballast water discharge and suggest some emerging solutions to overcome the challenges. The methodology used in this study comprised a review of scientific and technical literature published on ballast water management (BWM), the use of questionnaires, and interviewing of domain experts. By comparing and contrasting information obtained from different sources, seven important challenges are identified and discussed. Key among the challenges include (1) lack of sediment reception facilities at the shipyard and ports, (2) inadequate human and logistical capacity, and (3) lack of independent verification. Furthermore, the root causes of these challenges are investigated and possible solutions are proposed. We conclude that the findings of this study can help improve the safe management of ballast water in Ghana.

Keywords: Ballast water management, Maritime sector, Shipping, Ghana, Marine Pollution

Introduction

As part of the global response to regulate the spread of IAS, the International Maritime Organization (IMO) adopted the Ballast Water and Sediments Management Convention (BWMC) in 2004 and globally came into effect on 8 September 2017 (Čampara et al., 2019). However, existing ships were required to install ballast water management systems (BWMS) by September 2019 during their International Oil Pollution Prevention (IOPP) survey. In addition, all ships operating under the BWMC are compelled to strictly comply with the D-2 requirements by September 2024.

Since the adoption of the BWMC in 2004, some modest progress has been achieved towards reducing the spread of IAS into foreign waters. For example, in May 2019, it was projected that the magnitude of the BWMS market would increase owing to the 2024 cut-off (Craig, 2019). Additionally, over 70 BWMS received Type Approval from their respective maritime administrations according to the IMO guidelines (Schneider et al., 2018). In the area of capacity building, the successful implementation of the first Global Water Management Project which assisted countries in developing the necessary regulatory framework for addressing issues emanating from invasive species transferred into the ocean through ship's ballast water and the subsequent execution of the GEF-UNDP-IMO GloBallast Partnerships Programme which was aimed at promoting regional cooperation among emerging countries to minimize the effect of IAS introduced through ballast water discharge represent some of the progress made globally toward safe management of ballast water (Tamelander et al., 2010).

Despite the above-mentioned global efforts to minimize the effect of IAS transferred through ballast water discharge from ships, some developing countries are still struggling to ensure stricter compliance with BWMC standards. Ghana is a developing country with two seaports, namely Tema and Takoradi ports, and approximately 85% of its bulk trade is carried by sea (Ansah, Obiri-yeboah, and Akipelu, 2020). With the recent expansion of both ports, it is anticipated that the numbers and sizes of ships being received at these ports are likely to increase considerably, thus translating into a potential introduction of IAS into the marine environment via the release of ballast water and sediments.

Although Ghana ratified the BMWC in 2015, key issues yet to be interrogated by scholars in the maritime sector of Ghana are the challenges hampering effective compliance with the BWMC and how the challenges could be managed to ensure safe and sustainable shipping. This is because there is insufficient research evaluating the implementation of BWMC in Ghana leading to the inability of stakeholders to identify the challenges and find appropriate solutions to them. On the contrary, identifying the challenges and finding appropriate solutions to them guarantee that limited resources are applied efficiently to achieve safe and sustainable shipping while consolidating environmental gains chalked so far.

Thus, investigating the challenges confronting BWMC implementation can help regulators, Ghanaian shipping companies, and other stakeholders to appreciate the factors affecting the progress of BWMC in Ghana. The results of this research can be useful to maritime stakeholders in other West African countries facing similar challenges. Based on this context, a literature review of scientific and technical papers was conducted and questionnaires were also used to assess stakeholder's insight into BWMC in Ghana. Information obtained from the literature review together with that from domain experts and other stakeholders were compared and contrasted to identify the challenges. Subsequently, appropriate solutions to overcome the identified challenges were proposed.

2.0 Literature review

To gain deeper insight into the study, recent scholarly work on published on ballast water from 2020 is briefly reviewed. In considering the literature on ballast water regulations and policy review, Wang et al. (2020) combined a shipping cost approach and a global economic approach to assess the effect of BWM laws on international trade, shipping and the world economy. The shipping cost approach estimated the variation in transport cost due to stricter ballast water regulations while the economic approach focused on external factors with the potential to impact the shipping sector in international and national economies. Outinen et al. (2021) summarized the various exceptions and exemption alternatives under BWMC through the review of case studies. The purpose of the study was to aid regulators and shipping managers in conducting exceptions and exemption analyses of the various ports and shipping routes under their control. Kim et al. (2022) through the use of surveys and interviews provided state-of -the-art information on how Korean shipping companies can respond to BWMC. The study further provided a clearer understanding of the plans and strategies for responding to the BWMC by determining the appropriate treatment options and modifications that can be used by Korean shipping companies. Kurniawan et al. (2022) in a review paper focused on the potential concerns arising from on-dock systems fitted on some ships. The review indicated that treatment methods such as chlorination, ozonation, and oxidation are the commonly used methods for treating ballast water on-dock. The review further pointed out three toxic acid compounds classified as disinfection by-products (DBPs) with concentrations greater than are 10 µg/L are released as results of the chemical treatment of ballast water. Sayinli et al. (2022) presented a thorough review of the progress and the barriers impeding the treatment of ballast water. The review covered topics like types of ballast water treatment systems (BWTS), inactivation mechanisms taking into water conditions, and the merits and demerits of BWMS. The review provided stakeholders with detailed information to assist in the selection of BWTS. Wang et al. (2022) looked at the likely policy alternatives for BWM in the Mediterranean Sea. The study further helped to appreciate the dynamics and risks relating to the spread of species mediated by ballast water in the region. The findings indicated that from 2012 to 2018, Gibraltar, Suez, and Istanbul continued to be high-risk ports even though they serve as hub ports.

Focusing on BWTS assessment and selection, Bailey et al. (2022) assessed the ballast water discharges from 14 different BWMS from 29 ships arriving in Canada between 2017 – 2018. The objective of the study was to determine whether BWMS meets the D-2 standards (organisms ≥ 50 µm). The outcome of the study indicated about 48% of the samples tested exceeded the D-2 standard. Sezer et al. (2022) combined Dempster-Shafer theory and failure mode effects and criticality analysis to conduct a risk assessment on BWTS on board ships. The result of the study was useful to Port State Control officers, compliance officers, Health, safety, and environmental officers, ship crew, and others in assessing the potential risk associated with the failure of BWMS on board ships. Ye et al. (2022) studied the effective ways to manage the challenges that will be associated with ballast water discharge if Japan releases 1.3 million tons of stored radioactive water from the Fukushima Daiichi Nuclear Power Plant. Bradie et al. (2023) using empirical data investigated the potential risk management strategies for non-native organisms transferred through the discharge of ballast water from vessels using the bypassed treatment methods. Chen et al. (2023) combined the fuzzy analytical hierarchy process (FAHP) and TOPSIS as a decision support framework to help shipowners and original equipment manufacturers (OEMs) select appropriate BWMS.

Focusing on sequencing, culturing, and testing, Tolian et al. (2020) evaluated the existence of heavy metals in ballast water found in tanker ships calling at the Port of Bushehr in the Gulf of Persia before and after the implementation of the BWMC. Wang et al. (2020) investigated the effect of holding time on the potential distribution of pathogens presence in ballast water. The results of the study indicated that the abundance of potential pathogens such as Pseudoalteromonas reduces significantly in ballast water held for a longer time than when it is held for a short time. In addition, Bacteroides vanishes in ballast water held for a long time while pathogenic species such as Arcobacter, Aeromonas, Enterobacter, and others survive in ships with long ballast water holding times. Gollasch and David (2021) provided test results of biological and abiotic parameters of 97 controlled ballast water tests over 10 years. The results showed a significant decline in ballast water organisms during the early days of holding up ballast water in tanks. The results further indicated that about 82.5% of onboard tests satisfy the IMO standard for ballast water uptake. Casas-Monroy and Bailey (2021) using information collected from ships arriving in Canada from 2017 – 2018 concluded that the use of BWMS together with BWE has the potential to significantly reduce the transfer of phytoplankton species through ballast discharge compared to those managed by BWE only. Lv et al. (2020) investigated the presence of antibiotic resistance genes (ARG) found in ballast water and their impact on ocean organisms and the environment. The analyzed ballast water data was collected from 28 vessels operating between Shanghai and Jiangyin and the results showed that ARGs were significantly present in 16S rRNA and intI1 genes of the collected ballast water samples. Thus, it was concluded that ballast water was a potential pathway for the spread of ARGs into the ocean. Bradie et al. (2021) compared the results of onboard treatment systems together with the open sea exchange method to that obtained from onboard treatment only through the modeling of different non-native zooplankton introduced into different habitats in Canada through ballast water discharge. The study suggested that a combination of onboard treatment plus open sea exchange will be an effective strategy to minimize the movement of non-native species into new habitats. Salleh et al. (2021) using the16S rRNA amplicon sequencing examined the bacteria diversity and pathogens presence in ballast water discharged at Tanjung Pelepas Port, Malaysia. The study further provided critical information to improve the ballast water guidelines in Malaysia. Hasanspahić et al. (2022) analyzed ballast water discharged in the Port of Ploˇce (Croatia) according to the type of ship, age, and the flag state. The analysis showed that about 87% of ballast water discharged in Port of Ploˇce was from general cargo ships and bulk carriers while 70% of the discharged ballast water originated from the Adriatic Sea. Casas-Monroy et al. (2022) analyzed and compared the results from four indicative devices to epifluorescence microscopy using ballast water samples from different climatic and geographical locations. The study concluded that the indicative devices have high degrees of uncertainty when the organism abundance in ballast water samples is lower than the D-2 standards. Lv et al. (2022) investigated the bacterial composition, community, and assembly processes alongside their potential functions using 70 bilge water and soil samples collected from several vessels. The findings demonstrated that whereas Proteobacteria predominated in the ballast water, the bacterial communities in the ballast sediments had a larger diversity. Wang et al. (2022) using 44 samples obtained from 40 commercial ships calling at the Yangshan deep port examined the diversity and abundance of bloom-forming species in ballast water which is a concern for stakeholders in the marine transportation sector. The study concluded that harmful bloom-forming species are more abundant in ballast water uptake from coastal waters than that from the open seas. Yang et al. (2022) found Deferribacteres, Actinobacteria, Bacteroidetes, and Proteobacteria as the four dominant phyla in the bilge water of 10 ships. Chen et al. (2023a) evaluated the performance of flow imaging microscopy (FlowCAM) as a tool to examine the abundance, size, and classes of organisms present in ballast water samples. Similarly, Chen et al. (2023b) applied FlowCAM to detect phytoplankton during land-based and onboard testing and FlowCAM was found to underestimate the abundance of some particles compared to other tools such as fluorescence microscopy. Duan et al. (2023) used mesoscale experiments to investigate the efficiency of filtration and electrolysis as ballast water treatment methods. Drillet et al. (2023) verified the compliance of ballast water discharge to the D-2 standard during the commissioning test of newly built ships. Results obtained from 676 biological test data indicated a significant improvement during 2019 - 2022. Feng et al. (2023) using 28 ballast water samples obtained from 28 vessels with 20 different treatment methods arriving in Shangai during 2020 -2022, investigated the compliance of the different treatment methods based on the D-2 standard. The results of the study indicated approximately 7.1% of the samples did not conform to the D-2 standard, although treatment systems installed on LNG and container ships obtained 100% compliance with the D-2 standard. Lu et al. (2023) examined a sequential succession of bacterial and microeukaryotic communities' compositions, functional groups, and assembly processes in a simulated microcosm experiment conducted on ballast water. The results showed that during the initial period, there were significant differences in the diversity and compositions of the bacterial and microeukaryotic communities. Lv et al. (2023) investigated the bacterial pathogen's makeup, abundance, and relationship to indicator microorganisms assessed in ballast water and sediments. The results identified Rhodococcus erythropolis, Bacteroides vulgatus, and Vibrio campbellii as dominant pathogens in ballast water, while Pseudomonas stutzeri, Mycobacterium paragordonae, and Bacillus anthracis as dominant in ballast sediments. Seridou et al. (2023) collected seawater samples from a port located in Chania, and Crete, Greece, and compared the disinfection capacity of ozone nanobubbles (OzNBs) to other traditional ozone disinfection methods.Xiao et al. (2023) assessed the impact of filtration and real-time ultraviolet irradiation treatment methods on bacteria and pathogens found in ballast water uptake from fresh water.

The West African region represents a major maritime trading hub in Africa, nonetheless, a significant number of countries in this region are facing challenges in complying with the BWMC. As can be seen, despite the important contribution to ballast water research from other geographical locations, very little scholarly work can be found in the West African region. So, inspired by this, this paper contributes to global ballast water research by employing scientific approaches to identify challenges hampering the implementation of the BWMC in Ghana while proposing suitable solutions to overcome the challenges. Moreover, the majority of existing studies on ballast water focused on addressing BWMS, and testing issues with very few studies discussing the challenges developing countries are facing in implementing the BWMC.

4. Research Methodology

4.1 Design of questionnaire survey

In order to investigate the challenges that exist within the scope of the BWMC among stakeholders in Ghana, a survey was conducted among the crew on international and local ships, port state control officers, environmental protection officers, port managers, academics, and Certificate of Competency (CoC) students from the RMU. These respondents were selected for the study due to their high level of experience and knowledge about the subject area and thus brought expert opinion to the study within the Ghanaian context. The respondents were identified through a literature review alongside interactions with other colleague researchers and industry players.

The survey questions were designed based on the theoretical insight provided via literature review (Endresen et al., 2004; Jing et al., 2012; Liu et al., 2019). The questions asked were geared toward the institutions responsible for the implementation of the BWMC in Ghana, the challenges associated with the execution process, the enforcement of ship BWM strategies, and how regulatory authorities conduct inspections on incoming vessels reporting at the ports.

Several meetings were held by the authors to refine the questionnaire for clarity, in order not to deviate from the core objectives of the study. The questionnaires were self-administered and involved closed questions on the five-point Likert scale. A total of 45 questionnaires were distributed, with an approximately 70% response rate.

4.2 Design of semi-structured interview

To further obtain more information about the challenges existing in the implementation of the BWMC in Ghana and investigate the root causes of such challenges, the authors in addition to the questionnaire adopted a semi-structured interview approach. A set of semi-structured interview questions were developed. The interview process provided respondents the opportunity to answer the questions while simultaneously responding to other important questions that were not captured in the questionnaire. The interview questions were divided into five parts including the background of interviewees, challenges related to BWMC implementation, and root causes related to the challenges. The questions involved both open-ended and close-ended questions. The closed-ended questions were suitable for finding the potential challenges faced by the interviewees while the open-ended questions were employed to investigate the root causes of the challenges.

In-depth interviews were conducted with three experts within the maritime industry of Ghana. Two of the interviews were conducted face-to-face while one was by telephone. The interviewees comprised a regulator, port authority staff, and an academic. These experts were selected due to their sufficient relevant work experience and proven research background in the field of ballast water as well as their active involvement in several ballast water initiatives and partnership programs within the sub-region. Although efforts were made to reach out to more experts for interviews to enhance the quality of our analysis, none responded to our invitation.

The interviews focused on obtaining background information about the interviewees, BWMC implementation challenges confronting interviewees, and the root causes of the challenges. The background information collected included the number of years of experience and gender. During the interview, the authors took the time to clarify questions while sometimes probing the answers provided by respondents to seek proper understanding. The answers to the questions were recorded and transcribed and subsequently compiled into a list of challenges, which were further investigated for root causes.

5 Results and discussion

5.1 Questionnaire Survey Results Analysis

The questionnaire was used as a basic tool to investigate the general understanding of ballast BWM-related issues among seafarers. Based on the findings of the questionnaire, about 93% of the respondents demonstrated a fair understanding of the definition and uses of ballast water on ships. However, responses to questions on the management of ballast water were not satisfactory, which indicated that there may be gaps in the implementation of the BWMC in Ghana. For instance, on the question of which authority is responsible for ballast water management in Ghana, it was discovered that about 67% of the respondents could not identify the agencies responsible for BWM in Ghana. Also, about 42% of the respondents did not know about the IMO BWMC while 69% were not aware of the ratification of the BWMC by Ghana. In addition, 100% of the respondents were not aware of whether or not the IMO BWMC has been passed into domestic law in Ghana. On the question of if ever ballast water samples have ever been collected from their vessels by regulators in ports of Ghana? This question was meant for the crew and CoC students sailing on ships that report at Ghana’s ports and 100% of the respondents answered no.

Furthermore, with a mean value of approximately 2 (1 = strongly agree to 5 = strongly disagree), respondents agreed that the D-1 standard of the IMO BWMC is applied for the management of ballast water in Ghana as opposed to the D-2 standard. Again, with a mean value of 2, respondents agreed that there is no sediment reception facility either in the ports or shipyard.

5.2 Analysis of interview results

In comparing the outcome of the questionnaire to the interview process, the latter provided a more detailed picture of the challenges existing in the implementation of BWM in Ghana. A significant amount of good quality information was obtained from the interviewees answering a series of questions as well as sharing their experiences about the implementation of BWMC in Ghana.

5.2.1 Background

The background information about the interviewees was analyzed and the results indicated that all the interviewees were males. Concerning experience, two of the respondents had over 16 years of working experience in their respective roles and had served in different capacities in the maritime sector of Ghana while one had about 11 years of working experience. All the interviewees occupied upper management-level positions in their respective organizations.

5.2.2 Vessel movement in Ghana and other neighboring countries

The question of the number of ships and amount of ballast water being handled in Ghana and other neighboring ports and shipyards in the last five years was to enable authors to identify the magnitude of the problem at hand. Interviewees were unable to provide instant answers to this question and therefore suggested that researchers should follow up with an official request. Two companies responded to the request and the information indicated that from January 2014 – August 2020, a total of 12581 ships called at the Tema Port but no information was obtained on the quantity of ballast water handled by the ships. The percentage share of vessel movement for Tema Port for the period January 2014 – August 2020 is shown in Figure 1. The PSC Tema shipyard, on the other hand, provided information for the year 2019 and the result showed that 39 ships reported to the drydocks, however, there was no information on the quantity of ballast water handled.

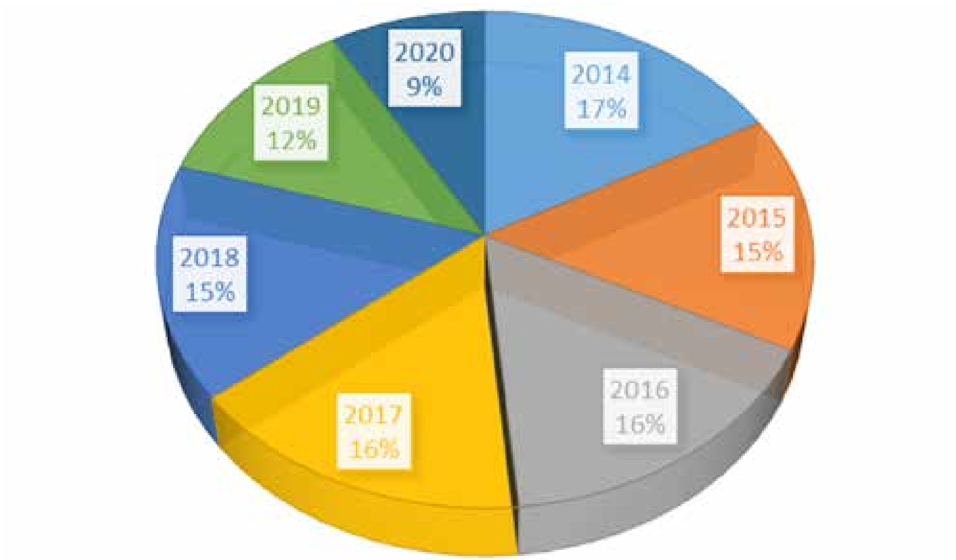

Figure 1. Summary of vessel movement for Tema Port for the period January 2014 – August 2020

5.2.3 Sediment and reception facilities

The results in Table 1 suggest that there is no sediment reception facility sited neither in the shipyard nor the ports. The unavailability of sediments reception facilities/ infrastructure near the shipyard and ports exposes Ghana to the risk of environmental pollution near the shipyard and the ports where sediments from ships' ballast tanks are likely to be handled.

Table 1. Results for "sediment reception facilities" in interviews

Item	Classification	Results (n)
How do vessels handle sediment found in the ballast water onboard in Ghana?	Do ballast water flushing of tanks in deep seas.	0
	Dispose into the shore reception facility	0
	Dispose at drydocks	1
	No idea	2
Has any vessel ever disposed of sediments in Ghana's shipyard?	Yes No	0 3
Are you aware if sediment facilities are closer to the ports in Ghana?	Yes No	0 3
Are you aware if sediment facilities are closer to the shipyard in Ghana?	Yes No	0 3

5.2.4 Human and logistical capacities

As presented in Table 2, the human and technical capacity to handle ballast water and sediments in the ports and shipyards seems inadequate in the context of this research.

Table 2. Results for "human and logistical capacities" in interviews

Item	**Classification**	**Results (n)**
Rating for capacity building projects (1= very inadequate to 5 = very adequate)	1	3
	2	0
	3	0
	4	0
	5	0
Rating for educative activities (1= very inadequate to 5 = very adequate)	1	3
	2	0
	3	0
	4	0
	5	0
Rating for technology transfer (1= very inadequate to 5 = very adequate)	1	3
	2	0
	3	0
	4	0
	5	0

5.2.5 Independent verification

Referring to Table 3, the results indicate that regulators in Ghana have never collected ballast water samples for further testing and analysis to ensure proof and acceptability of existing compliance and monitoring methods is a major gap in the implementation of the BWMC. Moreover, regulators could not identify appropriate laboratories in the country capable of testing and providing accurate and independent results for analyzing ballast water samples (Table 3).

Table 3. Results for "independent verification" in interviews

Item	Classification	Results (n)
Do you have records of gathered samples of ballast water from ships calling at the ports for examination?	Yes No	0 3
Do you know any laboratories in Ghana specifically for testing ballast water samples?	Yes No	0 3
Does Ghana have stricter testing parameters compared to those specified in the G8 guidelines of the BWMC?	Yes No	0 3
Rating the capacity of other biological testing laboratories in Ghana for testing ballast water samples (1= very poor to 5 = very high)	1	No answer provided
	2	
	3	
	4	
	5	

5.2.6 Communication and domestic regulation

Although effective communication and domestic environmental laws are crucial in the management of ballast water, Table 4 shows that there is poor communication between regulators and other stakeholders while domestic legal instruments for the regulation of ballast water are not available in Ghana.

Table 4. Results for "communication and domestic regulation" in interviews

Item	Classification	Results (n)
How often do regulators communicate to other stakeholders concerning information on ballast?	Very often Often Not at all	0 0 2
How often do you receive communication from regulators concerning information on ballast?	Very often Often Not at all	0 0 2
Does Ghana have a domestic legal instrument for BWM?	Yes No	0 3
Has the GMA given Type Approval to any ship, since the ratification of the BWMC?	Yes No	0 3

5.2.7 Ships not meeting D-2 standards

Referring to Table 5, the results from the interview show that a good percentage of ships reporting at the ports in Ghana may not meet the D-2 standard of the BWMC.

Table 5. Results for "ships not meeting the D-2 standard" in interviews

Item	Classification	Results (n)
How do ships discharge ballast water in Ghana?	Use BWT BWE method No de-ballasting	3 0 0
If the BWT method is used, at what nautical should vessels discharge ballast water?	> 200 nm < 200 nm Next to the neighboring port	3 0 0
Rating of Ghana's preparedness toward full compliance of vessels to D-2 standard by 2024 (1= very poor to 5 = very high)	1 2 3 4 5	3 0 0 0 0

5.2.8 Research and development support

Active research support for ballast water-related issues not only ensures the successful implementation of the BWMC but can play an essential role in safeguarding the maritime environment in different countries. Results from Table 6 indicate that support for BWM research and development in Ghana is very poor.

Table 6. Results for "support for research and development" in interviews

Item	Classification	Results (n)
Rating the level of funding support for scientific research into ballast water within Ghana	Very low Low Average High Very high	3 0 0 0 0
Rating the level of joint research and development programs aimed at effective implementation of the BWMC in the West African sub-region.	Very low Low Average High Very high	3 0 0 0 0
Rating level of awareness on BWM issues by stakeholders (1= very poor to 5 = very high	1 2 3 4 5	3 0 0 0 0

The outcome of the interview (Table 7) indicates that Ghana does not have a designated alternative ballast water exchange zone (ABWEZ), which is a major deficiency.

Table 7. Results for "alternative ballast water exchange zone" in interviews

Item	Classification	Results (n)
Does Ghana have an alternative ballast water exchange zone for ballast water exchange?	Yes No	0 3

5.3 Discussions of challenges and gaps

5.3.1 Lack of sediment reception facilities at the shipyard and ports

The provision of sediment reception facilities is essential for the holistic management of ballast water. In light of these circumstances, Article 5 of the BWMC requires that parties to the convention must identify reception facilities to serve as a safe and environmentally friendly means of disposing of sediments from ballast tanks. According to the IMO GloBallast Monograph Series No.23 report, the siting of sediments reception facilities must be closer to a shipyard, since the cleaning of sediments, as well as ship repairs and modifications, are carried out in the shipyards. In countries where such shipyards are unavailable, then sediment reception facilities should be cited in exiting ports or near existing ports.

The Tema and Takoradi harbors are the two main port facilities in Ghana under the control of GPHA while the Tema shipyard is the only shipyard in the country. The Tema shipyard is among the largest shipyards in Africa, located close to the port. Nonetheless, referring to Table 2 and the questionnaire's lack of sediment reception facilities at the ports and shipyards in Ghana was identified as a major deficiency in the implementation of the BWMC.

5.3.2 Inadequate human and logistical capacity to deal with ballast water-related issues

The maritime industry in Ghana over the years has built some level of human and technical capacity to handle various sectors of industry including the environment (Nyarko et al., 2014). Stakeholders such as GPHA and GMA through the GEF-UNDP-IMO GloBallast Partnerships Project and their initiatives have trained GPHA staff and PSC officers to be aware of the BWMC. Additionally, GPHA also developed further capacity in conducting the port biological baseline survey (PBBS) at the port of Tema. As presented in Table 2, the human and technical capacity to handle ballast water and sediments in the ports and shipyards seems inadequate in the context of this research. This is because the human and technical capacity required for the implementation of the BWMC goes beyond training stakeholders to be aware of the dangers of IAS and conducting PBBS. For instance, cleaning, inspection, repair, and maintenance of ballast tanks are likely to be carried out during drydocking. In line with this, personnel at Tema shipyard should possess the right skills by demonstrating a proper understanding of the use of technology and technical concepts required for cleaning, inspection, repair, and maintenance of ballast tanks. Currently, the process of cleaning, inspecting, repairing, and maintaining ballast tanks during drydocking is done manually in Ghana. The manual cleaning, inspection, repair, and maintenance of tanks is labor-intensive, expensive, and also exposes workers to increased health risks (Christensen et al., 2011). The idea of using robots to perform cleaning, inspection, repair, and maintenance of ballast tanks is increasingly becoming popular in the maritime industry. However, a job of this nature requires workers with a deeper understanding of Artificial Intelligence (AI) and other advanced analytical tools. The challenge of workers in the Tema shipyard applying new tools and technologies to support the cleaning, inspection, repair, and maintenance of ballast tanks exists.

5.3.3 Lack of independent verification

To stop the spread of IAS through ship ballast water, accurate test findings from independent testing institutions are essential. As per the results in Table 3, ballast water compliance inspection in Ghana solely relies on the testing parameters specified in the G8 guidelines. According to David (2013), the compliance control requirements in the G8 guidelines are not robust enough to produce acceptable and accurate results for ballast water discharges in challenging waters. In Brazil, records indicate that there have been some violations with the BWE method, which was revealed as a result of the inconsistencies identified during the analysis of information in the Ballast Water Records Forms (BWRF) submitted to PSC officers (Pereira et al., 2016). Thus, regulators must be prepared to monitor compliance by occasionally collecting samples and conducting detailed sample analyses to ensure independent verification. However, the results from the interview and questionnaire indicate (see Table 3) that Ghana lacks the appropriate laboratories to provide independent tests and verification under the BWM regulations.

5.3.4 Lack of communication from regulators to other stakeholders and domestic regulations

Establishing improved channels of communication between regulators and their stakeholders plays an important role in the successful implementation of the BWMC by IMO member countries (Caribbean Environment Programme, 2012). The GMA being the regulator must regularly update stakeholders on both major and minor changes in the BWM regulations at the international, regional, and national levels. As indicated in Table 4, the GMA does not provide the other stakeholders in the maritime sector of Ghana with regular updates on amendments made to BWM regulations at all levels.

Moreover, aside from the ratification of the BWMC in 2015, it appears that very little attempt has been made to develop a well-established domestic ballast water regulatory framework (Table 4). This means that GMA cannot provide updates on local ballast water-related issues. Domesticating the ballast regulatory regime will empower the GMA to strictly enforce discharge standards, thereby minimizing the introduction of IAS in Ghanaian waters.

5.3.5 Ships not meeting the D-2 standard

The BWMC outlines two different sets of management regulations. Regulation D-1 is also referred to as the Ballast Water Exchange (BWE), which stipulates that a minimum of 95% of ballast water needs to be exchanged by ships conducting BWE while regulation D-2 outlines requirements for the removal and destruction of biological organisms in ballast water. Furthermore, regulation B4 of the convention indicates that ships employing D-1 must conduct BWE 200 nautical in open seas and at a water depth of 200 m from the nearest shore. For details on regulation D-2, readers can refer to the following documents (IMO, 2009, 2017a). To meet the D-2 standard, ballast water treatment technologies must be installed on ships.

Although regulation D-1 is presently used in many countries, Liu et al. (2019) indicated the big scale shipping companies consider the regulation as an interim measure and hence efforts must be intensified for the acceptance of the provisions outlined in D-2 regulation, since they are more stringent than that of D-1. The IMO plans to gradually phase all ships onto the D-2 standard by 2024 (SAFETY4SEA, 2019) and thus maritime administrations in many countries, as well as other stakeholders in the maritime industry are actively involved in this process, however, referring to Table 5 and the outcome from the questionnaire as indicated in Section 5.1, majority of ships reporting at the ports of Ghana do not meet the D-2 standard of the BWMC and therefore failure on the part of regulators and other stakeholders to actively participate in this process has the potential of creating lack of enforcement of BWMC in Ghana by 2024 since PSC officers will lack the requisite technical capabilities to enforce the provisions of the D-2 standard by 2024.

5.3.6 Lack of support for research and development (R&D) in the area of BWM in Ghana

Ghana appears to be lagging in the area of ballast water research and development. This is due to policymakers and stakeholders not placing a premium on the marine environment and its resources. Hence, failure to allocate funding support for marine environment research may have contributed to the slow handling of ballast water challenges in Ghana. Based on the results in Table 6, it was realized the level of support toward research, innovation, and development in ballast water management is very low. Moreover, a review of scientific published work indicated that only two works have been published on BWM management in Ghana. This includes one scientific peer-reviewed article concentrating on selecting the appropriate BWM system for shipowners in Ghana (Animah, 2018) while the other work is the national ballast water management strategy (Nyarko et al., 2014).

5.3.7 Lack of established alternative ballast water exchange zones (ABWEZ)

Goldsmit et al. (2019) indicated that safety concerns and environmental conditions can prevent BWE by ships outside the 200 nautical miles zone. If such a situation arises, ships must be authorized to perform BWE in an alternative ballast water exchange zone (ABWEZ) within the country. Regulation B4 of the convention also provides countries the opportunity to establish ABWEZ with neighboring countries for ships on short-distance voyages in shallow waters. The outcome of the interview (Table 7) indicates that the majority of the ships received at Ghana's ports employ the D-1 standard to manage ballast water. However, Ghana does not have designated areas as ABWEZ.

5.4 Root causes of challenges

After identifying the challenges and gaps in the implementation of the BWMC in Ghana, the authors proceeded to investigate the root causes of these challenges. To determine the root causes, interviews were further conducted among the experts together with a review of institutional documents. In what follows, the root causes contributing to the gaps in the implementation of the BWMC in Ghana are discussed.

The GMA is the regulatory body charged with the responsibility to oversee the implementation of the BWMC in Ghana. However, the first root cause identified was the seemingly unconcerned attitude of the authority to ballast water-related issues. Challenges such as the absence of onshore reception treatment facilities, lack of designated ABWEZ, lack of independent verification, and ships not meeting the D-2 standards can all be attributed to the weak and unconcern attitude of the GMA as far as ballast water-related issues are concerned. This was corroborated in our interview when one of the experts indicated that the GMA has failed to prioritize the issues of IAS and their impact on the environment. Hence, there is no stricter adherence to the BWMC in Ghana.

The lack of existence of comprehensive biological baseline data for seaports and other sensitive areas in Ghana was identified as another root cause. As revealed by the study, since the first PBBS conducted in Tema port, there is no record of a review of the PBBS or new information on baseline surveys in other sensitive areas of Ghana. The paucity of biological baseline data can also be attributed to the lack of sampling and testing protocols in Ghana.

The contribution of ballast water discharge to marine pollution and its impact has been noticeable in the maritime industry, however, in Ghana the level of public awareness of ballast water pollution and its impact is extremely low among the public. This is because the media in Ghana plays a key role in setting the agenda on the environment for public discussion. However, during the study, it was revealed that there is an absence of media reportage on marine pollution compared to freshwater bodies' pollution as a result of illegal mining. In the case of freshwater bodies' pollution by illegal mining, stakeholders including civil society organizations, media, and the public brought unbearable pressure on the government to call for attitudinal change and reforms (Agbozo and Spassov, 2019; Frimpong, 2019). Nevertheless, in the case of marine pollution, since it has not gained prominence in the media space, there is no public pressure on the government, regulators, and the public to call for reforms.

The importance of marine pollution prevention has not been on the front burner of national politics in Ghana, thus making it unimportant and not on the table of national policy. It is therefore not surprising that the results of the interview indicated that the Tema ports and the drydocks did not have records of the amount of ballast handled by these two critical national entities. This was evident in our interview where one of the interviewees opined that "he wonders how many of our policymakers are familiar with ballast water-related issues ".

There was also a general acceptance among the interviewees that there is a lack of technical and financial assistance for agencies responsible for marine environmental protection in Ghana, which was identified as one of the critical causes of the gaps in the implementation of the BWMC. Technical and financial assistance will ensure that adequate resources are allocated for capacity building for BWM. The research output on ballast water from GMA and other institutions in Ghana is woefully inadequate. For example, there is no proper profiling of IAS and their pathways in Ghana and this may be attributed to the lack of technical and financial support for agencies responsible for environmental protection.

Lack of proper coordination among state agencies responsible for protecting the marine environment in Ghana was identified as another root cause of the gaps existing in the implementation of the BWMC. For example, the Marine Pollution Act 2016 (Act 932) 2016 proposes a proper framework for oil spill response among state agencies, however, on BWM, the Environmental Protection Agency (EPA) which is the foremost governmental agency responsible for monitoring and enforcement of environmental regulations and guidelines plays a very little role as far as the implementation of BWMC is concerned.

6. Ways forward

6.1 Pushing ballast water issues onto the policy agenda

Pushing ballast water issues onto to policy agenda could surely be one of the key approaches to filling the implementation gaps in the BWMC in Ghana. This can be achieved by stakeholders in the maritime industry getting policymakers to regard the prevention and control of harmful non-indigenous aquatic invasive species in Ghana as of one the critical national environmental issues. According to Wan et al. (2018), pushing ballast water issues onto the policy agenda requires a high level of public awareness through the engagement of the media. As has been already highlighted, public awareness on the degree of damage to the marine ecosystems caused by harmful non-indigenous aquatic species is practically non-existence in Ghana, therefore stakeholders in strong collaboration with the media must raise the level of public awareness on the dangers of discharging untreated ballast water into the sea. Also, stakeholders can collaborate to solve the challenge of low-level public awareness of ballast water issues by putting in the public space more accurate and researched scientific information on ballast water.

6.2 Effective monitoring and enforcement

Currently, the monitoring and enforcement of ballast water regulations are the responsibility of the GMA which is under the MOT. The MOT is responsible for the road, ports, and inland water transportation, and thus the agencies under MOT do not have the necessary capacity and know-how to administer environmental-related matters such as monitoring and enforcement of ballast water regulations. Hence, the seemly indifferent attitude of GMA toward the enforcement of the BWMC in Ghana. The ineffective monitoring and enforcement of the BWM regulations may mean that violation of the BWMC may have happened in the Ghanaian jurisdiction unnoticed.

To overcome this challenge, the task of ensuring full compliance with the BWMC by ships calling at the ports of Ghana should go beyond the GMA. Other state agencies such as the EPA and Ghana Standard Authority (GSA) when drafted into the national ballast water strategy can ensure rigorous compliance with the BWMC in Ghanaian waters. However, a clear definition of mandate should be spelled out, in order not to create overlaps in the enforcement regimes of these agencies, which can lead to loss of efficiency in the discharge of their duties.

Moreover, the GMA must be equipped with the necessary expertise to detect violations of the BWMC by ships. This will mean that stakeholders must invest in regular capacity building of GMA personnel and build standard testing laboratories in the country.

6.3 Reform and attitudinal change by regulators

Reform and attitudinal change by stakeholders responsible for the implementation of the BWMC are critical in the effort to fill the implementation gaps discussed above. The weak and unconcern attitude of the regulator toward stricter implementation of the BWMC, if not worked on will result in the absence of a comprehensive plan to deal with the implementation challenges confronting Ghana. Again, the politics of Ghana are dominated by indicators such as economic, youth unemployment, education, and health rather than marine environment issues that save the country millions of dollars in revenue and drive maritime trade. This explains why since the ratification of the BWMC in 2015, Ghana has not passed the BWMC into domestic law. Thus, reform and attitudinal change by politicians and other stakeholders will ensure that ballast water-related issues attract the necessary attention from policymakers and ensure that the effects of damage caused by the discharge of untreated ballast water into Ghanaian waters are minimized.

6.4 Creating a forum for dialogue on ballast water-related issues

The commencement of commercial oil production offshore Ghana in 2010 as well as the recent port's expansion projects have generated a lot of discussion and interest among key maritime industry players. These activities which have occurred during the last decade, have the potential to increase the number and sizes of ships being received in Ghana's ports. Thus, the potential increase in the number of ships being received at the ports can result in a direct increase in ballast water violations. Although key stakeholders in the maritime industry are aware of the potential damage ballast water discharge can have on the economy and environment of Ghana, post the ratification of BWMC in 2015, proper forums in the form of workshops or conferences involving interested parties have not been created to deliberate on ballast water-related matters. Creating such a forum for discussion among stakeholders interested in BWM is one of the best ways to assess the preparedness of the country to prevent the spread of IAS while it can also serve as a platform to share internationally recognized best practices. In Taiwan, a workshop involving multiple stakeholders resulted in the development and adoption of PSC procedures for ballast water management (Liu et al., 2019).

6.5 Establishment of ballast water research and development (R&D) fund

Research and development (R&D) has played an essential role in the search for technical and economically viable solutions applicable to ships to prevent the spread of IAS. For example, the Canadian Shipowners Association (CSA) 2015 established a research and technical evaluation fund with initial money of $1.5 million for the search of ballast water technology on the Great Lakes and St. Lawerence Waterway.

In order to fill the gap of lack of technical and financial support for agencies and lack of adequate biological data, a dedicated funding source for strengthening the effort of ballast water-related research is required in Ghana. The establishment of a research fund will not only grow the ballast water research community in Ghana but can also ensure that adequate and quality data are available to support evidence-based decision-making on ballast water-related issues. During the study, it was evident that inadequate data on ballast water discharge exists in Ghana, which means some violations of the BWMC may have gone unnoticed.

The establishment of a research fund will ensure that good quality data is always available, which has the potential to pave the way for public and private sector collaborations in finding technical and economically feasible solutions to ballast water-related challenges in Ghana.

6.6 Regular awareness training on ballast-related issues by stakeholders

Any updates, amendments, and changes in ballast regulations must be well understood, communicated, and accepted by all stakeholders. It is against this background that regular and effective awareness training for stakeholders on regular basis is increasingly becoming important in the maritime industry. Regular awareness training offers stakeholders the platform to learn from best practices and share operational experiences. Hence awareness training on ballast water-related issues should be part of the annual budget of shipowners and regulators in Ghana.

6.7 Learning lessons from other countries

Learning lessons from countries that have succeeded in the smooth implementation of the BWMC and applying those lessons in the Ghanaian context is a key strategy to minimize the damage caused by IAS in Ghana. For future mitigation strategies, Ghana should learn good lessons from countries that have integrated the technical standards in the BWMC into their domestic regulations. For example, some countries have instituted proper monitoring systems to regularly update PBBS information for risk assessment. It will therefore be appropriate that Ghana learn from these countries by taking all the necessary steps to conduct comprehensive PBBS for all ports, with follow-up surveys every 3 to 5 years to update records.

7.0 Conclusions

The results of this study indicate that even though Ghana ratified the BWMC in 2015, the maritime sector recognizes that there are still challenges hampering the effective implementation of the BWMC. However, very little effort has been made by stakeholders to employ scientific approaches to identify the challenges and propose the necessary solutions. Hence, this study combined two established scientific methodologies to identify seven challenges hampering the effective implementation of the BWMC in Ghana and propose appropriate solutions to overcome the challenges and their root causes, making this study one of the key contributions to BWM research in Ghana.

The seven identified challenges are lack of sediment reception facilities at the shipyard and ports, inadequate human and logistical capacity to deal with ballast water-related issues, lack of independent verification, lack of communication from regulators to other stakeholders on ballast water-related issues, ships not meeting the D-2 standard, lack of support for research and development (R&D) in the area of BWM in Ghana and lack of established alternative ballast water exchange zones (ABWEZ).

To overcome the identified challenges and their root causes, seven emerging solutions were proposed and discussed. These include the provision of onshore reception treatment facilities, creating a forum for dialogue on ballast water-related issues, designating areas as ABWEZ, the establishment of ballast water research and development (R&D) funds, regular awareness training on ballast water-related issues by stakeholders, limiting ships conducting BWE in Ghanaian waters and a well-established port biological baseline survey (PBBS).

The results of this study are useful to governments and other stakeholders in developing strategies to comply with the provisions of the BWMC. Nonetheless, it should be recognized that the findings are specific to the maritime sector of Ghana, and therefore other studies must be conducted in other West African countries as future research work.

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Climate Change Adaptation in Maritime Transportation: Towards Enhancing Resilience and Sustainability in the Global Supply Chains

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ABSTRACT

Maritime transportation, the backbone of global trade, faces increasing threats from climate change, including rising sea levels, extreme weather events, and shifting ocean currents. These challenges disrupt port operations and shipping routes, jeopardizing the stability of global supply chains. This study explores strategies to enhance resilience and sustainability in maritime transportation, focusing on Dar es Salaam and Malindi ports, which are critical trade hubs but highly vulnerable to climate impacts. By integrating green technologies, climate-resilient infrastructure, and circular economy practices, this study highlights innovative approaches to mitigate climate risks while reducing the environmental footprint of maritime operations. Using a mixed-method approach, this study draws on qualitative and quantitative data to analyze adaptation strategies, including digitalization, stakeholder collaboration, and advanced forecasting systems. The findings underscore the importance of public-private partnerships, financial incentives, and inclusive policymaking in overcoming barriers such as high costs and regulatory gaps. This study provides actionable insights and evidence-based recommendations for policymakers, port authorities, and industry stakeholders, offering a robust framework for building a resilient and sustainable maritime sector. By addressing both immediate and long-term challenges, the maritime industry can safeguard global trade, align with international sustainability goals, and ensure its viability in a rapidly changing climate.

Keywords*: Maritime Transportation, Sustainability, Resilience, Climate Change*

1.0 Introduction

Maritime transportation is a cornerstone of the global economy, responsible for facilitating over 80% of international trade by volume (Ng et al., 2018). This sector enables the movement of raw materials, intermediate goods, and finished products across continents, underpinning the stability of global supply chains. The economic significance of shipping cannot be overstated, yet it is increasingly vulnerable to climate change. Rising sea levels, extreme weather events, and shifting ocean currents disrupt maritime operations, creating challenges for shipping routes and port infrastructure. These disruptions have cascading effects on global supply chains, threatening their reliability and the economic stability they sustain (Lee et al., 2019). As maritime transportation remains indispensable for global trade, addressing these vulnerabilities has become an urgent priority.

The impacts of climate change on maritime transportation are multifaceted, affecting the sector's infrastructure, operations, and environmental footprint. Extreme weather events, including hurricanes, typhoons, and storm surges, have caused significant damage to port facilities, while flooding and coastal erosion threaten the sustainability of low-lying ports (Er Kara et al., 2021). These events lead to delays, increased operational costs, and reduced safety standards. Rising sea levels and ocean temperatures also contribute to altered shipping routes, potentially increasing fuel consumption and emissions. The interconnected nature of global trade means that disruptions in one part of the supply chain can ripple through others, amplifying economic vulnerabilities. Addressing these challenges requires a comprehensive strategy focused on building resilience and reducing the sector's environmental impact.

At the same time, maritime transportation is a significant contributor to global greenhouse gas emissions, accounting for approximately 2.89% of total emissions annually (Ng et al., 2018). The sector's reliance on fossil fuels, coupled with the increasing demand for shipping services, exacerbates its environmental impact. In response, policymakers and industry stakeholders are championing the adoption of sustainable practices such as green shipping technologies, energy-efficient vessels, and alternative fuels (Lee et al., 2019). These initiatives align with global sustainability goals, including the United Nations Sustainable Development Goals (SDGs) and commitments under the Paris Agreement. However, the sector's transition to greener operations must be integrated with climate resilience measures to ensure its adaptability to emerging risks.

The urgency of addressing climate change in maritime transportation is reflected in the growing emphasis on sustainability and resilience. Sustainable shipping practices, such as green supply chain integration and circular economy models, are gaining traction. These practices not only reduce the sector's carbon footprint but also enhance its ability to withstand climate-induced disruptions. Resilient infrastructure, including ports designed to endure extreme weather events and rising sea levels, is crucial for maintaining uninterrupted operations. Digitalization and automation further contribute to operational efficiency, enabling shipping companies to optimize routes, monitor climate risks, and improve decision-making processes (Er Kara et al., 2021). Together, these measures ensure that the maritime sector can adapt to climate challenges while supporting the continuity of global trade.

Despite these advancements, significant barriers impede the sector's ability to implement climate adaptation strategies effectively. Financial constraints remain a critical obstacle, as the upfront costs of upgrading infrastructure, adopting green technologies, and training personnel can be prohibitive. Moreover, limited access to climate data and technical expertise hinders the development of targeted adaptation measures. Regulatory uncertainties further complicate the landscape, delaying the adoption of comprehensive strategies (Ng et al., 2018). These challenges highlight the need for coordinated efforts among industry stakeholders, governments, and international organizations to create an enabling environment for sustainable and resilient maritime operations.

This study aims to explore sustainable shipping practices and climate adaptation strategies to enhance resilience in maritime transportation systems. By systematically reviewing existing literature, the research identifies best practices that contribute to building a climate-resilient maritime sector. The findings provide insights into how the sector can balance its dual objectives of achieving sustainability and resilience while ensuring the efficiency and reliability of global supply chains. These strategies are vital not only for safeguarding the industry's long-term viability but also for supporting global economic stability amidst a changing climate.

The transition towards greener and more resilient maritime transportation requires a unified approach that integrates technological innovation, policy support, and stakeholder collaboration. Investing in renewable energy sources, resilient infrastructure, and advanced digital systems can mitigate the impacts of climate change while reducing the industry's environmental footprint. Collaboration across public and private sectors further accelerates the adoption of climate adaptation strategies, enabling the sector to navigate complex challenges effectively (Lee et al., 2019). By fostering a culture of innovation and resilience, the maritime industry can emerge as a leader in sustainable practices and a critical contributor to global sustainability agendas.

The maritime sector must address the dual challenges of climate resilience and sustainability to ensure its continued relevance and efficiency in the global economy. Enhancing the resilience of ports and shipping operations, adopting low-carbon technologies, and integrating climate risk management into logistics systems are critical steps towards this goal. This study contributes to the ongoing discourse by providing actionable insights and evidence-based recommendations for building a sustainable and resilient maritime transportation system. Through these efforts, the sector can continue to facilitate global trade while minimizing its environmental impact and adapting to the realities of a changing climate.

2. Literature Review

2.1. Theoretical Underpinnings

This study is grounded in two foundational theories: Resilience Theory and Sustainability Theory. These theories offer complementary perspectives on how maritime transportation can adapt to the challenges posed by climate change while maintaining efficiency and supporting global trade. Resilience Theory focuses on a system's ability to absorb disturbances, adapt to changes, and recover from shocks without losing its core functions (Walker et al., 2004). This perspective is particularly relevant to the maritime industry, which faces increasing risks from extreme weather events, rising sea levels, and regulatory changes. Sustainability Theory, on the other hand, emphasizes the integration of economic, environmental, and social dimensions to promote balanced growth and long-term stability (Brundtland, 1987). Together, these theories provide a comprehensive framework for enhancing resilience and sustainability in global supply chains, ensuring operational continuity in the face of environmental uncertainties.

2.2. Resilience Theory

Resilience Theory, developed by Walker et al. (1973), provides a framework for understanding how systems such as ecological, social, and economic networks respond to disruptions. The theory posits that systems can absorb shocks, maintain core functions, and adapt to changing conditions without collapsing into an undesirable state (Folke, 2006). It highlights the importance of feedback loops, learning, and evolution in enhancing adaptability. In the context of maritime transportation, Resilience Theory is instrumental in addressing the sector's vulnerabilities to climate change. Extreme weather events such as hurricanes and typhoons, combined with rising sea levels, pose significant risks to port infrastructure, shipping routes, and operational efficiency (Becker et al., 2018).

By applying Resilience Theory, the maritime industry can proactively identify stressors, thresholds, and tipping points, enabling stakeholders to mitigate risks and enhance operational stability. For example, ports in low-lying areas can adopt climate-resilient infrastructure, such as elevated platforms and flood barriers, to minimize disruptions caused by storm surges and flooding (León-Mateos et al., 2021). Additionally, resilience thinking supports the development of adaptive logistics systems that can respond dynamically to shifting weather patterns, ensuring the continuous flow of goods through global supply chains (Er Kara et al., 2021). The theory underscores the need for ongoing learning and innovation to build long-term resilience, making it a vital tool for addressing the challenges facing maritime transportation.

2.3. Sustainability Theory

Sustainability Theory, introduced by Brundtland in 1987, advocates for a balanced approach to development that integrates economic growth, environmental protection, and social equity. The theory asserts that these dimensions are interconnected and must be addressed collectively to achieve long-term stability (Berkes & Folke, 1998). In the context of maritime transportation, Sustainability Theory provides a lens through which the sector can balance its critical role in global trade with the need to minimize its environmental footprint. This is particularly important given the industry's contribution to greenhouse gas emissions and its vulnerability to climate change impacts (Ng et al., 2018).

Sustainability Theory supports the design of systems that can adapt to climate-induced changes while maintaining their functionality. For example, the adoption of alternative fuels such as liquefied natural gas (LNG) and biofuels can significantly reduce the sector's carbon emissions (Lee et al., 2019). Similarly, implementing green port initiatives, such as energy-efficient cargo handling systems and renewable energy installations, enhances the environmental sustainability of maritime operations (Chang et al., 2017). The theory also emphasizes social responsibility, encouraging the sector to address labor issues and engage with local communities affected by maritime activities (Becker et al., 2018).

By framing the challenges and opportunities of maritime transportation through a sustainability lens, the industry can develop strategies that not only address immediate risks but also ensure long-term viability. This holistic approach is essential for reducing the environmental impact of maritime operations, enhancing social equity, and supporting the economic performance of global supply chains. As such, Sustainability Theory complements Resilience Theory by providing a broader framework for building climate-resilient and sustainable maritime transportation systems.

3.0 Methodology

3.1 Research Approach, Design

This study employed a mixed-method research approach, integrating both qualitative and quantitative data to examine climate change adaptation in maritime transportation and its role in enhancing resilience and sustainability within global supply chains. By combining these methods, the research provided a holistic understanding of the challenges and potential solutions, while allowing for triangulation to enhance the reliability and validity of the findings. Quantitative data offered statistical insights into broad trends, such as the economic impacts of climate change on maritime shipping, while qualitative data delved into the nuanced perspectives and experiences of stakeholders, capturing complexities that numbers alone cannot convey. Data collection was conducted through surveys and interviews, targeting diverse participants including port authorities, shipping companies, government officials, and representatives from international organizations. Additionally, the study adopted a cross-sectional research design, which enabled the researchers to capture a snapshot of current practices and strategies for climate change adaptation, providing valuable insights into how various stakeholders are addressing resilience and sustainability challenges at a specific point in time.

3.2. Study area

The study was conducted at two key locations: Dar es Salaam Port and Malindi Port in Zanzibar. Dar es Salaam Port, Tanzania's largest and most critical hub for international trade, handles a significant share of the country's imports and exports, serving not only Tanzania but also landlocked nations like Zambia, Malawi, and the Democratic Republic of the Congo. However, its coastal location makes it highly vulnerable to the impacts of climate change, including rising sea levels, frequent storms, and coastal erosion. These threats pose significant risks to port operations, shipping routes, and the broader logistics network, potentially disrupting the seamless flow of goods and economic activities that the port facilitates.

Similarly, Malindi Port in Zanzibar is vital for both cargo and passenger vessels, playing a crucial role in trade, tourism, and the distribution of goods locally and internationally. Like Dar es Salaam, Malindi Port faces climate-related challenges such as rising sea levels, extreme weather events like cyclones, and shifting weather patterns, which jeopardize the efficient movement of goods and passengers. This study aimed to explore how both ports can adapt to these climate risks by focusing on key strategies such as port upgrades, the implementation of early warning systems, and the adoption of alternative transport options. Additionally, the research emphasized promoting sustainability through measures like reducing carbon emissions and integrating eco-friendly shipping practices. By addressing these challenges, the study provides valuable insights into strengthening the resilience and sustainability of the maritime transport sector in these vulnerable regions, ensuring the continuity and reliability of global supply chains.

3.3 Data Collection Tools

Data collection for this study utilized both quantitative and qualitative methods to comprehensively analyze climate change adaptation in the maritime sector. Quantitative data were gathered through semi-structured questionnaires distributed to a diverse group of participants, including maritime industry experts, port authorities, shipping companies, government officials involved in climate change policy and maritime transport, and representatives from organizations such as the International Maritime Organization (IMO). These questionnaires captured numerical and categorical information on key issues related to resilience and sustainability. In parallel, qualitative data were collected through in-depth interviews with key stakeholders, including maritime industry experts, port authorities, shipping company representatives, government officials, and environmental scientists specializing in climate change and coastal resilience. These interviews provided deeper insights into stakeholder perspectives and strategies for addressing climate-related challenges, enriching the study's findings with a nuanced understanding of adaptation practices in the maritime industry.

3.4 Data Analysis

The qualitative data collected through interviews were analyzed using thematic analysis, supported by NVivo software, to systematically identify and categorize emerging themes from participants' responses. This approach enabled the coding of data into key themes such as challenges in implementing adaptation strategies, stakeholder perceptions of climate risks, and the effectiveness of existing resilience measures. Thematic analysis provided a detailed understanding of the complexities and nuances in human and organizational factors influencing climate change adaptation in maritime transportation. Quantitative data, on the other hand, were analyzed using descriptive statistics to organize and interpret the data effectively. This method offered clear insights into the current state of climate change impacts on maritime transportation, focusing on adaptation practices at Dar es Salaam Port and Malindi Port in Zanzibar. Together, these analytical approaches facilitated a comprehensive evaluation of how these maritime systems are addressing climate risks, contributing valuable findings to the discourse on enhancing resilience and sustainability in global supply chains.

4.0 Results and Discussion

4.1. Results

4.1.1 Sustainable Shipping and Supply Chain Practices

The study aims to identify sustainable shipping and supply chain strategies that can improve operational stability and ensure the efficient movement of goods amidst climate change impacts. The findings in Table 1 indicate the sustainable shipping and supply chain practices such as port modernization, green supply chain integration, diversification of supply chain routes, collaboration across stakeholders, circular economy practices and investing in digitalization and automation.

T able 1. Sustainable Shipping and Supply Chain Practices (n=45)

Indicators	**frequency**	**Percentage**
Port Modernizations for Climate Resilience	40	17
Green Supply Chain Integration	38	16
Diversification of Shipping Routes	35	15
Collaboration Across Stakeholders	41	17
Circular Economy Practices in Shipping	43	18
Investing in Digitalization and Automation	40	17
TOTAL	**237**	**100**

Ports are critical nodes in the maritime supply chain, and their vulnerability to sea-level rise and flooding requires modernized infrastructure (17%). This includes elevated piers, better flood barriers, and more sustainable dredging techniques. This implies that modernizing ports to withstand climate change impacts reduces the likelihood of supply chain disruptions, ensures smoother cargo handling, and protects global trade flows from disruptions caused by extreme weather events.

Green Supply Chain Integration (16%) was another sustainable and supply chain practices that was revealed. It was noted that shipping companies are increasingly integrating sustainable practices into their entire supply chain. This includes working with suppliers who meet sustainability standards, reducing waste throughout the logistics process, and promoting low-emission transport options. This imply that integrating sustainability across the entire supply chain improves the environmental footprint of the maritime sector, while ensuring that the global supply chain operates more efficiently and sustainably, even in the face of climate challenges.

The study findings further revealed that diversification of shipping routes (15%) could be more helpful to ensure sustainable shipping and supply chain resilience. It was noted that by diversifying shipping routes and avoiding areas most affected by climate change, such as regions with frequent storms or rising sea levels, maritime transportation can enhance resilience. Diversification of routes improves supply chain stability by reducing the risk of bottlenecks or delays caused by climate-related disruptions in specific areas, allowing the global supply chain to function smoothly even during adverse conditions.

Collaboration between governments, shipping companies, and other stakeholders (17%) is crucial for developing and implementing effective climate adaptation strategies. The study findings revealed that public-private partnerships can lead to shared resources and better policy frameworks that benefit the entire sector. This imply that stronger cooperation can accelerate the implementation of resilience strategies, ensure that policies are aligned, and leverage resources for long-term adaptation goals, leading to more sustainable and robust maritime transportation systems.

Likewise, the circular economy practices in shipping (18%) were revealed by study whereby the respondents indicated that adoption of circular economy principles, such as recycling and reusing materials, reducing waste, and implementing eco-friendly practices in the lifecycle of ships, can significantly reduce the environmental impact of the maritime sector. Circular economy practices can make the shipping industry more sustainable by reducing resource consumption and waste, fostering more environmentally friendly operations, and improving the public image of maritime transportation as a responsible industry.

Digitalization and automation (17%) are increasingly being recognized as key strategies for improving the sustainability, efficiency, and resilience of shipping and supply chain operations. As the global maritime industry faces challenges such as climate change, fluctuating demand, and the need for operational efficiency, integrating digital technologies and automated processes offers significant advantages in both the short and long term. This imply that through digitalization and automation ports, shipping companies, and logistics providers can handle more goods with fewer resources, optimization of routes, and enable better coordination of shipments.

4.1.2. Climate Change Adaptation Strategies

The findings in Table 2 revealed that, several climate change adaptation strategies that enhance resilience and sustainability in maritime transportation can be used such as implementation of green technologies, resilient infrastructure development, enhanced data and forecasting systems, investing in digitalization and automation, green supply chain integration, and optimized shipping practices and energy efficiency.

Table 2. Climate Change Adaptation Strategies (n=45)

Indicators	**Frequency**	**Percentage**
Implementation of Green Technology	42	18
Resilient Infrastructure Development	40	17
Enhanced Data and Forecasting Systems	35	15
Climate-Adaptive Fleet Management	38	16
Improved Cargo Handling and Storage	42	17
Adoption of eco-friendly fuel alternatives	41	17
TOTAL	**238**	**100**

The findings from Table 2 indicated that the adoption of renewable energy sources (18%), such as wind-assisted propulsion and solar-powered vessels, can significantly reduce the carbon footprint of maritime transportation. Furthermore, the use of fuel-efficient engines and hybrid systems can improve operational efficiency. This implies that green technologies can reduce the industry's environmental impact, helping shipping companies meet international environmental regulations and reduce their reliance on fossil fuels, contributing to long-term sustainability.

Furthermore, resilient infrastructure development (17%) is very crucial whereby the findings show that ports and maritime infrastructure need to be upgraded to withstand extreme weather events such as storms, flooding, and sea-level rise. This includes strengthening port facilities, ensuring better storm water management systems, and incorporating climate-resilient designs in new shipping vessels and ports. This suggest that investing in climate-resilient infrastructure ensures that maritime transport operations are not disrupted by extreme weather events, minimizing downtime and maintaining stability in global supply chains. The findings are in line with (León-Mateos et al., 2021) that port infrastructure is vital importance in global supply chain, it is important to maintain and restore their operability in light of the extreme effects of climate change and to ensure port resilience.

The findings revealed that enhanced data and forecasting system (15%) can be used by ports as strategy towards climate change adaptation. The findings shoes that the use of advanced data analytics, real-time climate monitoring, and predictive modeling can help identify potential disruptions and optimize routing and scheduling. This enables better preparedness and reduces vulnerability to climate-related disruptions. This imply that enhanced data systems lead to more proactive decision-making, allowing shipping companies to avoid vulnerable regions or adjust operations before disruptions occur, which can help maintain the flow of goods without major delays.

Climate-Adaptive Fleet Management (16%). Developing fleet management strategies that incorporate climate risk factors such as storm forecasting, sea ice conditions, and ocean current patterns can help shipping companies optimize vessel routes and operations. This imply that climate-adaptive fleet management allows for more effective scheduling and routing, reducing delays and risks. This improves the overall operational efficiency and resilience of maritime operations against climate variability. Improved cargo handling and storage (17%) The integration of climate-resilient technologies in cargo handling systems, such as automated temperature-controlled storage, can help protect goods from climate-related damages, such as extreme heat or humidity. This suggest that protecting cargo from climate-induced damages ensures that goods arrive in better condition, reducing the need for costly repairs or replacements. This improves operational efficiency and reduces supply chain losses, especially for perishable goods.

Adoption of eco-friendly fuel alternatives (17%). The shift towards biofuels, LNG (Liquefied Natural Gas), and ammonia as alternative fuels can reduce greenhouse gas emissions and pollutants produced by traditional marine fuels. Implying that transitioning to eco-friendly fuel alternatives reduces the maritime sector's carbon footprint, helping companies meet emissions reduction targets and aligning with global environmental regulations. This shift can also provide operational cost savings in the long run by improving fuel efficiency. Optimized shipping practices and energy efficiency (17%) was also discovered as one of the strategies towards climate change adaptation. Practices such as operating ships at lower speeds to reduce fuel consumption and route optimization based on weather conditions can lead to significant reductions in energy use and greenhouse gas emission. This imply that energy efficiency measures reduce operational costs while lowering emissions, which not only benefits the environment but also helps shipping companies improve their bottom line by reducing fuel expenses.

4.1.3. Challenges in Implementing Climate Adaptation Strategies

4.1.3.1 Financial Constraints

The financial burden of implementing climate adaptation strategies emerged as a major challenge in the maritime sector. Stakeholders repeatedly emphasized the high costs associated with upgrading port infrastructure to withstand extreme weather events, rising sea levels, and other climate risks. As one port authority official noted, "The high costs of upgrading our port infrastructure make it challenging to implement climate adaptation measures effectively." Similarly, a shipping company representative highlighted that "Securing funding for green technologies and infrastructure upgrades remains a significant hurdle." These insights reflect the limited financial resources available for critical climate resilience projects. To address this barrier, financial incentives, subsidies, and innovative public-private partnerships are essential for mobilizing the necessary resources and reducing the financial strain on maritime stakeholders.

4.1.3.2 Regulatory and Policy Gaps

The absence of clear and harmonized regulations is another critical challenge identified by stakeholders. Ambiguities in international frameworks and inconsistencies in national policies hinder the alignment of climate adaptation strategies with global climate goals. According to a representative from the International Maritime Organization (IMO), "Ambiguities in international regulations create challenges for aligning our strategies with global climate goals." A government official also noted, "National policies lack clarity on integrating sustainability into port operations." These regulatory gaps complicate the implementation of effective adaptation measures, creating uncertainty for stakeholders. Harmonized policies, clear guidelines, and better enforcement mechanisms are needed to provide a consistent framework for maritime stakeholders to develop and implement climate adaptation strategies effectively.

4.1.4. Strategies for Enhancing Resilience

4.1.4.1 Resilient Infrastructure Development

Participants stressed the critical importance of investing in resilient infrastructure to safeguard maritime operations against climate-induced disruptions. This includes the development of elevated platforms, flood barriers, and reinforced port facilities designed to withstand extreme weather events. An environmental scientist remarked, "Investing in elevated platforms and flood barriers has significantly improved our port's ability to withstand extreme weather events." Similarly, a port engineer emphasized, "We need more robust designs to ensure the long-term functionality of our facilities." These measures not only mitigate immediate risks but also ensure the long-term functionality and stability of maritime systems. By prioritizing climate-resilient infrastructure, ports can minimize disruptions, maintain operational continuity, and secure global supply chain reliability.

4.1.4.2 Advanced Data and Forecasting Systems

Advanced data systems and predictive modeling are essential tools for proactive climate risk management. Stakeholders highlighted the role of real-time data in optimizing decision-making processes, reducing vulnerabilities, and ensuring operational continuity. As a shipping company official explained, "Real-time data helps us plan better and avoid vulnerable shipping routes during storms." A maritime expert added, "Forecasting systems allow us to anticipate risks and adjust operations accordingly." These systems enable maritime stakeholders to identify potential disruptions, optimize shipping routes, and implement timely interventions. Enhanced data systems not only improve preparedness but also reduce the risk of climate-related disruptions in maritime operations.

4.1.5. Sustainable Practices in Maritime Operations

4.1.5.1 Adoption of Green Technologies

The adoption of green technologies is a cornerstone of sustainable maritime operations. Stakeholders emphasized the use of renewable energy sources, hybrid engines, and alternative fuels to reduce the sector's carbon footprint. A shipping company representative stated, "Switching to hybrid engines and alternative fuels has reduced our carbon footprint significantly." A port manager echoed this sentiment, saying, "Renewable energy integration is a priority for us." These technologies not only mitigate environmental impacts but also align with international sustainability goals, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). By transitioning to greener technologies, the maritime sector can contribute to global decarbonization efforts while improving energy efficiency.

4.1.5.2 Circular Economy Practices

Circular economy practices are increasingly being integrated into maritime operations to enhance sustainability and reduce resource consumption. These practices involve recycling ship components, minimizing waste, and optimizing resource use throughout the lifecycle of maritime assets. An industry expert remarked, "Recycling ship components and reducing waste during operations are becoming standard practices." Similarly, an environmental scientist noted, "Circular economy principles are reshaping our approach to sustainability." By adopting these principles, the maritime sector can reduce its environmental footprint, foster operational efficiency, and demonstrate leadership in sustainable development.

4.1.6. Collaboration and Stakeholder Engagement

4.1.6.1 Public-Private Partnerships

Collaboration between public and private entities was frequently cited as a vital enabler of climate adaptation strategies. Public-private partnerships facilitate resource mobilization, policy alignment, and the development of innovative solutions to climate challenges. A government official highlighted this, stating, "Collaborating with private investors has allowed us to fund critical infrastructure projects." A representative from IMO added, "Partnerships enable resource sharing and policy alignment." These collaborations allow for shared responsibility and the pooling of resources, making climate adaptation measures more accessible and effective.

4.1.6.2 Community Involvement

Engaging local communities in climate adaptation strategies ensures that social and environmental concerns are addressed comprehensively. Stakeholders emphasized the value of community feedback in designing inclusive and sustainable operations. An environmental scientist observed, "Engaging local communities ensures that our strategies address social and environmental concerns effectively." A port manager added, "Community feedback has been invaluable in designing sustainable operations." By involving communities, maritime stakeholders can ensure that adaptation strategies are not only technically sound but also socially equitable, fostering long-term sustainability.

4.2 Discussion

The findings of this study highlight the pressing need for comprehensive climate adaptation strategies to enhance the resilience and sustainability of maritime transportation systems. Ports such as Dar es Salaam and Malindi are increasingly vulnerable to the impacts of climate change, including rising sea levels, extreme weather events, and shifting ocean currents, which disrupt operations and threaten the stability of global supply chains. These challenges demand innovative solutions that integrate technology, sustainability, and collaboration, as also emphasized by Becker et al. (2018). One of the key strategies identified in the study is the adoption of circular economy practices, which involve recycling materials, reducing waste, and reusing resources within maritime operations. Stakeholders emphasized these practices as vital for reducing the environmental footprint of the sector while improving efficiency. Chang et al. (2017) also underscored the economic benefits of circular economy models, highlighting their role in fostering resource optimization and cost savings. This focus reflects a shift towards sustainable maritime operations that balance environmental and economic goals.

Furthermore, investments in green technologies, such as renewable energy systems, hybrid engines, and alternative fuels, were another critical finding. Respondents highlighted that these technologies significantly reduce greenhouse gas emissions and align with global environmental targets, such as the Paris Agreement. Study by Ng et al. (2018) similarly emphasized that transitioning to low-carbon operations is essential for mitigating the maritime sector's contribution to climate change while ensuring operational efficiency. Yet, infrastructure modernization was a recurring theme, with stakeholders advocating for resilient port designs, including elevated platforms, flood barriers, and advanced stormwater management systems. These measures are essential for protecting maritime facilities against extreme weather events and rising sea levels. Study by León-Mateos et al. (2021) noted, resilient infrastructure ensures the continuity of operations and safeguards global supply chains, even under challenging climate conditions. This investment not only reduces operational risks but also secures long-term economic benefits for the sector.

Technological advancements, including digitalization and automation, were also identified as transformative strategies for enhancing maritime operations. Stakeholders highlighted the role of real-time data, predictive analytics, and automated cargo handling systems in optimizing routes, forecasting disruptions, and improving decision-making processes. These findings align with Er Kara et al. (2021), who demonstrated that integrating digital tools enhances supply chain adaptability and resilience to climate-induced risks. Moreover, collaboration among stakeholders emerged as a crucial enabler of successful adaptation strategies. Public-private partnerships, international cooperation, and community engagement were frequently mentioned as vital for resource sharing, policy alignment, and inclusive planning. For instance, governments and private investors were seen as pivotal in funding critical infrastructure projects and facilitating the adoption of green technologies. Chang et al. (2017) supported this view, emphasizing that collective action fosters innovative solutions and strengthens resilience across the maritime sector.

Another critical area identified was the role of advanced data and forecasting systems. These systems enable stakeholders to anticipate and mitigate climate risks by providing real-time insights into weather patterns, ocean currents, and other critical factors. This proactive approach ensures smoother operations and reduces disruptions. Lee et al. (2019) highlighted that accurate forecasting and data-driven decision-making are indispensable for navigating uncertainties and maintaining supply chain stability. The financial challenges of implementing these strategies, however, remain a significant barrier. Stakeholders frequently mentioned the high costs of infrastructure upgrades, green technology adoption, and workforce training. This underscores the need for financial incentives, subsidies, and innovative funding models to support the maritime sector in overcoming these obstacles. Collaborative frameworks that pool resources from public and private entities can play a pivotal role in addressing these constraints and accelerating the implementation of climate adaptation measures.

5. Conclusion and Recommendations

5.1 Conclusion

This study highlights the urgent need to integrate resilience and sustainability into maritime transportation systems to address the growing impacts of climate change. Ports and shipping operations, essential to global supply chains, are increasingly vulnerable to rising sea levels, extreme weather, and changing ocean dynamics. By adopting resilient infrastructure, green technologies, and circular economy practices, the maritime sector can mitigate climate risks and reduce its environmental impact. Additionally, leveraging digital tools and predictive systems can improve efficiency and ensure the continuity of global trade. The study also emphasizes the importance of collaboration among governments, private sector actors, and international organizations to drive effective climate adaptation strategies. Public-private partnerships, financial incentives, and community involvement are key to mobilizing resources and achieving sustainability goals. Despite challenges such as financial constraints and regulatory gaps, a unified and innovative approach can turn these obstacles into opportunities for growth. By committing to sustainable practices, the maritime sector can remain a resilient cornerstone of global trade and development.

5.2 Recommendations

To enhance the resilience and sustainability of maritime transportation amidst climate change, this study recommends prioritizing investments in climate-resilient infrastructure and green technologies. Port authorities should upgrade facilities with stormwater management systems, elevated platforms, and flood barriers to address extreme weather and rising sea levels. Shipping companies should adopt renewable energy sources, such as wind-assisted propulsion, solar power, and eco-friendly fuels like LNG and biofuels. Governments and international organizations should provide financial support through incentives, subsidies, and policies to promote these sustainable technologies. The study also emphasizes the importance of collaboration among stakeholders. Public-private partnerships can pool resources for infrastructure development and research, while coordinated global policies can align efforts. Engaging communities ensures adaptation measures are inclusive and address local concerns. Finally, investing in digital tools like real-time monitoring and predictive analytics will improve operational efficiency and risk management. By embracing innovation and collaboration, the maritime sector can turn climate challenges into opportunities for long-term resilience and sustainability in global supply chains.

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Implications of Gravity Waves Potential Energy on Coastal Resilience and Sustainability

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Abstract
Atmospheric gravity waves (GWs) are pivotal in regulating atmospheric energy transfer, influencing climate dynamics, and directly impacting tropical and coastal regions. This study focuses on the West African region, investigating GW seasonal variation using five years (January 2019–December 2023) of ERA5 reanalysis data. Gravity Waves Potential Energy (GWPE), calculated from vertical temperature profiles of the West African region with Linear Perturbation Analysis, reveals that atmospheric disturbances are induced by GWs, with maximum GW activity and upward energy propagation occurring during the June-July-August (JJA) period. These findings align with previous observations, which reported seasonal energy density variations from 9 Jkg^{-1} to 15 – 26 Jkg^{-1} peaks over the same JJA period. The seasonal variations in GWPE have significant implications within the context of climate change, particularly for coastal resilience and sustainability because of the direct relationship between GWPE variations and seasonal sea levels. As climate change intensifies, coastal communities increasingly face the impacts of shifting atmospheric-ocean dynamics. The analysis of GWPE trends and their impact on rising sea levels will enable coastal planners to predict shifts in erosion patterns and adjust their strategies for coastal protection. By connecting GW seasonal patterns to broader climate processes, this study contributes valuable insights for supporting sustainable economic practices in coastal regions, which are climate-sensitive regions.

Keywords: gravity waves potential energy, climate dynamics, coastal resilience, sustainable economicpractices

1 Introduction

Coastal regions are vital to global ecosystems, supporting diverse habitats and providing critical resources for human populations (Lakshmi, 2021). However, these areas are increasingly vulnerable to climate change impacts, including rising sea levels, intensified storms, and shifting erosion patterns. Understanding the atmospheric and oceanic processes influencing coastal dynamics is crucial for developing sustainable strategies to enhance resilience and sustainability. Among these processes, atmospheric gravity waves (GWs) have emerged as key drivers of atmospheric energy transfer, influencing climate dynamics and impacting tropical and coastal regions (Alexander et al., 2010). Atmospheric gravity waves are oscillations resulting from the displacement of air parcels in stable atmospheric layers. These waves facilitate energy transfer and momentum across different atmospheric levels, significantly impacting weather patterns, convection, and large-scale circulation. The potential energy associated with these waves, called Gravity Waves Potential Energy (GWPE), is a critical metric for assessing wave activity and its influence on atmospheric dynamics. Seasonal variations in GWPE have been linked to shifts in atmospheric energy distribution, particularly in tropical regions where convection dominates (Fritts & Alexander, 2003). In West Africa, gravity waves interact with tropical convection and monsoonal flows, significantly influencing regional climate and weather systems (Alexander et al., 2010). During the June-July-August (JJA) season, GW activity peaks, with energy density values ranging from 15 to 26 J/kg (Hindman & Gossard, 2013). The implications of these variations extend beyond atmospheric phenomena. GWPE influences atmospheric-ocean coupling processes, such as sea-level dynamics, which in turn affect coastal erosion, flooding, and sediment transport (Lindzen, 1981). In the context of climate change, where extreme weather events are expected to intensify, understanding GWPE's seasonal dynamics is essential for mitigating risks to coastal ecosystems and communities (IPCC, 2021).

Despite its significance, the relationship between GWPE variations and coastal sustainability remains underexplored, especially in the West African region. This study addresses this gap by examining GWPE seasonal variation using five years (2019–2023) of ERA5 reanalysis data. By focusing on this region, the research provides insights into how GW activity shapes seasonal energy distributions and contributes to coastal resilience and sustainability.

2 Methodology

2.1 Data

Temperature profiles and sea level data from ERA5 produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), was utilized as the primary dataset for this study (ECMWF, 2024). ERA5 is a state-of-the-art global atmospheric reanalysis product that combines observational data with model output through advanced data assimilation techniques, providing comprehensive, high-resolution meteorological data. Hourly data were used, which were aggregated to daily and seasonal averages for analysis. This high temporal resolution enables a detailed investigation of short-term and seasonal variations in GW activity. The horizontal resolution of ERA5 data is approximately 0.25O×0.25O (about 31 km). This fine spatial resolution ensures that regional-scale features of atmospheric gravity waves and their energy distributions are captured accurately.

The dataset spans five years, from January 2019 to December 2023, ensuring sufficient temporal coverage to capture seasonal and interannual variations in atmospheric gravity waves. Vertical temperature profiles, a critical parameter for analyzing atmospheric gravity wave potential energy (GWPE), were extracted at multiple pressure levels. The analysis focused on the West African region, encompassing latitudes from 4°N to 18°N and longitudes from 17°W to 15°E. This region was selected due to its climatic significance, particularly its interaction with the monsoonal system and its vulnerability to climate change impacts. Additionally, data on sea levels were obtained to assess its coupling with GWPE.

2.2 Gravity waves potential energy model

For the present study, the gravity wave activity measure used is gravity wave potential energy (Tsuda et al. 2000). In general, gravity wave energy is the sum of potential and kinetic wave energy, but linear gravity wave theory predicts that on average the ratio of potential to kinetic Energy, Ep/Ek, is constant (Nastrom et al., 2000; Venkat Ratnam et al., 2004). Therefore, we can assume the total gravity wave energy to be proportional to potential energy, which can be calculated from temperature profiles alone. The calculation of potential energy from temperature profiles is described in detail by Tsuda et al. (2000) using linear perturbation analysis and linear theory of gravity waves.

The atmospheric temperature profile (T) from ERA 5 as a function of pressure levels consists of the background temperature profile and the fluctuating component T'. The Ep has been used as a proxy for studying the gravity wave activities as presented by Tsuda et al. (2000) is given by:

$$E_p = \frac{1}{2}\frac{g^2}{N^2}\left(\frac{T'}{\overline{T}}\right)^2 \qquad (1)$$

where Ep is the Gravity wave potential energy, g is the gravitational field strength, N is the Brunt-Vaisala Frequency, T' is the mean temperature and T is the temperature perturbation.

The calculation of Ep is based on T' given by T' = T - T (2)

$$\text{d } N^2 = \frac{g}{\overline{T}}\left[\frac{\partial \overline{T}}{\partial h} + \frac{g}{C_p}\right] \qquad (3)$$

where Cp is the specific heat capacity of air at constant pressure and h is the altitude.
Python-generated time-series plots, box plots, and correlation graphs were used to analyze the data.

3 Results

3.1 Yearly Trend of Gravity Waves Potential Energy

Figure 1 shows the temporal evolution of GWPE over five years, highlighting seasonal and interannual variations. The GWPE trend demonstrates a distinct peak (23.8 J/kg) in 2019 and trough (21.1 J/kg) in 2020, indicating the influence of atmospheric conditions such as convection, wind shear, and seasonal variations in thermal gradients.

Figure 1. Yearly Trend of Gravity Waves Potential Energy (2019-2023)

3.2 Seasonal Variation of GWPE

To examine the seasonal variation of gravity wave activity, monthly means of all Ep profiles were formed. The data were grouped into four climatological seasons: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON).

GWPE values were averaged for each season to determine seasonal trends and peak activity periods. Seasonal energy density variations were compared to reported values (9 J/kg in DJF, 15–26 J/kg in JJA) to ensure reliability.

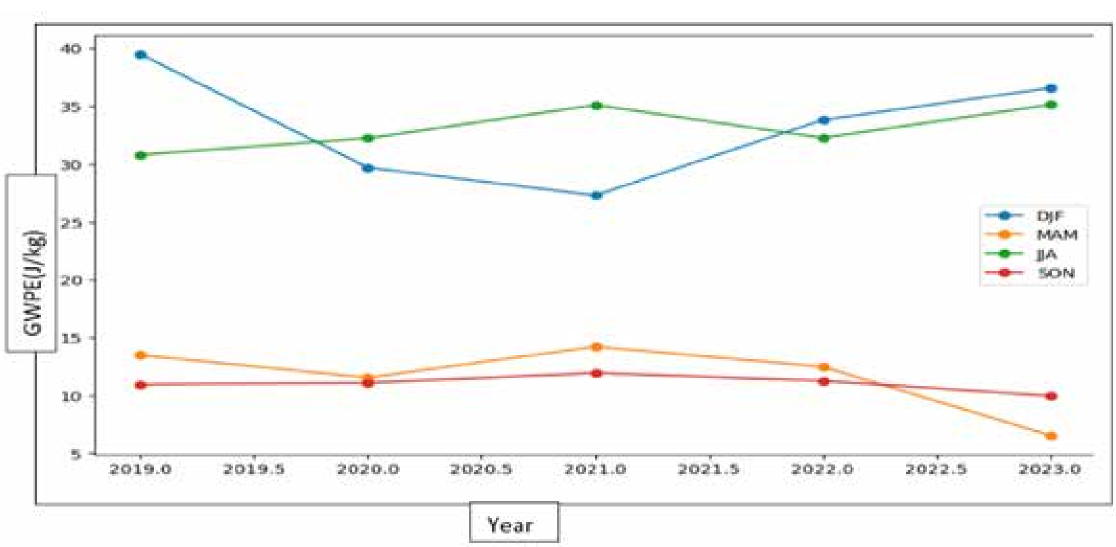

Figure 2. Seasonal variation of mean Gravity wave potential energy

The year 2019 stands out with the highest recorded potential energy (Ep) of 39 J/kg, as shown in Figure 2. This figure also highlights clear interannual variations in wave activity. Notably, the wave activity pattern observed in 2019 differs significantly from other years in several respects. The peak Ep in 2019 occurred during the DJF (December-January-February) period, indicating unusually strong wave activity during this season. Such heightened DJF wave activity has also been reported in previous studies, such as Venkat Ratnam et al. [2004b]. Conversely, the lowest wave activity in 2019 was recorded in January, a trend consistently observed across all years without significant year-to-year variation. While interannual variations are evident, they require further detailed analysis, which will be addressed in future studies. Aside from the anomalies observed in 2019 and 2023, a dominant seasonal cycle is consistently present in the data.

3.3 Sea Levels Trends

Figure 3 illustrates an increasing trend in annual average sea levels over the five-year period from 2019 to 2023. The sea level values rise consistently, from 80.2 mm in 2019 to 98.2 mm in 2023, indicating a sustained and significant increase. This trend is likely indicative of ongoing global sea level rise caused by climate change-related factors, such as thermal expansion of seawater and increased contributions from melting glaciers and ice sheets. This rising trend in sea levels is expected to intensify issues such as coastal erosion, extreme marine flooding, and saltwater intrusion into coastal aquifers, as noted by Nicholls and Tol (2006), Nicholls et al. (2007), and Nicholls and Cazenave (2010). While Figure 3 illustrates yearly average trends of sea levels, Figures 4 a and 4b give detail monthly average trends for the years 2019 and 2020.

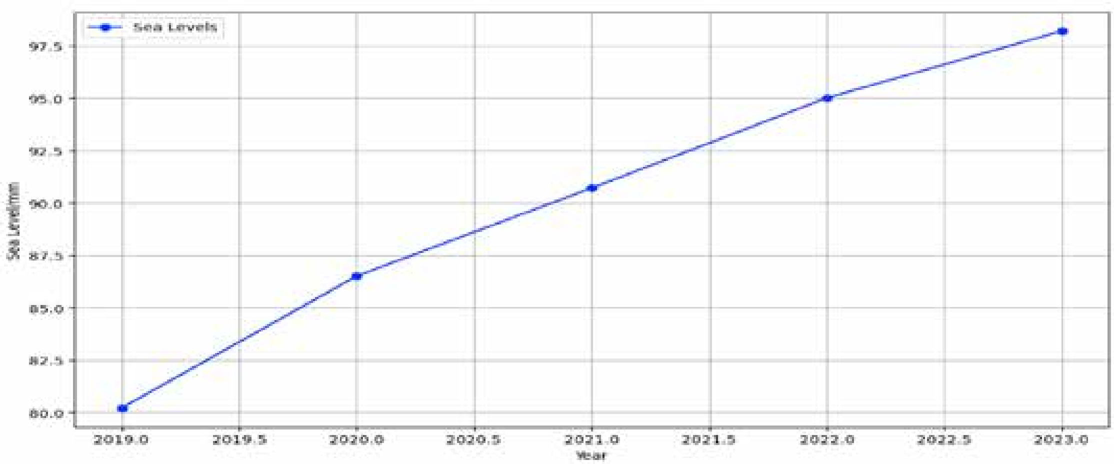

Figure 3 Mean Sea level variation from 2019 to 2023

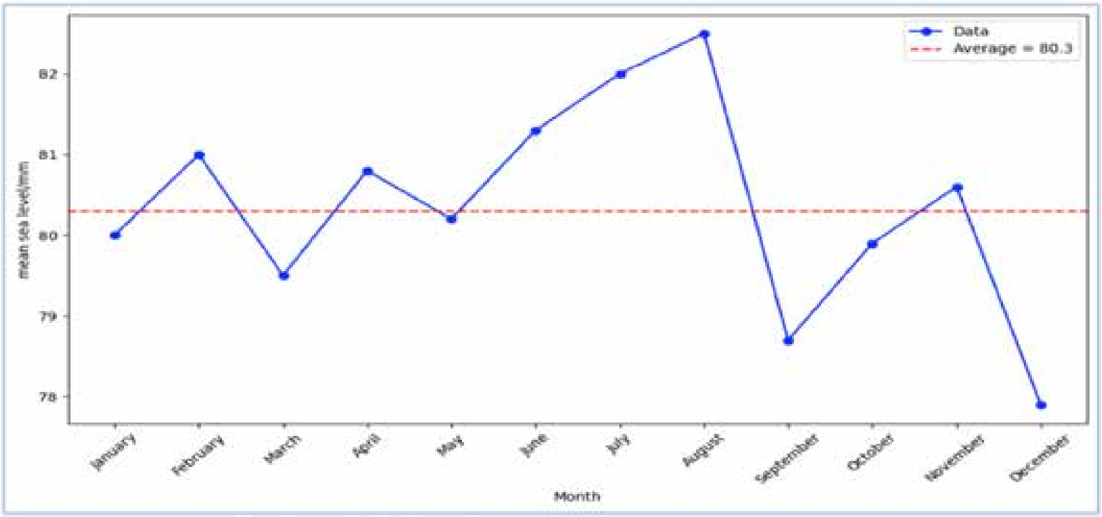

Figure 4a Time series plot of sea levels for 2019

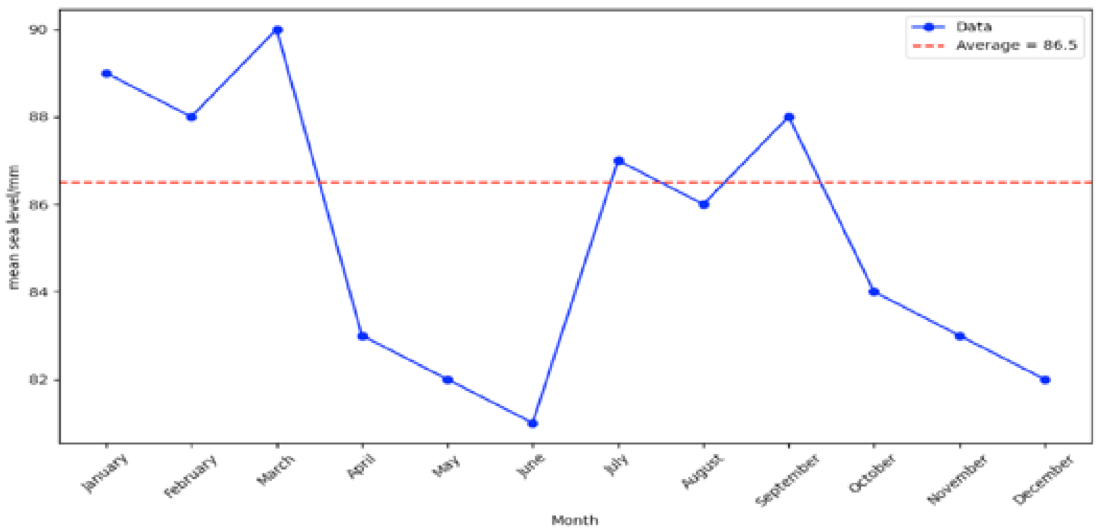

Figure 4 b Time series plot of sea levels for 2020

3.4 Interannual Variation of Sea Levels

There is upward trend in the mean sea levels from 2019 to 2023 as shown by the interannual variability of sea levels from 2019 to 2023 in Figure 5.. Starting from the lowest range in 2019 (77.9 to 82.5), the values progressively increase each year, reaching their highest in 2023 (98.1 to 99.5). This indicates a consistent rise in sea level across these five years. The steady rise in sea levels from 2019 to 2023, suggests a long-term trend in global mean sea level (GMSL) increase.

The median sea levels show a clear increasing trend over the years. Starting at around 80 mm in 2019, the median rises progressively to approximately 99 mm by 2023. This consistent increase suggests long-term drivers of sea-level rise, such as thermal expansion and melting ice.

Minimal outliers are visible, indicating that the monthly sea levels are relatively consistent within each year.

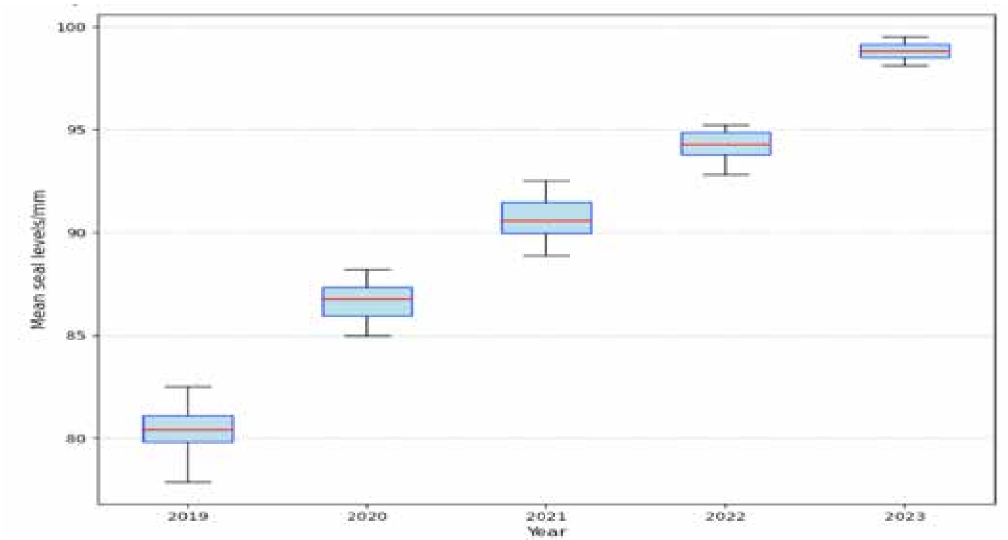

Figure 5 Yearly mean sea levels

3.5 Seasonal and Interannual Variations in Monthly Sea Levels (2019–2023)

The analysis of monthly sea level data from 2019 to 2023 reveals distinct seasonal and interannual variations, reflecting the dynamic nature of coastal environments. Seasonally, sea levels exhibit recurring patterns, with higher values typically observed during specific periods of the year, likely influenced by factors such as thermal expansion of water, regional ocean currents, and atmospheric pressure variations (Wolski & Wiśniewski, 2023).

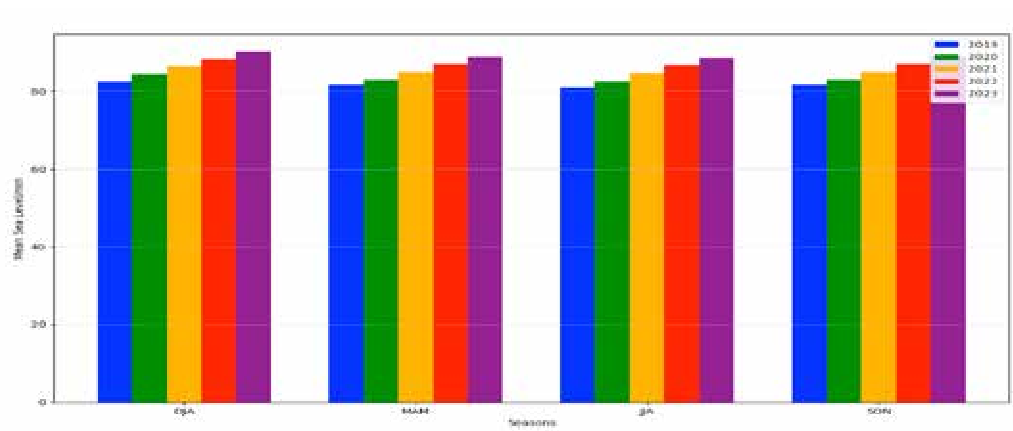

Figure 6. Seasonal variations in sea levels

Figure 6 shows a consistent increase in sea levels across all seasons from 2019 to 2023. This suggests a gradual rise in sea levels over the years. The increase is most prominent in the DJA and JJA seasons, indicating stronger dynamics during these periods.

3.6 Impact of GWPE on Sea Levels

To study the impact of GWPE on sea levels, the correlation between the two parameters and correlation coefficients were plotted against the years under consideration

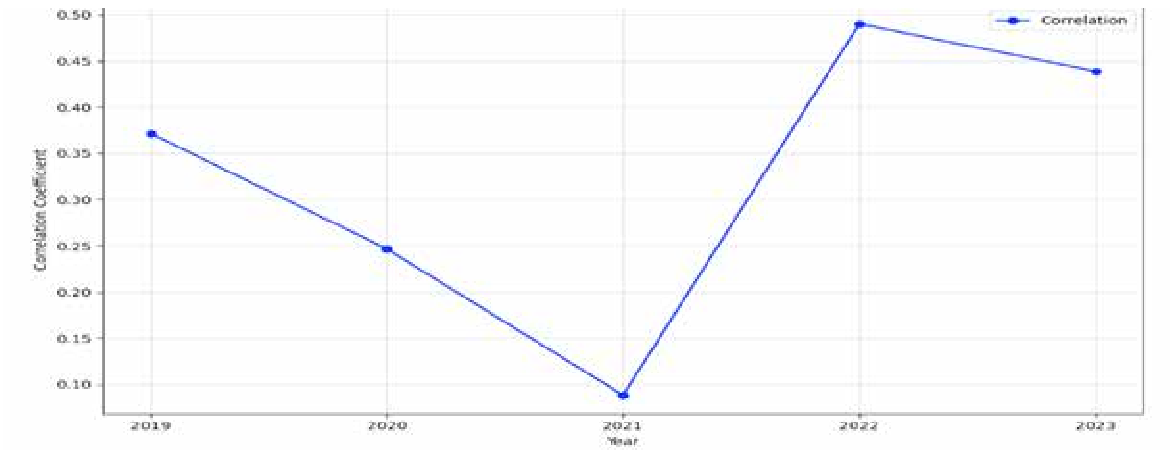

Figure 7 Correlation coefficient between sea level and gravity wave potential energy

Moderate positive correlation in 2019 as indicated in Figure 7 suggests that as GWPE increases, sea levels also show a tendency to rise. This year may reflect a balance between regional gravity wave influences and other factors affecting sea level, such as thermal expansion or glacial melt. The lower correlation in 2020 indicates a weaker relationship between GWPE and sea levels. External factors such as ocean currents, local meteorological conditions, or delayed effects of GWPE on sea levels could explain the reduced strength of the relationship. The very low correlation in 2021 suggests almost no direct relationship between GWPE and sea levels during this year. It's possible that other dominant factors, such as atmospheric pressure variations (e.g., ENSO effects) or local processes, overshadowed the influence of GWPE. The highest correlation among the years, 0.49, reflects a stronger association between GWPE and sea levels. This could indicate a year where gravity wave activity significantly influenced atmospheric and oceanic dynamics, leading to observable changes in sea levels. A moderately high correlation in 2023 further supports the idea that GWPE had a substantial impact on sea levels. This year may have experienced conditions where gravity waves played a critical role in vertical energy transfer, influencing atmospheric stability and subsequently affecting sea level dynamics.

4 Discussion

4.1 Interpretation of GWPE's role in influencing sea-level changes

Gravity waves can influence atmospheric circulation and pressure systems, which in turn affect sea levels. For example, enhanced GWPE may contribute to changes in atmospheric pressure gradients, indirectly influencing oceanic currents and sea levels. Strong wave activity could affect coastal dynamics, especially during extreme weather events, contributing to higher observed sea levels.

The variability in correlation coefficients from year to year suggests that the relationship between GWPE and sea levels is not linear or constant. This could result from differences in regional or global atmospheric and oceanic conditions. Also, the influence of other dominant factors like global warming, glacial melt, and thermal expansion.

It's also possible that GWPE influences sea levels with a lag, meaning the effects of wave energy from one year may manifest in subsequent years, which could dampen the apparent correlation in certain years. The moderate correlations in 2022 (0.49) and 2023 (0.44) suggest that GWPE plays a significant role in influencing sea levels, especially when coupled with other climate factors. The weaker correlations in other years highlight the complexity of sea level dynamics, where multiple factors such as thermal expansion, melting ice, atmospheric pressure, and regional ocean currents interact to determine sea level variations.

4.2 Impact on Coastal Sustainability

Gravity wave potential energy (GWPE) influences sea-level variations through its interaction with atmospheric and oceanic processes, with significant implications for coastal communities. These variations are primarily driven by atmospheric pressure changes, wave-induced wind patterns, and the modulation of ocean tides, resulting in localized shifts in sea level (Fritts & Alexander, 2003). Such fluctuations, though transient, can exacerbate the impacts of storm surges, tidal flooding, and long-term sea-level rise. One major effect of GWPE-driven sea-level variations is the heightened risk of flooding in low-lying coastal areas. During events such as high tides or intense storms, GWPE-induced changes can amplify water levels, increasing the likelihood and severity of inundation. This poses serious threats to coastal infrastructure, ecosystems, and human settlements, particularly in regions already vulnerable to rising sea levels (Hoffmann et al., 2013). Furthermore, these variations can disrupt sediment transport dynamics, contributing to shoreline erosion in some areas and sediment accumulation in others, altering coastal landscapes and affecting habitats for marine and terrestrial species (Smith, 2012).

For human communities, the socioeconomic impacts of GWPE-driven sea-level variations are significant. Increased flooding can damage homes, roads, and other critical infrastructure, disrupt livelihoods, and necessitate costly repairs. The intrusion of seawater into freshwater systems can lead to salinization, reducing the availability of potable water and affecting agricultural productivity. These challenges are particularly acute in developing regions, where limited resources and adaptive capacities exacerbate vulnerabilities (Alexander et al., 2010).

Addressing these challenges requires improved understanding and modeling of GWPE and its interactions with ocean dynamics. Early warning systems and predictive models can help anticipate and mitigate the impacts of sea-level variations. Additionally, incorporating GWPE considerations into coastal management plans and infrastructure designs can enhance resilience and reduce the vulnerability of coastal communities to these dynamic processes (Hendon & Salby, 1994).

4.3 Strategies for integrating QWPE trends into coastal protection and resilience planning

Integrating gravity wave potential energy (GWPE) trends into coastal protection and resilience planning is essential for mitigating the risks associated with dynamic sea-level variations and their impacts on coastal communities. GWPE influences atmospheric and oceanic interactions, and its variability can significantly affect weather patterns, storm surges, and sea-level changes.

Robust monitoring systems, including satellite observations and ground-based measurements, are essential to track GWPE trends and their impacts on sea-level variations, improving predictive models and preparedness for extreme events. Integrating GWPE trends into numerical models can provide insights into how gravity waves influence coastal flooding, erosion, and sediment transport, supporting better urban planning and disaster management. Coastal infrastructure should incorporate adaptable and nature-based solutions, like mangrove restoration and permeable pavements, to address the variability in sea levels influenced by GWPE. Community-based resilience programs, through education and awareness campaigns, can empower local populations to adopt adaptive practices and improve emergency preparedness. Policymakers must integrate GWPE considerations into coastal management and climate adaptation strategies, fostering collaboration among scientists, planners, and authorities. Securing climate adaptation financing is crucial to fund research and implement resilience measures that address the impacts of gravity wave dynamics on sea-level variability.

5 Conclusions

Temperature profiles and mean sea levels were obtained from ERA 5 to study the impact of gravity wave potential energy on rising sea levels. Potential energies calculated from the temperature profiles showed significant seasonal variation. The Ep were correlated with seasonal sea levels. The correlation coefficients highlight that GWPE has a weak to moderate influence on sea levels, with stronger impacts in certain years (2022 and 2023). This variability underscores the complexity of coastal and atmospheric systems, emphasizing the need for comprehensive studies to the contributions of different factors to sea level changes.

6 Future work

• A time-lagged correlation analysis should be conducted to determine if GWPE impacts sea levels with a delay.

• Combined effects of GWPE, atmospheric pressure, thermal expansion, and other factors on sea levels should be explored using regression or machine learning models.

• Further studies should be done to investigate whether correlations vary regionally, as local factors (e.g., topography, coastal infrastructure) may influence the relationship.

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Towards Sustainable Blue Growth: Socioeconomic effects of sand mining on coastal communities of Kombo South, The Gambia.

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Abstract
Coastal areas worldwide are crucial for humanity. They provide habitat for over 70% of the global population and provide various livelihood means highlighting its significance for humans and other ecosystems. Sand mining along the coast is a common practice in many developing coastal states, including the Gambia for numerous economic benefits. Although there is huge economic value in the sand mining industry, sand mining operations have significant negative socioeconomic impacts on coastal communities of Kombo South, the Gambia. The study was conducted in three selected coastal communities of Sanyang, Gunjur and Tujereng. Using a mixed method research approach, a concurrent exploratory research design was adopted for data collection. A semi-structured questionnaire was administered face-to-face to 400 household heads to collect data on the socioeconomic effects of sand mining and in addition, three focus group discussions at the study communities, 10 key informants interviewed from government and communities, and field observation, while for the quantitative study. This study aims to examine socioeconomic effects of coastal sand mining and its governance in the context of blue growth. Through triangulation of the qualitative and quantitative findings, the study anticipates revealing significant challenges to sustainable livelihoods and environmental conservation due to sand mining. Also, the study provides recommendations to for improve sustainable resource management in a conflict-free environment, empower communities, and enhance blue growth in line with Sustainable Development Goals 10, 14, 15, 16, and 17, and the African Agenda 2063.

Key words: *Blue growth, coast, sand mining, socioeconomic effect, sustainable development.*

1. Introduction

Coastal ecosystem areas continued to sustain human existence for centuries serving as a source of food, habitat for biological species, and provision of various materials for the construction of shelters and habitation for over 70% of the global population within

150km of the global coastline, job creation as well as provision of other livelihood ventures (Neumann, 2017; Sartono, 2019; United Nations, 2023). An average population growth of 3.5% has been experienced in the coastal systems since 1950 with an increase in coastal cities from 472 to 2226 between 1950 and 2020 (UN-Habitat, 2020; Rangel-Buitrago et al., 2023). This is a result of the strategic geography of the coast (between the land and the sea) culminating in its capacity as an environmental hotspot that provides multiple ecosystem services (Fegley & Michel 2021; Rangel-Buitrago et al., 2023).

Sand, also known as "the new gold" or "the new currency," forms one of the greatest and most used natural resources in the world after water (Bendixen et al., 2019; UNEP, 2022). Sand mining along the coast is a common practice worldwide, especially in developing coastal states, including the Gambia (Komma, 2019). Due to its extractive character, mining is one of the most pervasive, damaging, and fast-growing activities developing along the world's coasts (Asare et al., 2023). Also, it advances real and possible repercussions to coastal livelihoods, sustainable development, and the resilience of coastal communities (Mensah & Mattah, 2023). Sand mining is a pivotal economic activity in many developing countries globally (Bendixen et al., 2023). Often, sand is mined within coastal areas where the ecosystem and other economic activities are entangled with the daily life and livelihood of the inhabitants of those communities.

Globally, over 59 billion tonnes of material is mined annually, of which sand and gravel, hereafter referred to as aggregates, account for both the largest share and the fastest extracted resources (Bendixen et al., 2019; UNEP, 2019). An estimated 30 to 49 billion tons of sand aggregates are mined globally per annum, hence the most used resource globally next to water (UNEP, 2022; Asare et al., 2024) with a global projected value of $405 billion by 2030 (Global Construction Perspectives and Oxford Economics, 2022). This huge demand for sand has caused the practice of sand mining to become both a global and societal environmental issue posing a significant 21st century challenge for humanity (UNEP, 2022). Sand mining impacts are so crucial that this harmful activity generates major conflicts within all the 17 United Nations Sustainable Development Goals (Bendixen et al., 2023).

In Africa, thirty-eight (38) of the fifty-five (55) states are found in coastal areas (United Nations, 2016). The coast and its resources in these 38 countries generate approximately 49 million jobs mainly in the blue economy space (United Nations, 2016; 2023). As a result of an increasing human population along the coast resulting in competition for finite resources, human needs and wants for resources have led to heavy competition among the intended users of the scarce coastal resources (United Nations, 2016). Like in many continents, Africa has its fair share of issues associated with sand mining both on the socioeconomic status of the coastal communities and the environment (Mbaka & Rono, 2022). Unexpectedly, reliable data on sand and gravel mining remains a challenge in many underdeveloped and developing countries with an exception few developed countries in recent years (Essaw et al., 2023).

In the Gambia, 800 metres from the sea is designated as a Tourism Development Area (TDA) (Sambou, 2023). Interesting to note that the TDA meant for tourism recreation facilities is where the mining are taken place. Tourism being another important economic activity along the coast is of great value to the economy of the Gambia. The sector is the third largest contributor to the GDP of the Gambia amounting to over 20% of the GDP (International Trade Administration, 2022; Amnesty International, 2023). Approximately 100,000 to 160, 000 m3 of sand is extracted annually in the Gambia (NEA, 2020). Several factors have contributed to this rapid coastal sand mining such as; the commercialization of sand mining, road construction, housing, and other infrastructural developments proximity to the sand (Komma, 2019). Notwithstanding those economic benefits, the mining operations coupled with outstanding impacts on both the livelihood of the communities and the environment (Sambou, 2023). Moreover, sand mining activities have a direct and significant effect on the blue economy of the coastal communities.

Coastal communities of Kartong, Gunjur, Sanyang, and Tujereng in the Kombo South district are examples of areas where extensive sand mining is widespread within the coastline including the Tourism Development Area (TDA) and the beaches. The land tenure system is complex, with the land belonging to the community under the custody of the village head (Alkalo), clan head or the family head, whiles the government having control on the development of the land as per the so-called TDA policy. Consequently, there is lack of land policy and inadequate regulation of sand mining, competing land use for agriculture, fish and fish oil meals factories, beach bars, land disputes loss of livelihoods, and multiple land allocations to different parties (Komma, 2019; Sambou, 2023).

Despite UNEP (2019) has noted sand mining and sustainable development to be at odds globally, research to highlight the intricate effects of sand mining particularly in the context of blue growth and efforts to aid in developing effective governance and economic diversification on coastal communities is only at its early stages particularly in the Gambia. The available literature on effects of sand mining and governance is heavily skewed towards Asian countries and parts of West Africa, particularly, Indonesia, China, Nigeria, and Ghana. It shows the lack of understanding of sand mining effects, governance and implications on blue economy. This paper therefore, examines the effects, governance, and implications of sand mining in three communities in Kombo South district. It addresses the following research questions; (1) what are the socioeconomic and environmental effects of sand mining? and (2) how is sand mining governed in Kombo South?

2. Literature review

Sand forms an integral source to economic growth development in both the underdeveloped and developing countries (Mngeni et al., 2016). This developmental trajectory culminates in the growth of towns and cities that demand more and better infrastructures through construction of strong structures such as commercial shopping malls, schools, roads, bridges, and housing for an ever-increasing population (Mensah

& Mattah, 2023). Hence as a result of the rapid socioeconomic development, there lies high chances of environmental, social, and economic disturbances on the natural environment and communities as far as sand mining is concerned. Sand is the second most sought natural resource after water (Beiser, 2018), and its extraction forms the largest global mineral extraction, accounting for over 80 per cent of the global mineral extraction (Chandran, 2019; Pearce, 2019). The global demand for sand aggregates is rapidly increasing faster than its natural replenishing process leading to rising prices and shortage of sand in many developing urban areas (Mark, 2021; Miller, 2022). The rapid economic development around the world, especially in the developing states such as the United Arab Emirates, China, Singapore, and India, causes strong growth of the construction industry (Johnbull & Brown, 2017). Thus, making sand mining a common practice in many coastal countries globally (Mensah, 1997).

Rais et al. (2019) study in Batauga District, Indonesia found that illegal sand mining has cause surface land changes as a result of pits created which are inundated and becomes mosquitoes breeding sites thus a potential source of diseases for residents. Moreso, Anokye et al. (2023) on their study in Awutu-Senya East and West of the Central Region of Ghana found divergent views were expressed among the respondents. Truck drivers and block makers highlighted positive impact of sand mining on their livelihood whiles the key informants from the communities hold a contrary view as they see mining to have negatively affected their livelihoods through reduction in farm size, crop yield, and income. This shows that, depending on which actors are asked on the impact of sand mining, the interest of each individual or group always manifest over the other. However, the inherent negative environmental effects cannot be disputed.

Madyise (2013) in his case study in Gaborone, South Africa found sand as a source of revenue for the government in as in the form of royalties levied on mining companies, lease fees, while at the same time provides job opportunities for many youths thus reducing the unemployment burden and increase the purchasing power of many others especially the local. Whiles Asare et al. (2024) study in Accra, Ghana, acknowledges the financial gains in the mining sector, they found a huge disparity on the revenue gained from the mines as most of the revenue goes to the miners, land owners, and truck drivers rather the majority of the local residents who are more negatively affected with mining impacts due to environmental damaged. Similarly, Bendixen et al. (2023) in their extensive systematic review on Scopus journal articles on the drivers and effects of sand mining in Sub-Saharan Africa found that various literatures on sand mining in Sub-Saharan Africa have highlighted job creation, infrastructural buildings, taxes and income as some of the positive effects of sand mining. They however, stated that, infrastructural damages, pollution, erosion, and loss of agricultural lands are negative hall marks of sand mining as a result of the high dependency for the many of the Sub-Saharan countries for livelihood sustainability and development.

Komma's (2019) investigation on high-risk zone (cell 6) of the Gambian coastline found sand mining to be one of the human induced activities impacting the coastal zone specifically the cell 6 of the coastline. Similarly, Sambou (2023) in his empirical study using qualitative approach to assess resource-developmental challenges faced by residents of Kombo South, have found sand mining to be one of the major issues affecting many coastal communities in the Kombo South District of the Gambia as a result of its extraction. In his conclusion, he highlighted sand mining as one of the potential activities to cause conflicts. Interestingly, sand mining in the Gambia is both legal and illegal within the cost areas of the Gambia.

Several empirical studies (Bosco & Sumani, 2019; Komma, 2019; Ashraf et al., 2020; Ankiilu, 2021; Ado, 2021; Ibrahim et al. 2021; Mensah, 2022; Mensah and Mattah, 2023; Choudhary, 2023; Bendixen t al., 2023; Asare et al., 2024) agreed on the multiplicity of sand mining effects and absence of effective regulations for many sub-Saharan African countries, despite sand mining being recognised as a major economic activity along the coast.

The many effects of sand mining and weak governance has been attributed to a multifaceted and insufficient sand mining regulatory frameworks. Cognisant to the various studies, there is a consensus on the existence of sand mining effects and resource conflicts resource users in various parts of the globe, yet little is unknown as to the nature and magnitude of these effect of sand mining on coastal communities particularly in Kombo South Gambia. Thus, is essential to look into the effects of sand mining considering the many economic activities along the coast for blue growth. This paper aims to fulfil these gaps and expand the scope of research in this area.

3. Methodology

3.1 Study area

This study was conducted in three communities in Kombo South district in the Gambia (Figure 1). Kombo South District lies at latitude 13.25 and longitude -16.75. The district of Kombo South has 48 villages, of which 17 villages are along the coast line. For this study, the three selected communities of interest (Sanyang, Gunjur [Sambuya], and Tujereng) have a combined population of 61,583 people with 7698 households, a growth rate of 3.1% and an average household size of 8 people(GBoS, 2013). The district is one of the most populated districts in the Brikama Administrative Area, West Coast region of the country (GBoS, 2013). The study areas are 10, 14, and 26 km from Brikama, thereby making them relatively accessible for truck drivers to convey sand to Brikama and other cities. The three selected communities for the study are characterised by an agrarian economy, with majority of the residents engaged in horticulture and other subsistence farming (GBoS, 2013). The lands are the study areas are under customary ownership, predominately manage by Alkalos, clan heads or family heads who make land-use decisions (GBoS, 2013). The three study communities purposely selected based on the mining intensity as per the National Environment Agency insights within the last decades.

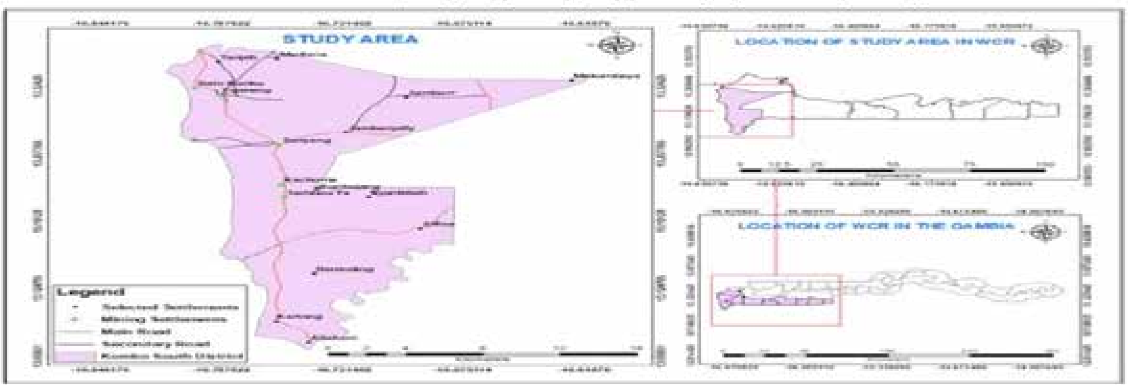


Figure 4: Map of the Gambia Showing Kombo South district and the study area Source: Barrow (2024)

3.2 Sampling, data collection, and analysis

The research was designed as mixed method study. The complexity of the sand mining sectors and the multiplicity of actors made the study to adopt mixed method study. Also, the ability to triangulate the findings from both qualitative and quantitative study and to discuss realities from the respondents' perspectives inform the decision to adopt this approach. The primary data were collected through a semi-structured questionnaire, field observation checklist, FGD guide, KII guide, and the secondary data was collected through a desk review. A multi-stage (systematic and convenience) sampling was use to select 400 household heads, and 3 FGDs were conducted, one in each community. A purposive sampling technique was used to select 10 key informants from the Government institutions, private individuals, local council, and the communities. Furthermore, a direct field observation was conducted and GIS mapping was done. The aims of the FGDs and KIIs was to sound the collective experience of the communities and the expert opinions on the effects of sand mining and its governance. The field visit and GIS were meant to ascertain the actual land-use and land cover changes pattern oof the mining sites. A content analysis was conducted on relevant regulations using strength, weaknesses, opportunities, and threats (SWOT) analysis with respect to sand mining governance in the Gambia in the context of sustainable development and blue growth. The data was collected between February 2024 and October, 2024.

4. Results and Discussions

4.1 Environmental/ Socioeconomic effects

The study reveals several environmental effects of sand mining. Among the effects identified include inadequate land, erosion, and biodiversity loss to be the most noticeable effects on sand mining in the communities. Also, road damage, flooding health hazards and other effects were found to be other severe effects as perceived by the communities in relation to sand mining. These findings indicate that the local variation of environmental effects is distinct with varying degree on each community. Also, the finding reveals that the severity of the effects varies from community to community. This indicates that community specific factors influence the severity of the environmental effects, thus the need for tailored interventions to tackle the individual challenges of each community.

Table 1: Environmental effects of sand mining as affected by categorical variables

		Frequency		
		No	**Yes**	**Total**
Variable	Category			
Sex	Female Male	170 158	33 39	203 197
Community	Gunjur Sanyang Tujereng	147 105 76	45 19 8	192 124 84
Ownership	Clan Individuals	183 145	40 32	223 177
Marital status	Married Single Divorced/Widow	216 88 24	58 13 1	274 101 25
Age	18-25 26-30 31-45 45+	77 60 117 74	10 7 28 27	87 67 145 101
Total		**328**	**72**	**400**

Source: Barrow (2024)

On socioeconomic effects of sand mining based on key categorical variables like sex, community, ownership, marital status, and age, the study found that male respondents are perceived to be the most affected gender on socioeconomic effects of sand mining from the survey. However, insights from FGDs and KIIs are contrary to that claim, as most of the participants highlighted perceived female to be the most affected. This claimed by the FGD participants is largely due to the destruction of women gardens by sand mining activities. This as sad by one woman participant who doubles as a gardener;

> *"the Chinese will use their machines and enter in the between women's "faroos" and spoil everything with their machines that place people grow their food stuff to use that to feed their families. And if they do that when heavy wind comes there is no tree to help our gardens because they brought down all the trees there so the wind will spoil all our garden" (Arokey 45, F).*

These findings support Nurhasan and Saputra (2018) study, which they found sand mining o have direct impact on agricultural land causing decline in the economic condition of the community. This as they continued triggers income decline, loss of livelihoods to farmers and increase social disparities between sand miners and farmers.

The FGD and KIIs respondents, the field observation, and subsequent land-use land-change analysis shows similar effects of sand mining on the communities. On the issue of agricultural land loss, the participants highly associate it to the intensity of the mining activities as most of the mining are happening in the same parcel of land which serve as farms and gardens for the community. This says; *"Ah it usually causes us flooding during rainy season and they usually spoil women's "faroos" and our lands are been spoiled for agriculture" (Yusupha 55, M).*

Another participant made emphasis that their farms have been completed out of touch for crop production as a result of lagoons formed post-mining. This, they said,

"…. and now the women can no longer cultivate rice in those fields and these has also affected our food sufficiency. This is because rice can no longer grow in those fields" (Female FGD participant from Sanyang)
"But that is like a lagoon of its own now. Where no one will be able to grow any crop or even to plant any tree there. …. nothing is able to be done there. ….. you are mining the farmland or the garden land of those women. So you are directly taking away their source of livelihood from them." (KI respondent from Sanyang).

These concerns as confirmed by Adedeji et al. (2020) study, communities take greater burden of environmental effects of sand mining activities compare to other stakeholders. Similarly, the issue of tree felling was a notable concerned associated to sand mining. This issue as one FGD participant succinctly put,

"…those big trees around our beach side have been cut down by those companies. Any trees they remove they just bury it and after those operation...." (Male FGD participant from Tujereng).

These findings confirm Amour and Haji (2024) study. Which they found findings, serious environmental damages, such as land destruction, damage to farmlands, ecosystem damage, and deforestation as a result of sand mining activities in the North 'B' district of Zanzibar, Tanzania. Moreso, the finding agreed with Adedeji et al. (2020) which found trees along the Sagamu/Ore highway to have almost cut off due to sand mining.

Threat to sea level rise and climate change impacts were associated with sand mining. Studies have confirmed human anthropogenic activities to be connected with impacts of climate change (Mbaka and Rono, 2022; Essaw et al., 2023) which the coastal communities of Kombo South are not an exception. This as stated by one respondent;

"In the past, people were mining beach sand, which is having a serious impact on the marine ecosystem. You cannot just come and dig, because we know that those dunes also serve as a barrier of protection from storm surges or the sea level rise. And within these coastal communities, we have mined all the dunes, except the dunes that we call the frontliners. …. if those dunes are cleared, the impact on the marine environment will be severe because you

are calling for the ocean or the sea to come in and when that happens, we are in the era of climate change. (KI respondent 6, Government Official).

Another key effects sand mining faced by the communities is the issue of road damage caused by heavy truck plying community roads to and from the mining sites. This according to them makes accessing the beach difficult. This as one participant stated;

"The road network is completely destroyed, affecting the people that are living within that particular area. And where the mining is happening, mostly it's along the beach. So they either use the main beach highway or the other highway. All of these roads are destroyed. So when they are destroyed, the economic activity that is supposed to take place at the beach is affected." (KI respondent from Sanyang).

These remarks are similar to Adedeji et al. (2020) findings, which they found sand mining to have generates heavy traffic which impairs the road networks and the environments. This as a result caused road damage especially when those roads where not design for heavy trucks.

Equally, the land use/land cover changes observed in the 30km2 study area between Tujereng and Gunjur (presented in red in Figure 8), provides compelling evidence of environmental and anthropogenic effect of sand mining and its related activities shaping the landscape from 2017 to 2023. These land use and land cover changes (Table 2) and (Figure 3 and 6) highlight significant shifts in key land use features such as increased water bodies, flooded vegetation, and built areas, alongside notable declines in tree cover, agricultural crops, and bare ground.

Table 2: Land Use/Land Cover Change in square km, 2017 and 2023

Study Area Land Use (km2)							
Year	**Water**	**Trees**	**flooded vegetation**	**Crops**	**built area**	**bare ground**	**Rangeland**
2017 (km2)	10.85	6.31	1.66	0.76	2.25	0.77	7.55
2023 (km2)	12.51	2.86	2.75	0.19	5.01	0.61	6.23
Km2 change (2017-2023)	1.66	-3.45	9.17	-0.57	2.76	-0.16	-1.32
% change (2017-2023)	5.53	-11.50	3.64	-1.90	9.20	-0.54	-4.40

Source: Barrow (2024)

Conversely, from Table 2, the decreasing presence of trees (-11.5% change), and crops (-1.9% change), and bare ground (-0.5% change), all indicates a rapid increased in mined areas in addition to other land use activities (Figure 2).

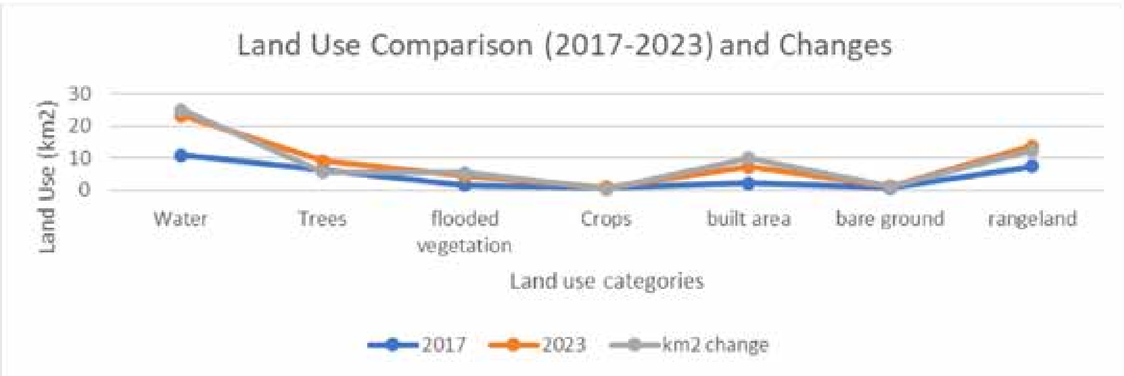
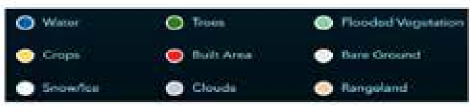


Figure 5: Land use comparison in square km, 2017 and 2023
Source: Barrow et al. (2024)

Figures 3 and 4 presents the land use land cover changes between 2017 and 2023 in the study area. The figures show the change in water, flooded vegetation, trees and built areas.

Figure 6: Land-use land-cover changes, 2017

Figure 7: Land-use land-cover changes, 2023
Source: Barrow (2024).Legend



As observed in Table 2, water coverage has significantly increased to 5.50 percent. This is directly associated to the encroachment of sand mining, which erodes the lands of its topsoil and vegetation, thus leaving behind depressions that fill with water over time. This finding is consistent with (Anokye et al., 2023) findings in central region of Ghana, which artificial ponds and water bodies were associated to have been created as a results of sand mining. Similarly, the proportion of flooded vegetation has also increased by 3.6 percent. Also, the built-up area as increased by 9.2 percent. This rapid increase shows the conversion of previously natural and serene coast into residential and other infrastructural developments. This finding is not surprising, as aligns with the global patterns of urbanization, particularly along the coast where economic drive and population growth drives the expansion of cities (UN-Habitat, 2016). However, the rapid growth in urban development in the study area coupled with lack of land use planning, poses challenges for environmental conservation and resource management including sand mining and sustainable coastal protection. This trends as stated by Bendixen et al. (2023), built-up areas have been noticed to be on expansion at the expense of ecological valuable lands in Sub-Saharan Africa.

Another striking concern associated with sand mining activities is the decline in tree cover (%11.5) in the study area. This tree decline is as result of tree feeling by sand miners, this as stated by KII informants;

"…. all the trees, the baobabs and other things, the big trees that are around the coast, they›ve all gone. So, all the big trees have gone" (KI respondent, Tujereng). This as re-echoed by a youth environmental activist, "… it›s just crazy. So, the huge destruction of the forest cover as well. Because wherever they are mining, they will cut down trees there. And we all know how important trees are to our environment. So, instead of them preserving those trees, they go ahead, cutting down all of those trees" (KI respondent, Sanyang).

These observed changes in Figures 3 and 4 are similar to Nurhasan and Saputra (2018) findings in Indonesia, where sand mining has led to deforestation and biodiversity loss in some part of the coastal areas.

Similarly, agricultural land areas decreased by 1.9 percent in the study area. This decline highlights the growing pressure on agricultural land, which are increasingly being converted into mining or other related land uses and it directly affects the local women gardener, many of whom heavily depend on gardening for their sustenance. These changes are indictive of sand mining's intensification, urban development, and the consequential environmental deterioration. Comparing these results to previous studies in similar contexts highlights the regional and global relevance of the observed changes.

4.2 Governance

A desk review on regulatory frameworks was conducted on key acts and regulations governing sand mining and its related activities. Through a content analysis using the SWOT methodology, gaps in sand mining governance in the Gambia were identified and discussed in the context of sustainable development and blue growth. As the primary environmental laws, the National Environment Management Act (NEMA) 1994, focuses primarily on environmental protection but does not adequately address the specific challenges posed by sand mining. Notwithstanding the act's provision of legal basis for general environmental management, it falls short to explicitly address the sustainable management of sand resources, a concerned that has been raised in similar study by

Suleiman (2020) in Zanzibar, Tanzania. For the Mines and Quarry Act 2005, serves as the primary legal tool for resource exploration including sand mining. Although, the act is clear in its delineation of roles and responsibilities for both miners and regulators, it is found to be weak in its enforcement mechanisms particularly in combating illegal mining and ensuring post-mining rehabilitations. Similar to NEMA 1994, the Mines and Quarry Act 2005 does not address the growing demand for sand, which leads to unsustainable sand mining practices.

The Environment Impact Assessment (EIA) regulations 1994 proof to be an essential regulatory tool for monitoring development projects and environmental activities at all spheres including sand mining activities. While the EIA act encourages public participation and promotes transparency, its enforcement is found to be weak particularly for EIA stakeholders on monitoring to legal sand mining sites. In addition, the fines levied against violators are often insufficient to serve as deterrent for illegal sand mining activities and non-compliance. Besides, the act seen an obstacle and faces opposition from industrial players in need of sand. This reflects the challenges stated in past studies, which noted that economic pressures and demand often undermine enforcement of environmental laws (Bendixen et al., 2023).

5. Conclusion

Sand is an important resource for economy wellbeing; however, the socioeconomic and environmental effects of its extraction highlight a critical intersection between sustainable development and the blue economy. Coastal ecosystems are integral for human survival and economic activities. However, are face with significant degradation due to sand mining, particularly in the coastal districts like Kombo South in the Gambia. Often driven by increasing demand from the construction industry and infrastructural development, sand mining comes at a substantial economic, environmental and social cost. Agricultural land loss, erosion, road damage, deforestation, and damage to TDA are among the severe effects of sand mining disrupting community livelihoods and exposing to climate vulnerabilities. These adverse effects highlight the need for sustainable resource management, as unrestricted exploitation of sand resources compromises the long-term viability of the coastal communities and their ecosystems.

In the context of blue economy, the nexus between sand mining and coastal resource management reflects a subtle balance between economic growth and environmental conservation. Whiles mining generate employment, revenue, and supports construction industry, its unregulated nature leads to conflicts over resource allocation, undermine community resilience, sustainable development and potential to impede blue growth. Governance frameworks, such as NEMA 1994, Mines and Quarry Act 2005, and EIA 1994 remains insufficiently equipped to address these challenges. Integrating sustainable practices and strengthening policy enforcement are essential in harmonising economic benefits with economical conservation and blue growth. Ultimately, ensuring the sustainability of sand mining within the blue economy requires collaborative effects across governance, community involvement, and innovative resource management strategies. To address the effects of sand mining for sustainable development and blue growth, the following recommendations are made for the regulatory agencies and local authorities; (1) it is prudent for the regulatory agencies and their stakeholders to review the various exiting laws and regulation governing sand mining and streamlined with the current realities of integrated coastal management for environmental conservation, (2) Strengthening enforcement through the national police and the organised youth vigilantes at the communities for monitoring of illegal sand mining activities. The police and organised groups can aid to minimise the illegal mining especially at night, (3) the government to come up with land policy and where possible zoning for proper and coordinate land use and management, particularly within the TDA. This will help in safeguarding the existing potential tourism space and promotes tourism at community level, (4) the government and partners to scout for alternative construction materials and chart ways for offshore sand dredging with proper coordination and for blue growth, (5) diversification of livelihood ventures at the community level to minimise the engagement into illegal and uncontrolled sand mining, (6) it is crucial for the central and local government and their partners to ensure that those negatively affected with sand mining are duly compensated.

Limitation

This study could not track and monitor illegal sand mining activities from the study area because of the sporadic and clandestine operations of the miners. Thus, makes it difficult to identify and know the perspective of illegal miners.

Declaration of competing interest

The author declares no known competing financial and personal relationship that could have appeared to influence the work reported in this paper.

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Toxicological risk assessment of unregulated ship scrapping in the territorial waters of Ghana

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Abstract

Ships have been integral to global commerce for centuries, serving as vital links between continents and enabling international trade. The life span of merchant ships and fishing vessels is estimated to be between twenty-five to forty years. The variance in the life span of these ships communicates the vast differences in the materials used for the construction of the vessels, the types of operations, maintenance culture and life extensions the vessels undergo in their life cycles. At the end of life, vessels are beached after useful parts are taken off by owners. The abandoned vessels are dismantled by local scrap metal dealers who lack proper protective gear and knowledge of safe ship breaking procedures, leave behind debris, pollutants, and toxic substances along the coastline. This poses significant risks to both human health and marine life. In this paper, a toxicological risk assessment is conducted on a selected beach site with convenience sampling technique. Soil samples were obtained and tested for the purposes of identifying hazards, performing evaluations, assessing exposure levels, and characterizing the toxicological risks of the unregulated ship breaking activities. The results from soil samples indicate the presence of varied levels of various heavy metals including Zirconium, Lead, Iron, Titanium, Strontium, Manganese, Nickel, and Zinc at the beach. The paper concludes that the beaches at which unregulated ship scrapping activities are being carried out are toxicity exposure zones, which present public health hazards to the surrounding coastal communities. There is an urgent need to regulate ship scrapping in Ghana to protect the environment and the health of the people. A comprehensive policy aimed at regulating ship breaking with modern shipyard may provide the needed infrastructure and make personal protective equipment available to the workers involved in ship breaking activities.

Keywords: *Toxicological risk assessment, unregulated ship scrapping, coastline degradation, environmental pollution, heavy metals contamination*

Introduction

The needs of human beings have strongly motivated the utilization of the sea (Kleingärtner, 2018). Human beings always have a close relationship with the marine environment through various activities including harvesting food from the sea and laying cables for communication. In addition, the transportation systems of man include the sea, where large volumes of cargoes and passengers are transported at a cheaper cost (Andersson et al., 2016; Christiansen et al., 2007). Ships have been integral to global commerce for centuries, serving as vital links between continents and enabling international trade. They are generally classified into three main categories based on their functions. Cargo ships, such as bulk carriers, tankers, and container vessels, transport goods across the globe. Passenger ships, including ferries and cruise liners, are designed for human transportation. Specialized vessels, like dredgers, icebreakers, and offshore support ships, cater to specific industrial needs. Over eighty percent of global trade volumes is through maritime transport, which is primarily facilitated with merchant ships. Constructed primarily from durable materials like steel, ships are not only engineered for longevity during their operational life but are also well-suited for recycling once decommissioned. The type and functionality of these vessels significantly influence their lifespan and the environmental impacts they generate both during their service and after their retirement (Kaluza et al., 2010).

Life cycle analysis of ships indicates that after the initial cost of building a ship, the operational, maintenance and life extension costs increase exponentially with the age of the ship (Tuan & Wei, 2019). Especially, the operational and maintenance costs of maritime vessels become financially unjustifiable after 25 to 30 years of the vessel. As such, it is financially beneficial to dispose vessels which are at least 25 years of age. (Dinu & Ilie, 2015). Therefore, the average operational lifespan of a ship is around 25 to 30 years, determined by factors such as structural wear, operational costs, and compliance with environmental regulations. Technological advancements often render older vessels obsolete. Regulations like those from the International Maritime Organization (IMO) promote the phasing out of older, less efficient vessels, such as single-hull tankers. This lifecycle is also influenced by market dynamics, with economic downturns sometimes accelerating the retirement of ships (Kaluza et al., 2010).

Decommissioning involves preparing a ship for its end-of-life phase. This includes removing onboard equipment, conducting environmental assessments, and determining whether the vessel will be recycled or repurposed. Economic pressures, such as recessions, often lead to increased decommissioning as shipowners retire less efficient vessels to cut costs and address overcapacity in the shipping market (Yin & Fan, 2018).

Shipbreaking, a practice integral to the maritime industry, involves dismantling end-of-life vessels to recover valuable materials, primarily steel. While this process addresses global demands for recycled resources, it is accompanied by significant environmental and human health risks. Many shipbreaking yards, especially in developing nations like India, Bangladesh, and Pakistan, use rudimentary techniques such as the beaching method. These methods result in the uncontrolled release of hazardous substances, including heavy metals, polychlorinated biphenyls (PCBs), hydrocarbons, and asbestos, into coastal soils and marine ecosystems. This contamination compromises biodiversity, disrupts ecosystems, and poses long-term toxicological risks to marine organisms and human populations dependent on coastal resources (Yin & Fan, 2018). According to Carpenter et al. (2021) humans have always polluted the marine environment. Ship breaking is another way man is polluting the marine environment by releasing various toxins.

The scrap value of a ship is determined by the realizable value of the ship's components as well as the cost of demolition. Both are heavily influenced by the cost mechanisms in place in the anticipated demolition country. Shipbreaking is predominantly concentrated in countries like Bangladesh, India, and Pakistan, where the beaching method—a process of dismantling ships on tidal beaches—is commonly used. This method, while economically viable, is environmentally hazardous. Toxic substances, including asbestos, heavy metals, and hydrocarbons, leach into coastal soils and marine ecosystems, posing significant risks to biodiversity and human health. Efforts to mitigate these issues include international frameworks like the Basel Convention and the Hong Kong Convention, but enforcement remains inconsistent (Kaluza et al., 2010).

In recent years, ship demolition has gravitated toward countries with cheap cost of labour, relaxed occupational health and safety standards, and less stringent environmental law enforcement. These prevalent conditions have turned the territorial waters of Ghana into a damping site for ships, which are at their end of life. These obsolete ships which are usually beached in the territorial waters of Ghana, in most cases are decommissioned by their owners who attempt to salvage stuff they deem valuable, and the demolished ships are dismantled by local scrap dealers who harvest steels and other valuables that can be sold to Steel firms in the Tema industrial enclave (Evans Ago Tetteh, 2022). Apparently, Ghana has become an emerging hub for shipbreaking activities in the West African subregion, and is mirroring the challenges seen in South Asia, with limited regulatory oversight and inadequate hazardous waste management infrastructure. Informal scrapping operations near coastal zones, like those in Tema, and the study area of this research, release toxic pollutants that leach into marine environments, and leave debris on the shore as evident in Figure 1.1 and Figure 1.2 endangering the marine ecosystem and the local communities. The combination of growing economic pressures and the global shift of shipbreaking to regions with weak environmental enforcement as stated by Yin & Fan (2018) may as well be the reason for the phenomenon.

Though metal smelting and processing is a major contributor to the country's formal industrial sector while scrap metal recycling serves as a common industry in the informal sector (Dowling et al., 2016), and shipbreaking and recycling is a major supply source to the country's steel product manufacturing industry, the unregulated phenomenon is usually conducted along beaches by the private sector without any regulatory agency's supervision as documented by Uddin et al. (2024) in the case of Bangladesh. In addition, the Country lacks Ship Recycling Facilities (SRF), which could employ environmentally friendly shipbreaking methods.

Therefore, this seeks to assess the toxicological risks associated with the emerging unregulated shipbreaking phenomenon in Ghana, with an emphasis on identifying hazard propagation into the soil, evaluation of hazards through quantification, assessment of exposure levels, and characterization of toxicological risks as well as impacts on coastal land, marine ecosystems, and the health of the people in the community.

Figure 0.1 A beached vessel being scrapped

Figure 0.2 Discoloration from debris at the beach

inadequate hazardous waste management infrastructure. Informal scrapping operations near coastal zones, like those in Tema, and the study area of this research, release toxic pollutants that leach into marine environments, and leave debris on the shore as evident in Figure 1.1 and Figure 1.2 endangering the marine ecosystem and the local communities. The combination of growing economic pressures and the global shift of shipbreaking to regions with weak environmental enforcement as stated by Yin & Fan (2018) may as well be the reason for the phenomenon.

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Methodology

Ship breaking activities occur as and when a decommissioned vessel is abandoned, and scrap metal dealers discover such a vessel. Shipbreaking is not a daily continuous activity along the coastlines of Ghana. In fact, ship breaking activities are random walk puzzles from the preying eyes of the Environmental Protection Agency (EPA). In most cases, by the time EPA gets to know about the activities, the scrap dealers are done and have vacated the location. Therefore, the selected location for this study was based on convenience sampling because the lead author discovered the ongoing ship breaking activity while on a vacation in April 28, 2021.

Sample Collection and Preparation

The selected site for the study is Prampram beach, which is about 31.00 kms or 16.74 nautical miles from Tema Port, the largest port of Ghana. Three samples were collected and analyzed for preliminary studies to determine whether there was a need for a full-scale study. The preliminary study samples, as indicated in Figure 3.1, were collected on January 14, 2024, from sample points P1, S1 and S2. The preliminary study indicated that there was a need for full-scale study.

Twelve (12) soil samples were collected on February 25, 2025, from the selected site spanning from the seashore to the community with a systematic sampling technique based on a grid system with the points situated 150 meters apart horizontally and 100 meters apart vertically into the community as indicated in Figure 2.1 with the aid of a handheld GPS device. Each sample collected was stored in a plastic bag, and labelled appropriately with the location labels S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14 as indicated in Figure 2.1. Samples were collected at a depth of about 5 – 10 centimeters below the topsoil because the shipbreaking activities had occur almost three years before the samples were collected. Even though there were still visible discoloration of the beach sand as indicated in Figures 1.1 and 1.2, the study seeks to analyze the propagation of toxics into the soil.

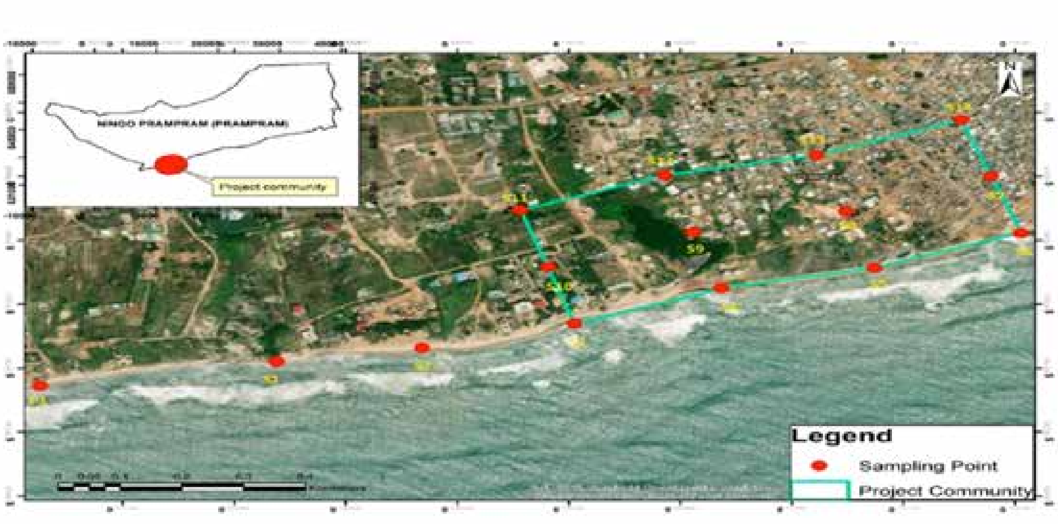

Figure 0.1 Map of the sampling points from the coast to the community

In preparation for the soil analysis, the obtained soil samples were washed with deionized water and allow to air dry. New disposable gloves were used for each sample to protect the integrity and reliability of the results of the soil analysis. Samples were preserved in a appropriate storage environment to prevent degradation until analysis.

Heavy metal analysis method

A ThermoScientific Niton brand handheld X-Ray Fluorescence (XRF) analyzer was used for a comprehensive analysis to determine the concentration of heavy metals in soil samples. The analysis of soil samples was conducted in a laboratory with hand gloves and safety glasses as part of the personal protective equipment employed. Non-leach sample bags and labels, and non-metallic scoops were used as the materials. The XRF device was calibrated using certified reference materials. At the start of testing every sample, verification checks were performed to ensure the device is accurately calibrated to ensure accuracy of the results.

Each sample was mixed thoroughly to ensure homogeneity of the constituents prior to the XRF analysis. Two distinct modes referred to as the Test All Mode and Soil Mode, were used three times for the conduct of the analysis for each sample to account for any variability and to enhance the reliability of the results in case the soil sample was not homogeneously mixed in the bag. The average value of the six values obtained from the three readings in each testing mode was computed and recorded.

Results and Discussions

Results

The results obtained from the RXF analyzer indicate the presence of various metals including Zirconium (Zn), Lead (Pb), Iron (Fe), Titanium (Ti), Strontium (Sr), Manganese (Mn), Nickel (Ni), Zinc (Zn), and Copper (Cu), at the beach. As mentioned in paragraph two of Section 2.2, Table 3.1 gives the record average values computed from the test results heavy metals identified in the soil samples.

There are other elements obtained which are not listed in Table 3.1 because they were not present in every sample. These elements which were not present in all the 12 samples include Arsenic (As), Mercury (Hg), Cobalt (Co), Niobium (Nb), Platinum (Pt), and Barium (Ba).

	Zr	Pb	Fe	Ti	Sr	Mn	Ni	Zn	Cu
S3	51.32	4.56	32126.06	4820	302.73	936.80	53.55	106.86	28.4
S4	53.32	5.5	7604.41	3586.67	321.28	312.09	44.25	25.03	27.95
S5	38.87	5.21	3436.67	2090.00	318.22	137.79	40.52	12.47	20.33
S6	143.86	21265.71	10083.75	2500.00	125.67	309.78	41.56	39.90	24.07
S7	264.64	26.20	10159.92	1900.00	126.06	174.92	37.08	108.56	26.85
S8	288.25	6.61	4177.85	2630.00	41.12	254.94	41.46	20.63	18.54

S9	100.11	3.70	2455.44	2845.00	19.26	102.41	24.76	22.45	13
S10	247.83	8.11	6103.62	943.33	45.45	192.75	48.28	37.38	14.99
S11	293.85	6.84	4547.25	6186.67	30.58	299.47	40.86	20.55	20.66
S12	137.97	5.46	8331.62	3533.33	49.18	246.69	48.72	51.80	19.26
S13	232.31	6.39	5359.74	2110	54.61	162.81	42.31	20.31	22.73
S14	178.12	6.78	7422.91	2953.33	131.50	305.88	38.94	62.45	24.73
Mean	169.21	1729.26	8,484.10	3,008.19	130.47	286.36	41.86	44.03	21.80
Std. Dev.	102.55	5896.08	7,873.84	1,579.07	117.97	222.76	13.46	33.97	7.66
EU/WHO Limit	-	300	150	-	-	437	50	300	36

Figure 0.1 Heavy metal concentrations (mg/kg) in various soul samples.

Discussions

Lead is highly toxic to humans, causing developmental delays, reduced cognitive function, and kidney damage. Children are particularly vulnerable, with exposure linked to learning disabilities and behavioural issues. In adults, chronic exposure leads to hypertension and organ dysfunction (Kacholi & Sahu, 2018; Mudgal et al., 2014). For marine life, lead bioaccumulates in aquatic organisms, impairing their growth and reproduction. It also disrupts water chemistry, endangering marine ecosystems. Unregulated shipbreaking introduces lead via paint and electronic components, contaminating coastal environments (Okereafor et al., 2020). Although Lead values were low in most samples, the 21265.71mg/kg value obtained in the sample from location S6 is quite alarming. That single value raised the average Lead value to 1,729.26 mg/kg which is over 5 times the acceptable threshold value of 300mg/kg according to the European Union. World Health Organization advises precaution on Lead in soil specified a threshold value of 85 mg/kg. The average quantity of Lead in the samples is best classified as severe risk to both humans and the marine ecosystem.

While Manganese is necessary for biological functions, excessive manganese exposure causes neurological disorders resembling Parkinson›s disease in humans (Mudgal et al., 2014). It can also lead to cardiovascular dysfunction and developmental issues. In marine environments, manganese affects plant growth and photosynthesis, impacting the entire food chain. Shipbreaking activities release manganese from steel and coatings, further polluting coastal ecosystem (Okereafor et al., 2020). Besides the quantity present in the sample obtained from location S3, all other samples including the average of all twelve samples is below the WHO threshold of 437mg/kg. Therefore, the average Mn value of 286.36mg/kg is %65.53 of the WHO threshold value. As such, Mn is classified as mild risk.

Nickel exposure can cause allergic reactions, respiratory problems, and increased cancer risks in humans, especially those in occupational settings. Excessive nickel harms aquatic life by disrupting enzymatic activities and reproduction. Its toxicity affects the health of plants and microorganisms, altering ecosystem dynamics. Shipbreaking processes often release nickel from metal alloys and machinery, contaminating coastal waters and soils (Okereafor et al., 2020). Except for the sample obtained from location S3, all the values of obtained and the average of the entire 12 samples is %83.75 of the acceptable WHO threshold of 50mg/kg. Therefore, the quantity of Ni present is classified as medium risk to both human and marine life.

Zinc is essential for human health but becomes toxic at high concentrations, causing nausea, vomiting, and copper deficiency. Excessive zinc in aquatic systems disrupts photosynthesis in plants and metabolic activities in marine animals. Its accumulation can lead to ecosystem imbalances. Unregulated shipbreaking contributes to zinc pollution through galvanized metals and coatings, affecting both terrestrial and aquatic environments (Mudgal et al., 2014; Okereafor et al., 2020).

Copper (Cu), while essential in small amounts, becomes toxic when released into the environment through industrial and agricultural sources. Elevated copper levels harm marine life by disrupting gill function in fish, impairing their ability to regulate ions and oxygen intake, and causing oxidative stress. In aquatic ecosystems, copper affects microbial communities, reducing nutrient cycling and threatening food chains. Excess copper in sediments bioaccumulates, further endangering organisms higher in the food web. Contaminated potable water and soil also pose risks to human and animal health (Kacholi & Sahu, 2018; Mudgal et al., 2014; Okereafor et al., 2020). Copper is the only metal that is approximately uniformly distributed over the samples with an average value of 21.80mg/kg, which is %60.56 of the WHO's limit value of 36mg/kg. Therefore, the quantity of Cu present in the samples poses a mild risk to human but medium risk to marine life due to bioaccumulation.

Conclusions and recommendations

This study conducted a Toxicological risk assessment of unregulated shipbreaking activities in the territorial waters of Ghana by considering a case in the Prampram, which is about 16.74 nautical miles from the Port of Tema, which is the largest port in the country. Various hazardous heavy metals were identified in varied quantities over the 120,000 meter squared area, spanning 200 meters from the seashore into the community, and 600 meters along the seashore. The contaminants identified include Zr, Pb, Fe, Ti, Sr, Mn, Ni, Zn, Cu, Hg, and Co most of which have been identified by Fosu-Mensah et al. (2018) in the western Region of Ghana. The results presented in Table 3.1 reveal significantly varied levels of heavy metal contamination in the soil samples near the ship scrapping site. Notable is the level of Lead concentrations (Pb) present at sample collection location S6, which resulted in a mean value of 1,729.26 mg/kg, exceeding the WHO standard of 300 mg/kg for soils by over 5 times. indicating severe risk posed to both human and marine life. Even though there is no agriculture activities going on at the time the samples were collected, it is highly likely an innocent individual may decide to engage in a backyard farming. This is likely to cause Lead poisoning in the community because the sample was collected 10 – 5 centimeters below the topsoil. In addition, although Fe and Mn, are less toxic, they were found in average concentrations of 8,484.10mg/kg and 286.36 mg/kg respectively. These values are exceedingly greater than WHO threshold values of 150mg/kg and 437mg/kg respectively, and these could disrupt soil chemistry and plant growth (Ahmad et al., 2021; Nasir & Bashir Barkoma, 2020).

Therefore, the beaches at which unregulated ship scrapping activities are being carried out are toxicity exposure zones, which present public health hazards to the surrounding coastal communities. There is an urgent need to regulate ship scrapping in Ghana to protect the environment and the health of the people. There is a need for collaborative effort between the Ghana Maritime Authority and the Environmental Protection Agency to proactively prevent unregulated ship scrapping by using tugboats to tow abandoned decommissioned vessel to a designated location. The current situation where ship scrapping is being done randomly along Ghana's beaches is littering the identified heavy metals along the neighboring communities.

Ghana›s nascent shipbreaking industry, centered around coastal regions like Tema, faces challenges like those in South Asia. The absence of formal infrastructure and regulatory oversight has led to informal practices that release pollutants, such as oil residues and heavy metals, into coastal and marine environments. This contamination threatens local fisheries and the health of communities dependent on these ecosystems. Learning from the experiences of countries with established shipbreaking industries could help Ghana develop sustainable practices and regulations (Kaluza et al., 2010) to solve the problem of coastline degradation and the heavy metals contaminations.

A collaborative effort between ministries of Agriculture, Transport, Science and Environment must urgently initiate a process to develop a comprehensive policy aimed at setting toxicology threshold values for various heavy metals and regulating ship breaking with modern shipyard that should provide the needed infrastructure and make personal protective equipment available to ship scrapping workers. A modern shipyard shall mitigate the horizontal and vertical propagation of the heavy metals, and the debris shall be properly contained to protect the environment and the health of the people. The people who are currently involved in the unregulated ship scrapping without adequate protective equipment must be identified and screened for possible bioaccumulation of Pb and the other contaminants identified in this study.

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MARINE POLLUTION: A CASE STUDY OF COASTAL REGION IN MOMBASA COUNTY, KENYA

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ABSTRACT

Marine pollution poses a significant threat to the world's oceans, affecting marine life, ecosystems, and human health. The primary sources of pollution include plastic waste, oil spills, sewage discharge, and chemical runoff from industries and agriculture (Chen et al., 2020). The prevention of marine pollution requires a multi-pronged approach involving international regulations, technological innovations, and community engagement. International conventions such as the International Convention for the Prevention of Pollution from Ships (MARPOL) play a critical role in regulating the discharge of pollutants from vessels (International Maritime Organization (IMO, 2022). Moreover, technological advancements in waste management and oil spill response systems have reduced the impact of accidental spills (Fingas, 2018). For instance, enhancing waste recycling programs and implementing green port policies are effective strategies for reducing land- based sources of pollution (Jambeck et al., 2015). Despite ongoing efforts, further research and international cooperation are needed to address emerging challenges such as microplastics and climate change-induced pollution (Boucher & Friot, 2017). Ultimately, preventing and mitigating marine pollution is essential to ensuring the sustainability of marine ecosystems for future generations. The objectives of the study were to identify sources for marine pollution, the impact of marine pollution on marine and human life and the effectiveness of mitigation strategies to control marine pollution. The research targeted 50 respondents but only 22 respondents were able to fill the questionnaire. The findings of the study established that land-based sources such as urban runoff and industrial waste were contributing significantly to marine pollution to close to about 80% as compared to sea-based sources, this had greatly affected the marine ecosystem that impacting the people dependent on them for their livelihood, additionally fish, crustacean and lobsters had faced extinction. Finally, the inadequate enforcement mechanism and monitoring on the perpetrators by the regulatory bodies. The need for stronger legal frameworks, clear government action, and continued community involvement therefore remains critical.

Key words: *Marine Pollution, Marine Prevention*

INTRODUCTION

1. International Background

Marine pollution is a global concern, with significant impacts on ocean health, biodiversity, and human livelihoods. According to GESAMP (2015), marine pollution originates from diverse sources, including plastic waste, agricultural runoff, and untreated sewage, with an estimated 80% of pollutants entering the ocean from land-based activities. Plastics, for instance, contribute to massive pollution levels, with approximately 8 million metric tons entering the ocean annually (Jambeck et al., 2015). The international community has recognized marine pollution as a pressing issue, as evidenced by the adoption of Sustainable Development Goal 14, which seeks to "conserve and sustainably use the oceans, seas, and marine resources."

Pollution hotspots such as the Great Pacific Garbage Patch illustrate the extent of plastic accumulation, posing severe threats to marine life and ecosystems (Lebreton et al., 2018). Heavy metals and chemical contaminants also persist in the marine environment, accumulating in sediments and biota, leading to bioaccumulation and biomagnification (Rainbow, 2007). Additionally, oil spills and maritime transport emissions exacerbate oceanic pollution, affecting both open seas and coastal regions.

1.0 Regional Context

In the regional context, the Indian Ocean and Western Indian Ocean regions are significantly affected by marine pollution. These areas face increasing pressures from urbanization, industrialization, and tourism (UNEP, 2019). Countries along the Indian Ocean rim, including those in East Africa, contend with challenges such as plastic debris, oil pollution, and eutrophication due to nutrient runoff (Van der Werf et al., 2016). Coral reefs and mangroves, critical ecosystems in the region, are particularly vulnerable to pollution, threatening biodiversity and the livelihoods of coastal communities.

Regional cooperation initiatives, such as the Nairobi Convention under UNEP, aim to address marine pollution in the Western Indian Ocean by promoting sustainable management of marine resources (UNEP, 2019). However, limited funding and enforcement capacity remain significant barriers to achieving effective pollution mitigation.

1.1 Local Perspective

In Kenya, marine pollution is a growing environmental and socioeconomic challenge. The country's coastline, stretching over 536 kilometers along the Indian Ocean, is vital for fishing, and tourism, positively impacting local livelihoods. However, sources of marine pollution include plastic waste, industrial effluents, agricultural runoff, and untreated sewage (Okuku et al., 2021). Major cities like Mombasa contribute significantly to pollution, with poorly managed solid waste systems leading to plastics and other debris entering marine environments (Kiage et al., 2015). Kenyan marine ecosystems, including coral reefs, mangroves, and seagrass beds, face severe degradation due to pollution. Coral bleaching, exacerbated by sedimentation and nutrient pollution, is a major concern (McClanahan et al., 2014). Marine species ingesting plastics, such as sea turtles and fish, face health risks, which in turn affect human populations relying on seafood (Okuku et al., 2021). Additionally, water contamination poses public health risks, including waterborne diseases.

Marine pollution has profound effects on marine and human life. For marine ecosystems, pollutants such as plastics and chemicals cause physical, biological, and chemical harm. Marine organisms, including fish, seabirds, and mammals, often ingest or become entangled in plastic debris, leading to injuries, reduced reproductive success, and death (Thompson et al., 2004). Chemical pollutants, such as pesticides and heavy metals, accumulate in the food chain, impacting marine biodiversity and ecosystem functions (Teuten et al., 2009).

For humans, marine pollution poses health risks through the consumption of contaminated seafood and exposure to polluted water. Microplastics have been detected in seafood consumed by humans, raising concerns about long-term health effects (Rochman et al., 2013). Coastal communities relying on marine resources for livelihoods, such as fishing and tourism, experience economic losses due to degraded ecosystems (Rochman et al., 2016).

Addressing marine pollution requires a combination of preventive and remedial measures. At the international level, agreements such as the MARPOL Convention aim to regulate maritime pollution by controlling oil spills, waste discharge, and ship emissions (IMO, 2019). Regional initiatives, such as the African Marine Waste Network, promote collaborative efforts to combat pollution in African coastal regions (UNEP, 2019).

In Kenya, mitigation strategies include policy frameworks, public awareness campaigns, and technological innovations. The National Environment Management Authority (NEMA) enforces laws on waste management and pollution control, such as the ban on single-use plastics in protected areas (NEMA, 2017). Community-based initiatives, such as beach clean-ups and recycling programs, have also gained traction, fostering local engagement in pollution mitigation (Kiage et al., 2015).

Technological solutions, such as wastewater treatment plants and plastic recycling facilities, are being implemented to reduce pollution sources. However, these efforts face challenges, including inadequate funding, limited technical capacity, and insufficient public participation (Okuku et al., 2021). Enhanced regional cooperation, stricter enforcement of regulations, and increased investment in pollution control infrastructure are critical for effective mitigation.

2 LITERATURE REVIEW

2.0 Conceptual Framework

Marine pollution is a complex and multifaceted issue that arises from the interaction of various anthropogenic and natural processes. The conceptual framework for studying marine pollution focuses on the sources, pathways, and impacts of pollutants on marine ecosystems. Key sources include land-based activities such as agriculture, industrial discharges, and urban runoff, as well as ocean-based sources like shipping and offshore oil drilling (Andrady, 2011; Gallo et al., 2018). Pathways for pollutants include rivers, atmospheric deposition, and direct dumping into oceans. This framework also emphasizes the interconnectivity between human activities and marine environments, illustrating the role of socioeconomic factors, governance structures, and technological advancements in addressing marine pollution (Jambeck et al., 2015).

To effectively analyze marine pollution, the conceptual framework integrates environmental, social, and economic dimensions. Environmental dimensions focus on the types and behaviors of pollutants, such as plastics, heavy metals, and oil spills, as well as their ecological impacts on marine biodiversity and habitats (Teuten et al., 2009). Social dimensions explore public awareness, community engagement, and the role of education in mitigating pollution (GESAMP, 2015). Economic dimensions address the cost of pollution control measures and the economic losses incurred due to degraded marine ecosystems. This holistic approach ensures a comprehensive understanding of marine pollution and its mitigation.

2.1 Theoretical Framework

The theoretical framework for marine pollution is grounded in several interrelated theories. One prominent theory is the "Tragedy of the Commons," which explains how shared marine resources are overexploited and polluted due to individual self-interest (Hardin, 1968). This theory highlights the need for collective action and effective governance to manage marine resources sustainably. Another relevant theory is the "Ecosystem Services Framework," which underscores the value of marine ecosystems in providing essential services such as food, climate regulation, and recreation (Costanza et al., 1997). This framework emphasizes the necessity of preserving these services by addressing pollution.

Additionally, the "Pollution Cascade Theory" provides insights into the cascading effects of pollutants in marine environments. For example, microplastics can enter the food chain, impacting marine organisms and ultimately human health (Thompson et al., 2004). This theory aids in understanding the long-term and interconnected impacts of pollution. Combined, these theoretical approaches offer a robust foundation for analyzing the drivers, impacts, and solutions to marine pollution.

2.2 Empirical Framework

Empirical research on marine pollution involves the systematic collection and analysis of data to understand its extent, sources, and impacts. Field studies, laboratory experiments, and remote sensing techniques are commonly employed to gather data. For instance, empirical studies have quantified the accumulation of microplastics in coastal and deep-sea environments, revealing alarming trends in pollution levels (Law et al., 2010). Research on heavy metal contamination has identified hotspots near industrial and urban areas, highlighting the need for targeted interventions (Rainbow, 2007).

Longitudinal studies have provided insights into temporal trends in marine pollution, while cross- sectional studies have examined spatial variations (Cole et al., 2011). Empirical evidence has also shown the economic costs of marine pollution, such as the decline in fisheries and tourism revenues (Rochman et al., 2013). Importantly, empirical frameworks emphasize the importance of local context in understanding marine pollution, recognizing that solutions must be tailored to specific geographical, cultural, and socioeconomic conditions.

2.3 Research Gap

Despite significant advancements in understanding marine pollution, critical research gaps remain. One major gap is the limited understanding of the synergistic effects of multiple pollutants. While individual pollutants have been extensively studied, their combined impacts on marine ecosystems and human health are poorly understood (Syberg et al., 2015). Another gap is the lack of comprehensive data on pollution in remote and deep-sea environments, where monitoring is challenging and expensive (Ramirez-Llodra et al., 2011).

Additionally, there is insufficient research on the effectiveness of policy interventions and governance mechanisms in addressing marine pollution. Few studies evaluate the long-term outcomes of international agreements and local regulations, creating a need for more robust policy analysis (Rochman et al., 2016). Furthermore, the social dimensions of marine pollution, such as community perceptions and behavioral changes, are underexplored. Addressing these gaps requires interdisciplinary research that combines natural sciences, social sciences, and policy studies.

Finally, emerging issues such as nanoplastics, pharmaceutical pollutants, and the impacts of climate change on pollution dynamics present new challenges. These areas require urgent attention to develop innovative solutions and safeguard marine ecosystems for future generations (Wright et al., 2013)

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter focused on the research design, population target for the study, the sample size, data collection method, data analysis, data reliability and validity.

3.2 Research Design

In this study, a quantitative research design was employed to examine the effects of marine pollution on human and marine life and mitigation strategies. A cross-sectional approach was utilized to collect data at a single point in time, providing a snapshot of the relationship between the sources, effects/impacts and mitigation strategies.

3.3 Target Population

The target population for the study comprised of 50 people from the regulatory agencies, boat building and repairers, people living along the coastline and fisher folk communities among others. The study aimed to understand the sources, effects/impacts to human and marine life and mitigation strategies of marine pollution.

3.4 Sample Size and Sampling Technique

Given the manageable size of the population, a random sampling method was employed. This method was particularly suitable because the population size was relatively small, in this case, 22 respondents. All eligible individuals within the accessible population were included in the study to ensure comprehensive coverage and representation.

3.5 Data Collection Method

Data was collected through a structured questionnaire designed to assess the participants' level of understanding on marine pollution on the sources, effects/impacts to human and marine life and mitigation strategies. Additionally, open-ended questions allowed participants to provide qualitative insights to understand the sources, effects/impacts to human and marine life and mitigation strategies on marine pollution.

3.6 Validity and Reliability

To ensure the validity and reliability of the research instrument, the pilot test was undertaken for 10 respondents to ensure clarity and correctness of the research instrument. This was done to ensure the validity and reliability of the research responses to avoid ambiguity in gathering information. The respondents who undertook the pilot test were not included in the final survey.

3.7 Data Analysis

Quantitative data collected through the survey was analyzed using descriptive statistics approaches such as frequencies, pie charts while qualitative data will be analyzed using content analysis to summarize the participants' responses regarding the sources, effects/impacts to human and marine life and mitigation strategies on marine pollution.

3.8 Ethical Considerations

Ethical considerations were paramount throughout the research process. Informed consent was obtained from all participants, ensuring their voluntary participation and confidentiality of their responses. Participants were informed about the study's purpose, and their rights to withdraw from the study at any point were emphasized. The study adhered to ethical guidelines, respecting the dignity, privacy, and well-being of the participants.

4. DATA PRESENTATION AND ANALYSIS

4.0 Overview

This chapter presents the analysis and discussion of the research findings. The objectives of the study were to identify the sources of marine pollution, the effects to human and marine life and the mitigation strategies within Mombasa County in Kenya. Qualitative data was analyzed using content analysis whereas quantitative data was discussed using descriptive statistics where frequencies, percentages were used to present the research findings.

4.1 Data Presentation and Analysis

4.1.1 Social and demographic characteristics

This section analyses the characteristics of the sample of the study; which includes, Age, Gender, and the Level of Education of the respondents.

4.1.2 Age of Respondents

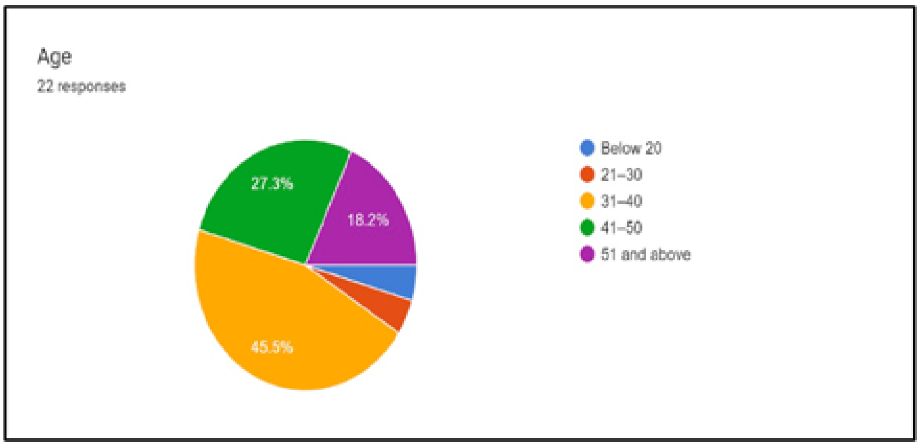


Figure 4.1: From the analysis majority of the respondents were between the age bracket of 31-40 which represents 45.5% followed by 41-50 which represents 27.3% and 51 and above which represents 18.2%. This diverse age distribution ensures a comprehensive understanding of views on marine pollution.

4.1.3 Gender of Respondents

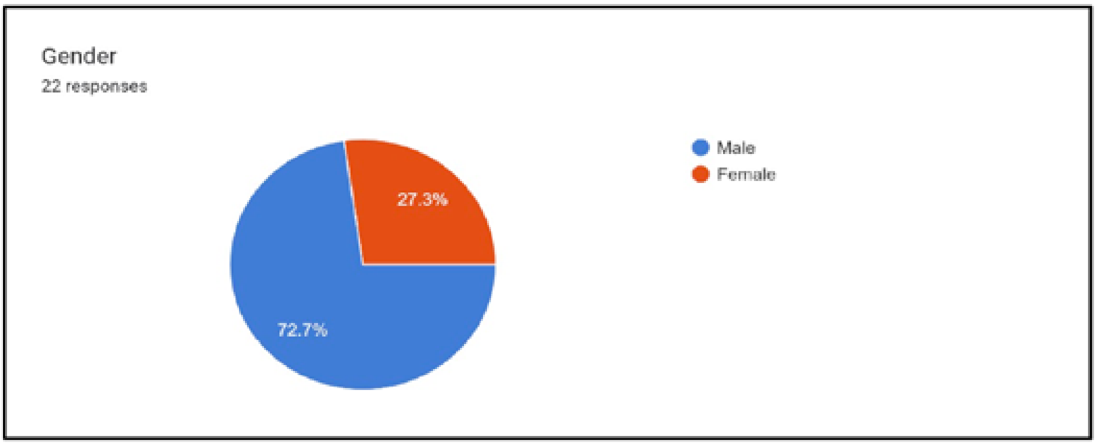


Figure 4.2 *From the analysis, male dominated in the response making up 72.7% of respondents whereas female constituted 27.3%. This affirms the low involvement of women in the maritime industry.*

4.1.4 Level of Education of Respondents

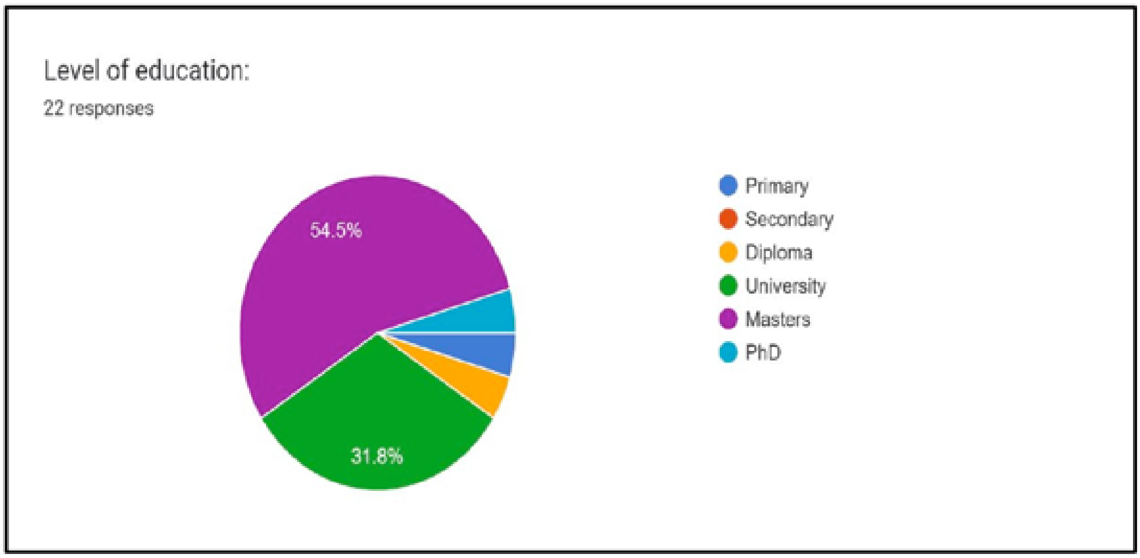


Figure 4.3 From the analysis, majority of respondents were having masters represented by 54.5% followed by Degree which represented by 31.8 percent. This means that respondents were well educated hence they could easily understand the area under study.

4.1.5 Occupation of Respondents

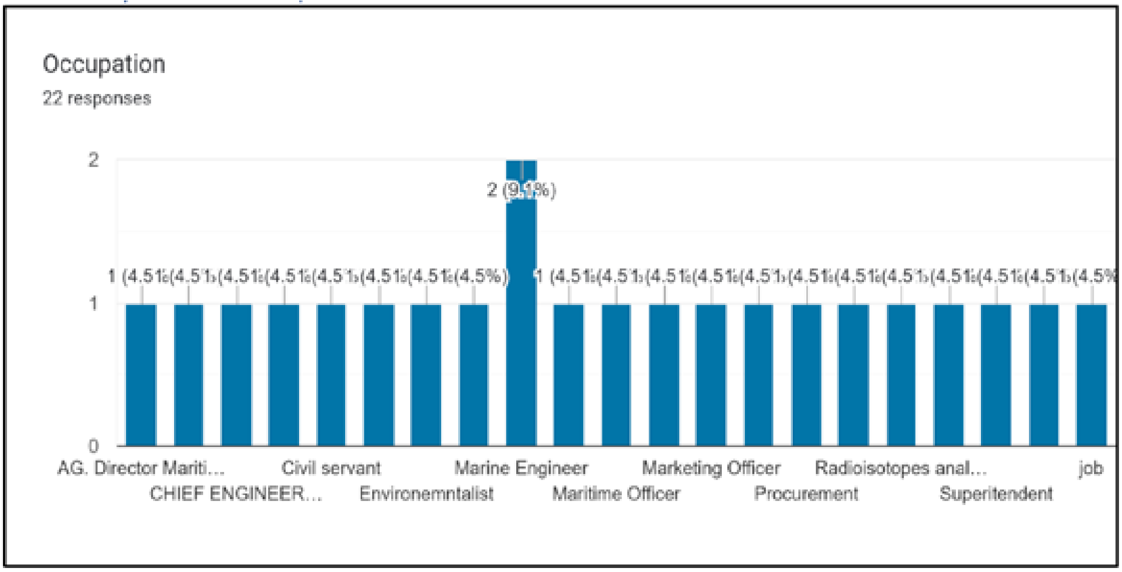


Figure 4.4 shows the careers of various correspondents who were randomly targeted for this survey. This demonstrates that all disciplines at least were considered.

4.1.6 Targeted Organizations for Responses

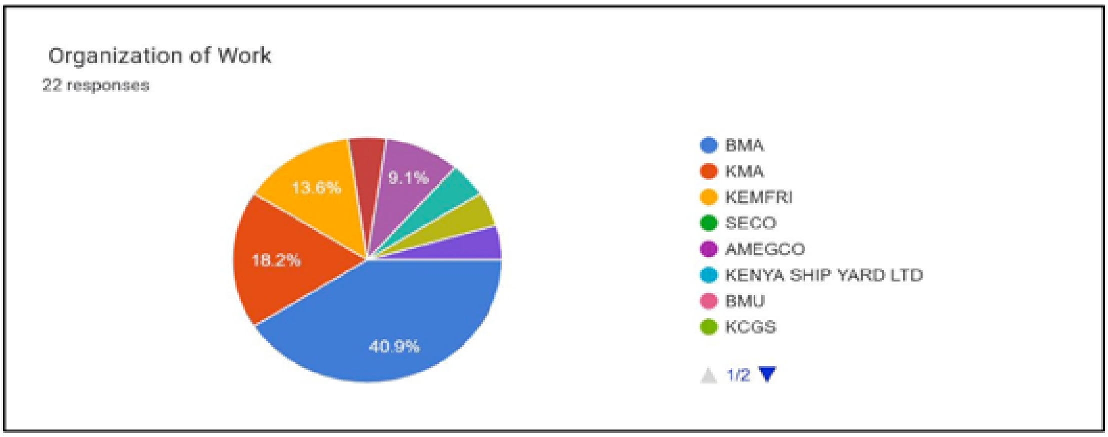


Figure 4.5 The above pie-chart shows the agencies that were targeted for responses in respect to research study.

4.2 The study sought out from respondents on how frequently do they encounter pollution incidents from maritime activities such as oil spills discharge from Ships in Mombasa's waters and the results are presented as below on pollution sources.

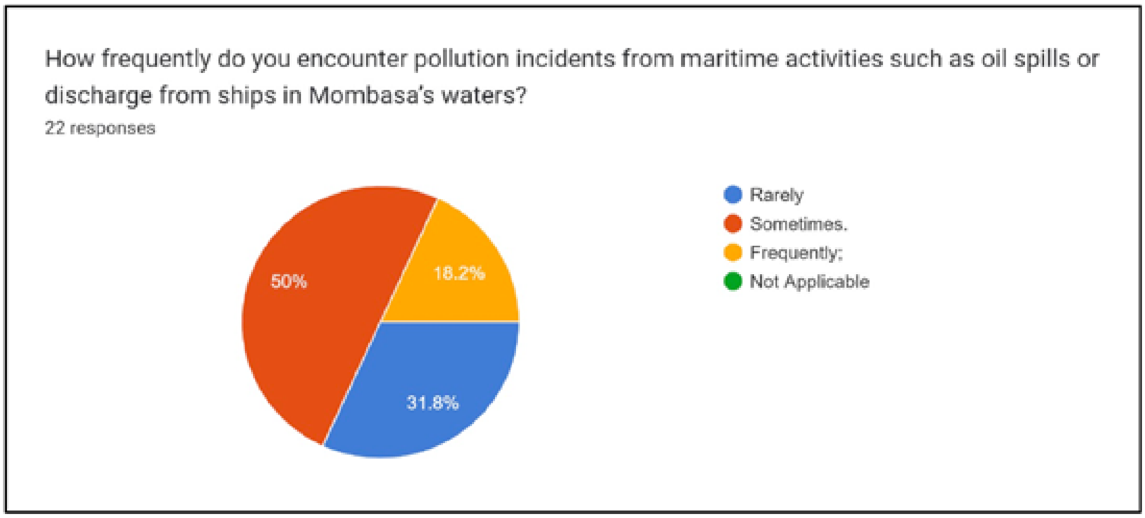


Figure 4.6 50% represents sometimes, 31.8% represents rarely while 18.2% presents frequently. This percent of frequently implies that necessary mechanisms have to be put in place to mitigate the pollution.

4.3 Respondents were asked to state what extent do they think land-based waste, including urban runoff and sewage, contributes to marine pollution compared to sea-based sources in Mombasa and the responses were as below?

Majority of Respondents reported that Mombasa County being an island city generally lacks a proper waste disposal system, hence most of its solid and liquid waste finds itself channeled to the sea. Industrial waste from factories within the island is also channeled to the sea as a result of convenience disposal with close proximity to the ocean. In comparison to the waste from platforms at sea, land-based pollution is by far high which accounts about 80% as demonstrated by respondents below.

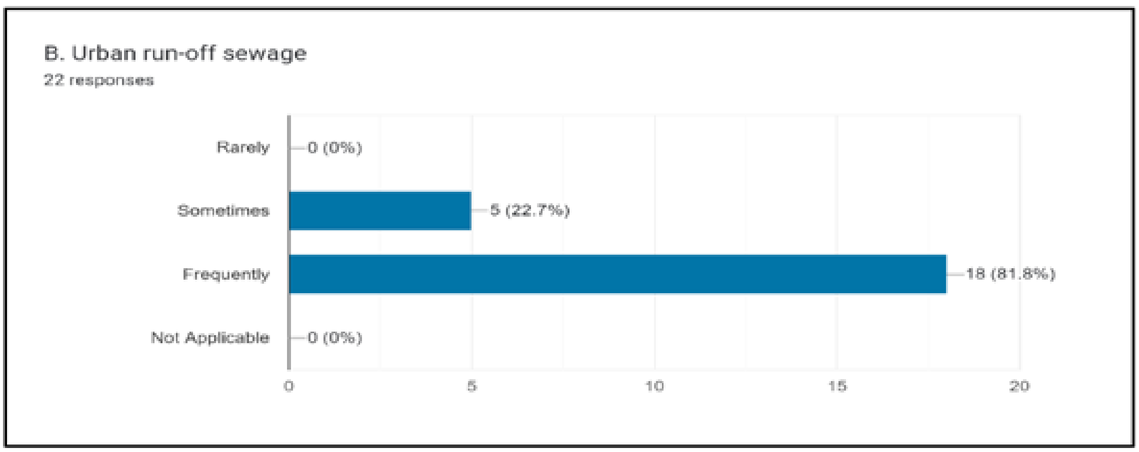


Figure 4.7 Urban Run- Off

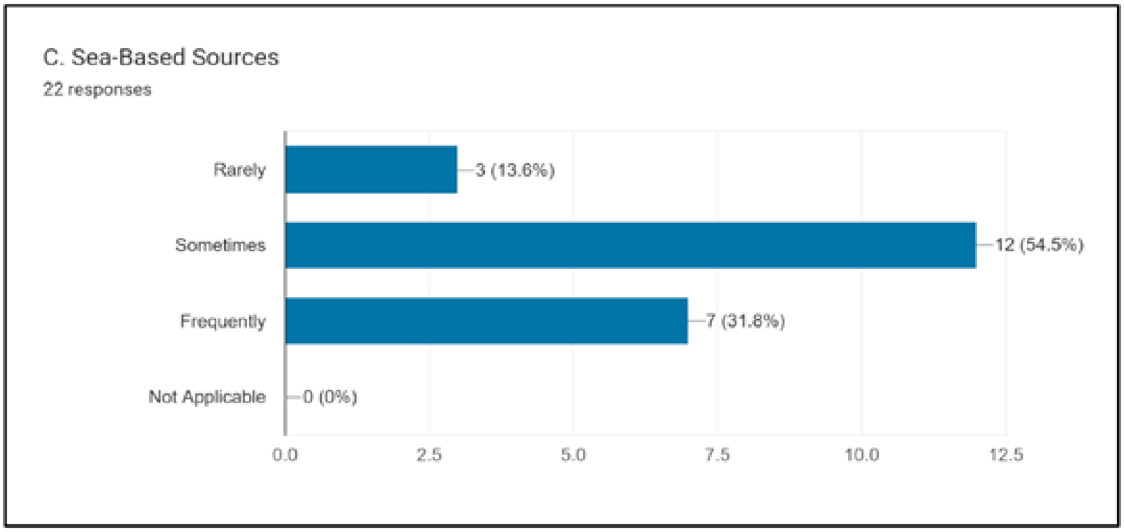


Figure 4.8 Sea Based Sources

From the analysis on the above on the sources of marine pollution; land based and urban run-off sewage was taking 81.8% which is supported by the frequently responses as opposed to sea-based sources which only accounts 54.5 %.

4.4 The study further sought to find out what role does insufficient waste management infrastructure in Mombasa County play in exacerbating marine pollution from respondents and the following were responses?

Majority of respondents cited that Mombasa County lack an elaborate waste management system and lack of proper waste disposal enforcement mechanism giving a leeway for massive pollution into the sea as individuals and entities pick the option of disposing to the sea as a convenient means of getting rid of the waste. It has led to plastic leakage into the environment and marine litter including foam and plastic fragments and also exposed the residents to communicable diseases.

4.5. The Study further sought to rate the current state of marine life in Mombasa County's coastal and marine areas for Fisheries, Lobsters and Crustacean?

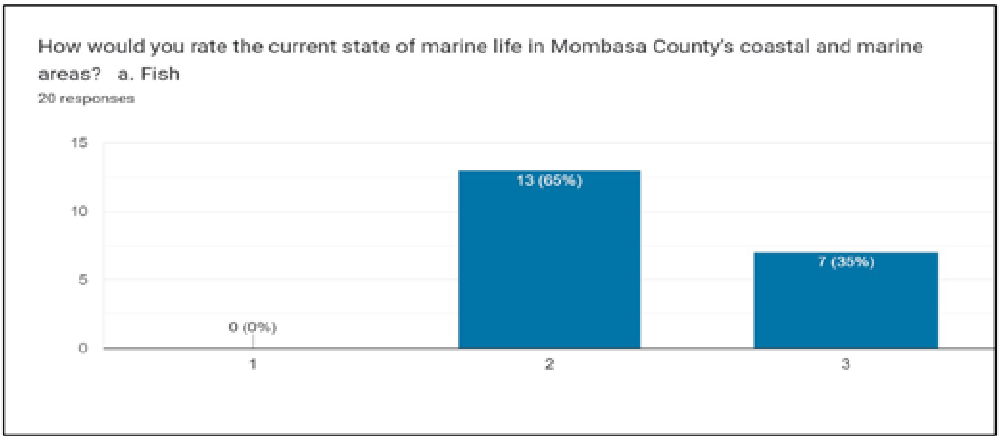
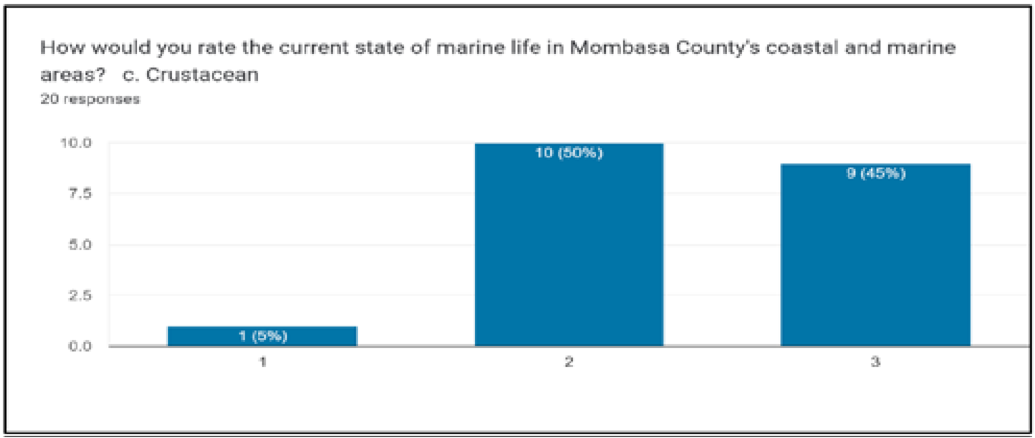
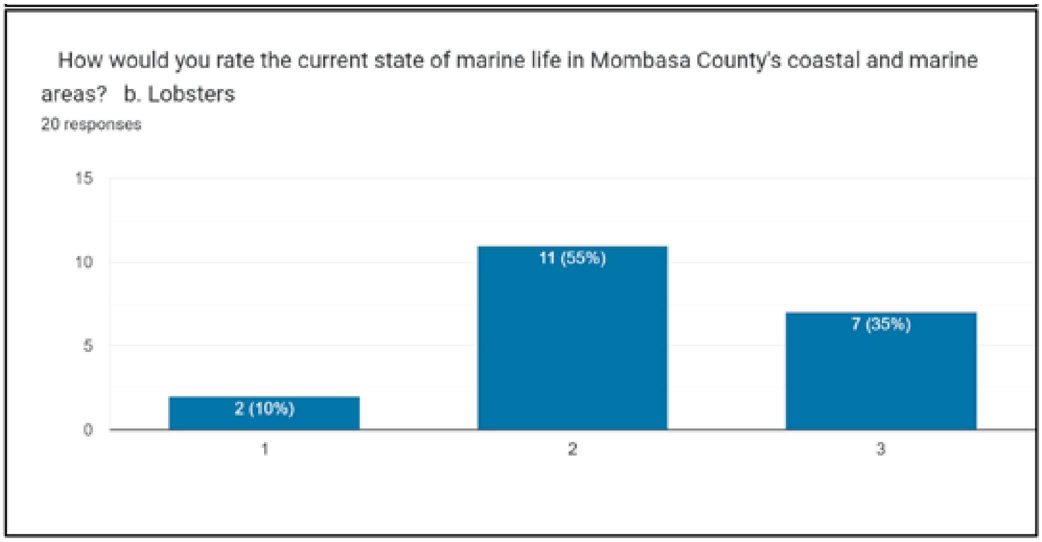


Figure 4.9 Fish





From the above analysis; the fish, lobsters and crustacean were facing extinction as a result of the marine pollution which is not supporting the growth and sustainability of the indigenous species as supported by highest percentages of 65%, 55% and 50% respectively as reported by respondents

4.6 The study sought to investigate the most impacts of pollution on Mombasa's marine environment and the following were findings?

The majority of respondents highlighted that pollution is causing significant environmental degradation, including the entanglement and ingestion of waste by marine organisms, which often leads to death, reproductive anomalies, and deformities. This pollution has resulted in a loss of biodiversity, destruction of mangroves and coral reefs, and the introduction of toxins into marine ecosystems. It also poses serious threats to marine wildlife such as whales, sea turtles, seabirds, fish, and mollusks, further endangering the health and sustainability of marine habitats.

4.7 The study sought to investigate how has marine pollution in Mombasa impacted the livelihoods of local communities that rely on fishing and tourism and the following were the findings?

The majority of respondents agreed that the decline in fish stocks has negatively impacted the livelihoods of local communities, as fishing is both a source of income and food. Fisherfolk in areas such as Makupa and Mikindani have lost much of their livelihood, forcing some to resort to illegal fishing techniques. The lack of adequate monitoring and enforcement against these practices has further exacerbated the situation. Additionally, scavenging on solid waste has increased, contributing to growing insecurity along the shores. The loss of the natural beach shore appeal, which has traditionally attracted tourists, further compounds the socioeconomic challenges faced by these communities.

4.8 The study sought to find out the long-term implications of ongoing pollution on marine biodiversity in Mombasa and the following were the findings?

The depletion of oxygen caused by debris degradation is leading to the inevitable death of sharks and other marine species. This process, which consumes significant amounts of oxygen, results in widespread impacts, including the eradication of corals and mangroves, increased climate change vulnerabilities, and the acidification and toxicity of marine environments, which suffocate biodiversity. The consequences include extinction of marine species, ecosystem destruction, disruption of food cycles, and bioaccumulation and biomagnification of toxic substances. Additionally, the consumption of microplastics and other plastic waste by marine animals leads to death, while eutrophication caused by sewage pollution promotes algae and bacterial growth, further endangering marine organisms.

4.9 The study sought to investigate whether there were any changes in the population or diversity of marine species in Mombasa over the past decade? If yes, what changes?

Some fish species have significantly depleted, with some even facing extinction. Coral bleaching and death have been observed in areas such as the Mombasa Marine Reserve and Wasini LMMA, largely due to pollution from plastic debris. This pollution has caused a severe decline in the populations of fish, seabirds, and marine mammals as they suffer injuries, suffocation, and death. Additionally, rural-urban migration has led to increased population pressures, exacerbating marine pollution and contributing to a decrease in the diversity of marine species in the ocean.

4.10 The study sought to identify the measures, if any, that have been taken by the local or national government to control marine pollution in Mombasa County and the following were the findings?

Efforts to address marine pollution and its impacts include assessments of fish stocks, patrols, and regular beach cleanups involving Beach Management Units (BMUs), government institutions, and private entities. Initiatives such as planting mangroves, conducting public awareness campaigns, and sensitizing fishermen and local communities aim to mitigate pollution and protect marine ecosystems. The national government, in partnership with Mombasa County, has implemented measures such as routine waste collection, the deployment of garbage trucks, and the development of national marine litter and sea-based action plans. Additional measures include promoting sustainable waste management, relocating dumpsites near the ocean, and improving water treatment systems. However, challenges persist, including inadequate policy endorsement, limited enforcement of legislation, and insufficient resources for comprehensive monitoring and prevention of harmful substances. Despite these efforts, the need for stronger legal frameworks, clear government action, and continued community involvement remains critical.

4.11 The Study sought to determine the effectiveness of the existing laws and regulations are in mitigating marine pollution in Mombasa County?

The legal and regulatory framework for addressing marine pollution in Mombasa is moderately effective but requires significant strengthening and better enforcement. While punitive measures and public participation have contributed to some progress, the main challenges l ie in the lack of consistent implementation and proper enforcement by relevant authorities. Existing laws and regulations need to be revised and bolstered to address gaps and effectively mitigate pollution. Employing the latest technologies and enhancing enforcement efforts are crucial to improving the situation. Despite some positive impacts, such as reducing marine ecosystem destruction, more needs to be done to ensure comprehensive and effective regulation.

4.12 The study sought to identify if any local community-based or non-governmental initiatives in Mombasa focused on reducing marine pollution?

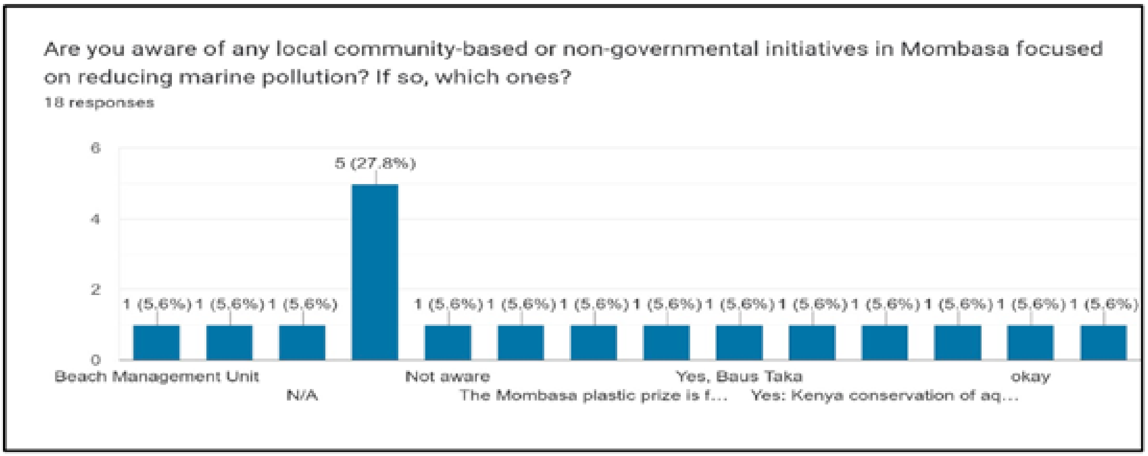


Figure 4.10. From the above analysis it can be seen very few CBO and NGOs are involved in marine pollution.

4.13 The study sought to identify whether public awareness and education were done with an aim of reducing marine pollution in Mombasa County?

Creating awareness and education on marine pollution is extremely important for reducing its impacts in Mombasa County. These efforts have significantly increased public understanding of the effects of pollution and fostered a culture change toward environmental care. Awareness initiatives are essential for addressing human activities, such as waste dumping, that contribute to marine pollution, and they play a vital role in reducing ignorance and promoting sustainable practices. By educating communities, these initiatives have improved local perceptions and helped mitigate the destruction of marine ecosystems and biodiversity.

4.14 The Study sought to determine what additional steps should be implemented in County to better control and prevent marine pollution?

Enhanced surveillance and monitoring, along with the establishment of a dedicated department within the Mombasa County Government to address marine pollution, are essential for effective management. Efforts should focus on formulating and endorsing appropriate policies, creating efficient waste disposal systems, and enforcing strict penalties for violators. Public awareness campaigns, local training, and community engagement are crucial to fostering a culture of environmental care. Multi-stakeholder forums can improve coordination among various actors, while modernizing sewerage systems, installing waste receptors, and implementing sustainable waste management practices are necessary steps. Monitoring waste discharge from industries and urban areas, imposing heavier fines on polluters, and supporting marine protected areas can further mitigate pollution. Incentives for reporting violations, continuous education, and frequent evaluation and reporting are vital for sustained progress. Efforts should also include mapping and monitoring potential polluters, discouraging illegal fishing, and promoting recycling and modern waste management facilities to protect Mombasa's marine environment.

5. SUMMARY OF FINDINGS

5.1 Overview

This research study aimed to investigate the sources of marine pollution for the coastal communities, the effects to human and marine life and the mitigation strategies in Mombasa County.

5.2 Findings

5.2.1 Sources of Marine Pollution

The data analysis reveals several key findings related to marine pollution in Mombasa County. A pie chart (Figure 4.5) shows the agencies targeted for responses during the research study. Respondents reported varying frequencies of encountering pollution from maritime activities, with 50% stating "sometimes," 31.8% "rarely," and 18.2% "frequently," indicating a need for stronger mechanisms to mitigate pollution (Figure 4.6).

Regarding pollution sources, the majority of respondents highlighted that Mombasa, being an island city, lacks a proper waste disposal system, resulting in significant land-based waste, including urban runoff and industrial waste, being channeled into the sea. In comparison to sea- based pollution, land-based sources were found to contribute approximately 80% to marine pollution, as illustrated in Figures 4.7 and 4.8. Specifically, 81.8% of respondents emphasized the dominance of land-based and urban runoff waste in marine pollution.

Further findings indicate that insufficient waste management infrastructure exacerbates marine pollution. Respondents cited the lack of a robust waste disposal system and enforcement mechanisms, leading to widespread pollution, including plastic leakage and marine litter, which also exposes residents to communicable diseases.

The study also assessed the current state of marine life in Mombasa's coastal areas. Results from Figure 4.9 reveal that marine species such as fish, lobsters, and crustaceans are facing extinction, with 65%, 55%, and 50% of respondents indicating significant declines in these populations due to marine pollution, which is hindering the growth and sustainability of indigenous species.

5.2.2 The effects of marine pollution to Human and Marine Life

The study found that pollution in Mombasa's marine environment is causing significant degradation, including the entanglement and ingestion of waste by marine organisms, leading to death, reproductive anomalies, and deformities. It has also resulted in the loss of biodiversity, destruction of mangroves and coral reefs, and the introduction of toxins into marine ecosystems, threatening marine wildlife such as whales, sea turtles, seabirds, fish, and mollusks, thereby compromising the health and sustainability of marine habitats. The study also highlighted the negative impacts of marine pollution on the livelihoods of local communities. Declining fish stocks have severely affected communities relying on fishing for income and food, particularly in areas like Makupa and Mikindani. This has led to illegal fishing practices, increased scavenging on waste, growing insecurity along the shores, and a loss of the natural beach appeal that once attracted tourists, further exacerbating socio-economic challenges.

Long-term implications of ongoing pollution include the depletion of oxygen caused by debris degradation, which threatens the survival of species like sharks and other marine life. This process also leads to the eradication of corals and mangroves, increased vulnerability to climate change, acidification, and toxicity, suffocating biodiversity. Further consequences include the extinction of species, destruction of ecosystems, disruption of food cycles, bioaccumulation of toxic substances, and the death of marine animals due to consumption of microplastics and plastics, as well as eutrophication driven by sewage pollution.

5.2.3 The Mitigation Strategies for Marine Pollution

The study found that both local and national governments have taken some measures to address marine pollution in Mombasa County, including regular beach cleanups, assessments of fish stocks, patrols, and initiatives like planting mangroves and conducting public awareness campaigns. Additionally, the national government, in partnership with Mombasa County, has implemented routine waste collection, deployed garbage trucks, and developed national marine litter and sea-based action plans. However, challenges such as inadequate policy endorsement, limited enforcement, and insufficient resources remain. The legal and regulatory framework is seen as moderately effective but requires significant strengthening, with better enforcement and technological adoption necessary to ensure more effective pollution control. Few community- based organizations (CBOs) and NGOs are involved in reducing marine pollution, and while public awareness campaigns have increased understanding of the issue, there is still a need for greater involvement. Enhanced surveillance, improved waste disposal systems, multi-stakeholder coordination, and stricter enforcement of policies are critical for further mitigating marine pollution. Additionally, establishing a dedicated department to address marine pollution, modernizing sewerage systems, imposing heavier fines, and supporting marine protected areas are among the steps recommended for better pollution control in Mombasa.

5.3 Conclusion

Marine pollution in Mombasa County is a significant environmental challenge, primarily driven by land-based sources such as urban runoff and industrial waste, which account for approximately 80% of pollution, these findings corroborate with the study by Okuku et al., (2021). This has led to the degradation of marine ecosystems, loss of biodiversity, and severe impacts on marine life, including the decline of fish, lobsters, and crustaceans. The pollution also affects the livelihoods of local communities, particularly those dependent on fishing, and threatens the tourism sector. Despite efforts by local and national governments to mitigate pollution through beach cleanups, waste collection, and public awareness campaigns, the lack of effective enforcement, inadequate waste management infrastructure, and insufficient policy endorsement hinder progress.

5.4 Recommendations

Strengthening the legal and regulatory framework, enhancing surveillance and waste disposal systems, promoting multi-stakeholder collaboration, and modernizing sewage and waste management practices. Furthermore, greater community involvement, the creation of dedicated departments for marine pollution, and the implementation of stricter penalties for violators are essential to effectively combat marine pollution and protect Mombasa's marine environment for future generations.

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An Assessment of Safety Equipment Utilization In Ensuring Safety of Navigation in Ghana's Inland Waterways

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Abstract

Water bodies, especially rivers have been essential to human existence since the beginning of time. Ghana is gifted with numerous inland water bodies which can be exploited for Inland Water Transportation. The safety of navigation on these water bodies has been a major concern. Lives lost through boat accidents has been alarming. To curb this, pragmatic and bold steps must be taken. The main objective of this study was to assess utilisation of safety equipment in ensuring safety of navigation in Ghana's inland waterways. The specific objectives were to assess the current state of safety equipment utilisation, identify the barriers to effective safety equipment utilisation, and examine the effectiveness of regulations towards utilisation of safety equipment. The descriptive method was used with a sample size of four hundred (400) respondents. Researcher administered questionnaire and observation methods were the data collection instruments used. Data was analysed using thematic data analysis approaches. The study revealed that users of the inland waterways do not utilise conventional safety equipment but rather use makeshift items which are not effective. Life jackets were hardly used. Inaccessibility and high cost of equipment were identified as common barriers to safety equipment use. The enforcement of regulations was described as ineffective. Regulators, typically Ghana Maritime Authority face capacity and logistical constraints in enforcing safety regulations. The issue of the absence of a clear-cut regulation on inland water safety came up. To resolve the issues surrounding inland water navigation safety, the study recommends demographic-targeted campaigns, standardised equipment measures, more stakeholder engagement and sensitization, and development of specific regulation for inland waterways.

Key Concepts and Definitions

Lifebuoy: *a life-saving buoy designed to be thrown to a person in water to provide buoyancy and prevent drowning.*

Life Jacket: *A sleeveless buoyant or inflatable jacket for keeping a person afloat in water.*

Inland Waterways: *navigable or passable channels such as rivers and lakes used to transport goods and passengers.*

Safety equipment: *protective gear used by boat operators and passengers to prevent injuries, casualties, and life-threatening situations.*

1.0 INTRODUCTION

Globally, maritime transportation is important for both overall economic growth and a nation's transportation infrastructure (Hossain et al., 2019). Boadu et al (2021) define inland water transportation as the transportation of goods—animate or inanimate—between points of origin and destination through the use of pontoons or other water vehicles.

As per Fellinda's (2006) research, Inland Water Transport Systems have been in use for millennia in various nations such as Bangladesh, China, India, Egypt, the Netherlands, Germany, and the United States, to name a few. 46% of the inland freight in the Netherlands is handled by IWT; 32% is handled in Bangladesh, 14% in the US, and 9% is handled in China. However, the country's use of these waterways for freight transportation is far less than that of other

According to Obosu (2022), Ghana is endowed with a multitude of inland sources of water. Ghana's most notable rivers are the Afram, Oti, and Volta Lakes, as well as the upstream Volta Rivers. Approximately 8,500 km2 is occupied by the Volta Lake, one of the biggest artificial lakes in the world, which was created following the building of the Akosombo dam. These waterways play a vital role in the movement of people and products, yet there have been questions raised over the availability and use of safety gear.

There have been numerous studies and publications on the safety of navigation on Ghana's inland waterways. Lloyd et al (2019) have identified several issues and challenges related to inland waterways. These include insufficient infrastructure, insufficient capital for craft investment and maintenance, unsatisfactory incentives for investors, a dearth of indigenous carrier vessels, the seaworthiness of these vessels when they are present, and inadequate integrated water transport systems.

In a more recent study, Boateng and Ansah (2018) examined the Volta Lake, the biggest artificial lake in Ghana, and found that overloading boats, having insufficient safety gear, and having poor communication amongst vessel operators were among the factors that contributed to accidents on the lake. A study by Boateng and Mensah (2019) claimed that a major factor in the unsafe navigation of Ghana's inland waterways was inadequate infrastructure, including badly built jetties and landing sites, as well as a lack of maintenance for the infrastructure that was already in place.

According to a GMA (2019) annual report, there has been a noticeable rise in the frequency of accidents on Ghana's inland waterways. Overloading and disregarding safety requirements have been identified as the primary causes of most of the incidents. The goal of the GMA's 2020 safety campaign was to raise awareness of safety among boaters and users of Ghana's waterways. Distribution of safety gear, instruction courses, and stepped-up enforcement of laws were all part of the campaign.

2.0 LITERATURE REVIEW

2.1 Theoretical Framework

The Safety Culture Theory and the Pressure and Release Model serve as the study's foundations.

2.1.1 Pressure and Release Model

This is a paradigm based on science that explains how disasters unfold. This concept states that various elements that occur in a progressive manner interact to cause disasters. This is broken down by Wisner et al. (2004) into susceptibility, underlying causes, dynamic pressures, circumstances, and disasters.

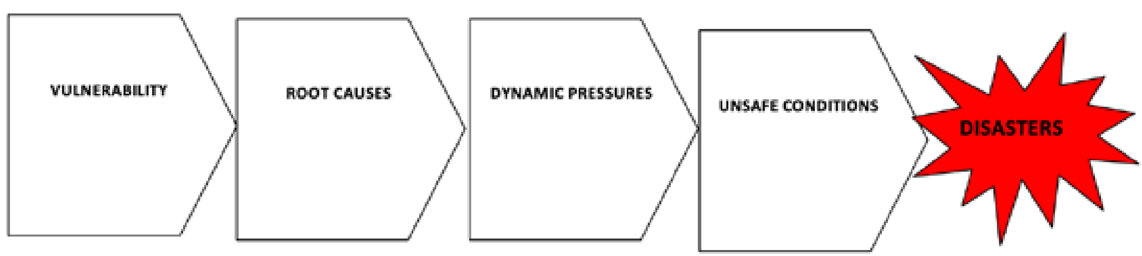
Vulnerability: This serves as the foundation and describes the circumstances that leave individuals vulnerable to the effects of dangers. It encompasses elements such as restricted resource availability, economic exclusion, and disparities in society.

Root Causes: These are the fundamental elements that make someone vulnerable. These encompass an extensive range of ingrained problems that create the conditions for catastrophe. Poverty, illiteracy, and political unrest are a few examples.

Dynamic Pressures: These are the forces that interact with vulnerability and accumulate over time. They might be macro-level or micro-level (individual or community-specific) (societal or global). Economic volatility, environmental degradation, and population increase are examples of dynamic pressures.

Conditions: Conditions are the particular situations that individuals live under. These can be financial or physical, such as a delicate ecosystem (such as a struggling local economy). Conditions and dynamic pressures come together to produce the danger of disaster.

Disasters: Disasters happen when conditions, dynamic pressures, vulnerability, and underlying causes come together. Disasters are situations from which individuals cannot recover on their own. They emerged from this intricate interaction (Figure 1).



Adapted from Wisner et al, (2004)

Figure 2: Pressure and Release Model

2.1.2 Safety Culture Theory

According to safety culture theory, fostering a culture of safety requires strong leadership, open communication, and responsibility. Accordingly, the theory supports common attitudes, values, and beliefs that impact safety procedures within a company or sector (Yorio et al, 2019 and Bisbey et ai, 2021). In this case, it concerns the safety culture in the inland water navigation sector and how it affects the use of safety gear. This theory aids in the analysis of safety-related attitudes, actions, and procedures within the inland water navigation sector. It can be used to evaluate the industry's dedication to safety, which affects the use of safety gear.

Abeje and Luo (2023) pointed out that safety culture is intricate and multidimensional, and it can be difficult to identify the precise elements that affect safety inside an organization while analysing the theory's shortcomings. It may be challenging to pinpoint the underlying reasons of safety concerns due to this intricacy.

Conversely, the idea promotes a proactive and preventive approach to safety management, emphasizing risk minimization and hazard identification prior to occurrences. Furthermore, the theory best matches the study on the use of safety equipment in Ghana's inland waterways since it addresses beliefs, attitudes, and perceptions among other things, and because there may be a variety of reasons why safety equipment is not used or is not used at all. In light of this, the study concurs with Thimthong and Sooraksa (2019), who claimed that an instrument that may be used to gather information about employees' perceptions of corporate safety culture in a variety of aspects is the safety culture assessment. Thus, this theory is appropriate for the investigation at hand.

2.2 Barriers to Effective Safety Equipment Utilisation

In general, there are obstacles to using personal protection equipment. Organizational and human variables that operate as barriers include the lack of needed Personal Protective Equipment (PPE), an unbalanced work environment, discomfort, and the size and quality of PPE, according to Sharms et al. (2022) and Tamene, Afework, and Mebratu (2020). They concluded that in order to avoid these obstacles, future attempts to maximize the usage of PPEs should concentrate on providing sufficient quantities and quality of supplies.

The reasons for not using safety equipment vary in the maritime sector as well. A study conducted by Devereux, H., and Wadsworth, E. (2023) indicated that sailors reported a variety of PPEs to be ill-fitting, with women sailors reporting a higher incidence of incorrectly fitting gear.

According to Bekale and Ndjambou (2023), the main obstacle to going fishing with complete peace of mind has been the lack of protective gear. The lack of tools to aid in marine navigation creates a security risk for the different artisanal fishermen who operate there; these fishermen are frequently involved in several nautical mishaps. Due to their high cost, professionals are reluctant to purchase all of the necessary gear, and those who are interested are often forced to associate them with the conventional methods of maritime rescue.

2.3 Effectiveness of Regulation in Ensuring the Utilisation of Safety Equipment

Certain developing nations lack the well-established bodies and organizations that are required by law to supervise and govern inland water transportation (IWT), in contrast to developed nations like Canada and the European Union. As a result, there are unclear rules governing things like hiring crew, purchasing ferries, registering and inspecting them, and coordinating with nations within subregions. Due to these, it is exceedingly difficult to regulate the activities of inland water transportation (Solomon et al, 2021).
According to Solomon et al. (2021), inland water transportation, like other modes of transportation, calls for the creation of an institution that is exclusively tasked with overseeing and coordinating water transport operations in areas like boat production and standardization, freight costs, security, monitoring, registration, and inspection of boat activities. Regretfully, Ghana does not currently have such a state-established institution. A portion of these tasks are carried out by the agencies that are in place, which work in tandem with other organizations to promote navigational safety.

Inadequate infrastructure and a lack of safety precautions on board have been exacerbated by Ghana's disjointed and frequently non-enforced legal and regulatory framework for inland waterways transportation. In order to address this issue, the Ghana Maritime Authority (GMA), mandated by law to establish and carry out maritime treaties and inspect watercraft to guarantee their seaworthiness, ought to establish a separate department which should collaborate with the Ghana Navy to supervise operations on interior waterways (Solomon et. al, 2021).

The Inland Waterways Division was established to manage all issues pertaining to the safety of inland waterway transportation to further improve the Ghana Maritime Authority's performance in this area. The three units of this division were Navigational Aids and Services, Inspection and Surveys, and Surveillance and Patrols. Preventable accidents on the lake should disappear once the division has all the police it needs, together with the boats for patrols, inspectors for surveys, and lake traffic control units (GMA, n.d).

2.4 Types of Crafts used for Transportation in Ghana's Inland Waterways

In Ghana's interior waterways, a variety of vessel kinds are utilized for transportation, according to Boateng and Oppong (2019). Canoes, ferries, motorized boats, and dugout boats are some examples of these craft. Numerous factors, such as cost, cultural preferences, and the availability of resources, affect the utilisation of these crafts. Canoes and dugout boats, for instance, are common in regions with plenty of bamboo and wood, as well as inexpensive labour. Wherever individuals can afford to buy engines and gasoline, motorised boats are more prevalent. When it's necessary to cross wide bodies of water, ferries are utilised.

2.5 Causes of Accidents in Ghana's Inland Waterways

Numerous studies have evaluated the safety of navigation in Ghana's interior waterways and have identified a number of risk factors. For example, a research by Agodzo et al. (2023) found that inadequate safety precautions have historically led to a substantial number of accidents at Volta Lake. According to Bekale and Ndjambou (2023), the primary causes of accidents in inland waterways are boat operators' noncompliance with safety laws and the absence of safety equipment, such as life jackets. The government should impose safety laws, carry out routine safety inspections, and supply boat operators with safety gear, according to the study's recommendations.

Boadu et al. (2019) evaluated the safety of navigation on Volta Lake in a different study and found a number of factors that contribute to accidents on the lake. Submerged tree stumps, a dearth of navigational aids, insufficient boat operator training, overcrowding of vessels, and poor vessel maintenance are some of the problems. The study recommended several actions in this regard, including the removal of the submerged stumps, the creation of an organization to oversee inland water transportation, frequent training sessions for boat owners and operators, making sure boats have life-saving equipment on board, and enforcing sanctions against noncompliant boat operators.

Regarding the reasons for marine mishaps, Fan et al. (2020) argued that human factors play a significant role. They clarified that, statistically speaking, human error causes about 80% of maritime mishaps, which is crucial information for disaster prevention. They claim that other pertinent aspects, such as work environment, natural and physical surroundings, protocols, technology, training, organization, management, and individual characteristics including task load, exhaustion, and mental state, are typically linked to human factors in marine accidents.

2.6 Dealing with Issues of Safety in Ghana's Inland Waterways

Without a question, the worldwide movement of commodities and international trade have benefited from the efficiency, speed, and convenience that the shipping industry has provided. Despite this significant advancement, there have unavoidably been a number of maritime mishaps (Mansyur et al., 2021; Wang et al., 2023). These incidents typically have a major negative influence on environmental, property, and life safety (Wang et al., 2022).

Despite major efforts by the International Maritime Organization (IMO), national maritime agencies, shipping firms, and other stakeholders to improve maritime safety, the alarmingly high frequency of maritime accidents persists (Cao et al., 2023). For instance, 22,532 water traffic incidents were reported between 2014 and 2020 by the European Maritime Safety Agency (EMSA) in its yearly accident data (EMSA, 2021). According to the Allianz Global Corporate and Specialty Risks (AGCSR) annual report for 2022, there were 3000 ship accidents that year despite the fact that ship losses in 2021 were 57% fewer than ten years prior (AGCSR, 2022). This blatantly demands action to address the accident problem.

Equipment and infrastructure are essential for safe inland waterway navigation. Hagan (2019) asserts that the infrastructure of Ghana's inland waterways is deficient, citing a lack of proper berthing facilities and navigational aids. To remedy these shortcomings, the author recommends creating a comprehensive strategy for infrastructure rehabilitation. Furthermore, in order to guarantee that vessels are seaworthy, Xing and Zhu (2023) argued that frequent maintenance and inspection are necessary.

In order to enhance their abilities and expertise, Moreno et al. (2022) advise ship crew members to undergo training. Furthermore, Alamoush et al. (2023) agreed that regulations would be necessary to address some of the problems facing the maritime sector. As the maritime industries experience rapid technological change and autonomous shipping becomes a more viable possibility, new hazards are always emerging (Jalonen et al, 2017). It is consequently crucial to enhance society's capacity to handle threats arising from canal transportation systems. The international nature of maritime commerce necessitates that national authorities explore regional cooperation among the littoral countries of a given body of water, engage in international initiatives to ensure safe shipping, and ensure safety of navigation within their authority (Kulkarni et al, 2020).

Generally speaking, addressing the issues that threaten Ghana's inland waterways navigation safety requires strong stakeholder coordination and engagement. For this reason, according to Schaefer and Barale (2011), maritime spatial planning offers the proper framework for stakeholders and public authorities to coordinate their efforts across administrative boundaries and sectors while making the most use of natural resources.

2.7 The Gap in Literature

Although a number of authors such as Boateng and Ansah (2018), Sharma et al (2022), Tameme, Afework and Mebratu (2020), and Devereux and Wadsworth (2023) have addressed the topic of safety equipment, there doesn't seem to be any material that focuses specifically on how safety equipment is used in Ghana's inland waterways. For instance, the study conducted in the United Kingdom by Devereux and Wadsworth (2023) on the reasons why seafarers were hesitant to utilize safety equipment found that many pieces of personal protective equipment were ill-fitting, with women seafarers experiencing this problem more than men. The literature has not sufficiently addressed the causes behind Ghanaian mariners' general unwillingness to use safety equipment, let alone their hesitation in Ghana's interior waterways.

2.8 Conceptual Framework

According to Bisbey et al. (2019), industry, group, and individual enabling elements come together to form safety culture. The traits of each person completing the task individually make up the individual-level elements. Individual characteristics differ between members of an organization and can influence people's propensity to embrace safety culture-consistent norms, values, and presumptions. Group level elements are the interpersonal and social aspects of one's workplace that have an impact on the norms, values, and presumptions that people embrace. The work group could offer a microenvironment where culture can grow and thrive as a result of different social forces.

The organizational conditions that establish the framework within which people function on a daily basis are dealt with by the industry/organization level factors. Leader commitment to and prioritizing of safety, as well as policies and resources for safety, are two important organizational elements that may facilitate individuals' adoption of the values, norms, and assumptions of safety culture.

The circumstances that lead people to embrace beliefs, values, and customs that align with safety culture are known as enabling factors. As a result of these elements, safety culture can grow over time as people accept common beliefs, attitudes, and conventions. Individual behaviours are a manifestation of underlying assumptions, conventions, and values that influence safety outcomes. Humans learn from safety results in the sense that while negative events cast doubt on underlying beliefs, values, and conventions, happy ones are validated. Safety culture develops and is maintained when there is consistency and stability across time and across persons.

Promoting a safety culture at the individual, collective, and industrial levels is crucial to ensuring the security of navigation in Ghana's inland waterways. In the end, this results in safe passage on inland waterways or safety consequences. The process leading to navigational safety is conceptualized in the Figure 2 below.

Figure 3: The Process to Navigational Safety

3.0 METHODOLOGY

The study made use of the descriptive research approach. The survey research used interviews or standardized questionnaires to gather information from a population or sample. Observation was also used for this research because it gave the opportunity to the researcher to observe the operations of inland water crafts in the natural setting and to notice things that respondents may not say.

Both primary and secondary data were used for the study. The sample size for the study was four hundred (400), comprising Regulators, Craft Operators, and Passengers. This number was obtained at the point of data saturation during interactions with the various respondent categories. According to Vaselieou et al (2018), data saturation is a point whereby no new responses come out from the respondents as they all virtually begin to say the same thing.

The methodological framework of the study is captured in Table 1 below.

Table 1: Methodological Framework

OBJECTIVE	RESPONDENTS	SAMPLING TECHNIQUE	NUMBER	INSTRUMENT
To assess the current state of safety equipment utilisation in Ghana's inland waterways.	Craft Operators Passengers	Convenience Sampling	100 250	Questionnaire and Observation
To identify the barriers to effective safety equipment utilisation.	Craft Operators Passengers	Convenience Sampling	100 250	Questionnaire
To examine the effectiveness of regulation in the utilisation of safety equipment.	Craft Operators Regulators	Convenience Purposive Sampling	100 50	Questionnaire & Observation

The descriptive statistics were employed where the data was presented using graphs, charts, tables, and other visualizations. This research adhered to ethical guidelines, ensuring informed consent, confidentiality, and anonymity of participants.

4.0 RESULTS AND DISCUSSIONS

4.1 Socio-Demographics

The findings revealed a relatively balanced representation between male and female passengers, with 48% being male and 52% female. This gender parity suggests that both men and women actively participate in inland waterway transportation in Ghana, highlighting the importance of considering gender-specific factors in the assessment of safety equipment utilisation. The age distribution among passengers and operators surveyed in the assessment of safety equipment utilisation for navigation in Ghana's inland waterways reveals higher percentage of young individuals (26-35 years.) reliance on inland waterway transportation. Implicitly, majority of the active labour force rely on Inland Water Transportation.

In the context of navigation safety, understanding the educational background of passengers is crucial for designing interventions and communication strategies. The study found that 64% of respondents had completed basic school education, indicating a substantial representation of individuals with at least a foundational level of formal education. Also, the study found a high percentage of married individuals involved in this form of transportation. This should motivate duty bearers to ensure safety in the inland waterways as any disaster will have severe implications on households. Among the surveyed passengers, traders constitute the majority, comprising 64% of the passenger sample.

4.2 Utilisation of safety equipment

The study revealed that there was low utilisation of life jackets and reliance on makeshift alternatives, such as wet jute sacks as fire extinguishers, 25 litre gallons and inflated car tubes as life buoys raising concerns about safety awareness and enforcement. The unconventional safety equipment used underscored the need for standardised safety measures.

The low compliance with safety equipment usage; (72%) not using safety equipment) and challenges faced by respondents in using safety equipment raised concerns about the observation and effectiveness of safety protocols.

4.3 Challenges to Safety Equipment Utilisation

Craft operators reported high costs and accessibility major challenges, highlighting economic barriers to safety compliance. The study emphasised the importance of addressing financial constraints to enhancing accessibility and affordability of safety equipment, as well as the need for comprehensive and specific regulations for inland waterways.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The study revealed low utilisation of certified life jackets and reliance on makeshift alternatives for other safety equipment. This raises concerns, emphasising the urgency of regulatory intervention and increased awareness. The number of lives that are always at stake on any given day on our inland waterways underscores the need for a multifaceted approach involving regulatory agencies, stakeholders, and the communities to enhance safety in Ghana’s inland water transportation.

The issues of high cost of safety equipment and limited access that hinder the utilisation of safety equipment call for a comprehensive approach in working to ensure safety in our inland waterways. The unavailability of a clear-cut regulation for inland waterways operations is a major concern. This could be the reason for the low awareness issue among passengers and operators.

Th study recommends comprehensive safety education programmes that are intelligible and accessible to people with varying educational backgrounds. This will guarantee proper understanding of the issues. There is also the need to standardise safety equipment measures to guarantee safety protocols' dependability, uniformity, and public trust. The study also recommends specific regulations for Inland Waterways, logistical support to operators for safety compliance, comprehensive monitoring and evaluation (M&E) of regulatory measures, and regular stakeholder engagement and community sensitization. These measures, when put in place, will guarantee the safety of both passengers and craft operators in our inland waterways thus impacting the blue economy of Ghana and the African Continent at large.

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ADOPTING OPEN SHIP REGISTRY IN GHANA: PROSPECTS AND BARRIERS

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Abstract

Registering a ship is a crucial phase in vessel ownership, mandated by legal requirements that afford vessels access to the global market and open seas. Ship registration plays a pivotal role in contributing to the socio-economic development of flag states. The extent to which flag states benefit from ship registration varies due to the specific registry systems they adopt. This study delved into the current state of ship registration in Ghana, focusing on the impact of the closed ship registry system. Additionally, it attempted to delineate the potential advantages of transitioning to an open ship registry in Ghana. The study identified barriers that might impede the benefits of adopting an open ship registry and suggested strategies to overcome these barriers. The research employed a qualitative methodology for data collection and thematic data analysis. Given the study's nature, a convenience sampling technique was utilized and overall, 23 industry experts participated in the study from the maritime sector, including individuals from the Ghana Maritime Authority, shipowners, seafarers, academics, and ship managers were interviewed. The findings indicated that the socio-economic benefits derived by Ghana from its current ship registration system are limited, and an open ship registry has the potential to enhance both financial and social gains. Obstacles such as the inconvenient and cumbersome registration process, nationality as a determinant factor in registration, substantial tax burdens without government incentives, corruption, inadequate capacity, implementation bottlenecks, competition, and lax policies pose challenges that could impede the effective implementation and benefits of an open ship registry. The study recommends development of a comprehensive policy framework for implementation of open ship registration, automation and digitalisation of registration systems, delegation of some functions to recognised organisations as well as easing of tax regime and introduction of incentive schemes.

Keywords: *Ship Registration, Open Ship Registry, National Registry, Optimal Benefits, Barriers*

1.0 Introduction

1.1 Background to the Study

Ship registration is an essential condition in the shipping domain (Shaheen, Ziauddin and Islam, 2020), which allows ships to enjoy the freedom of navigation on the high seas (Shaheen, 2018). Through ship registration, ships acquire the nationality of a State and gain the legal rights to enter ports in order to carry out their operations (Rojas, 2019). When a State confers its nationality to a ship, it becomes the flag state and administrative authority of that ship. As the administrative authority, the Flag State is mandated by the international law to ensure the seaworthiness and compliance of ships registered under its jurisdiction. Other states that a vessel is not registered to but visits for business purposes are known as the Port States of the vessel. Port States are also mandated by law to conduct inspections and surveys on vessels to verify their seaworthiness and compliance to international regulations during their visits (Rojas, 2019).

Ship registration has the potential of generating income and creating potential job opportunities for states (Shaheen, et. al., 2020). Over the years, states have adopted different forms of registration system, among these are closed, open and hybrid registration (Shaheen, et. al., 2020). The closed registration system is the maiden and oldest system of registration which largely permits registration of vessels under a state's jurisdiction to the citizens or registered enterprises of the State (Xiao, 2021). This system was birthed by the British government legislation in the 14th century and operated mostly by European countries (Xiao, 2021). The open ship registration system started by the Panamanian government in the 1920s, permits the registration of ships under a state's jurisdiction regardless of the nationality of the ship owner. This system is mostly practiced by small island states and the least developed countries, such as the Marshall Islands and Liberia (Shaheen, 2018). The hybrid ship registration system combines both the open and closed systems of registration. This system was initiated by European countries that operated the closed registry system (Xiao, 2021).

Approximately, 70% of the world's trading fleet is registered under states that have adopted the open registration system (Shaheen, et. al., 2020). Open ship registry has been a major contributor to national revenue for many flag States and has created many job opportunities in States' maritime industry (Hung, et. al., 2015). As the world's first and leading open ship registry State, Panama Ship Registry was estimated to have made about $87.3 million from ship registration in 2021(International Shipping News, 2022) and the Liberian ship registry is estimated to make approximately $18 million worth of income annually (Hung & Son, 2015). With regards to creation of employment avenues, Singapore in 1969, switched to open ship registration system with the expectation of resolving its then unemployment issue (Shaheen, 2018).

Ghana adopted the closed ship registry purposely to protect the then national shipping line (established to provide employment opportunities for Ghanaian seafarers and supporting Ghana's economy in times of crisis), in a time when the country's agenda of championing national independence and self-reliance was in initiation (Afful, 2016).

However, presently the closed ship registry seems to no longer serve the country to the optimum, after the goal behind the establishment of the Black Star line was curtailed as a result of it crumpling in the late 1990s. The country's register (Table 1) has one of the most crippling number of total registered vessels (247), with fishing vessels have the most share of about 42% of the total fleet. Inland water crafts have a share of 21% whilst other crafts such as pleasure crafts, tug boats, work boats and other small crafts makeup the rest of the 35% share (GMA, 2019).

Table 1: Flag Vessels Classification

s/n	Type of Vessel	Number	Percentage
1	Merchant Vessels	1	1
2	Fishing Vessels	104	42
3	Inland water vessels	52	21
4	Other small crafts (Pleasure Crafts, tug boats, mooring launches, supply boats and small dredgers)	90	36
	Total	**247**	**100**

Source: GMA, 2019

The size of the national fleet and its composition is a reflection of the country's low performance in revenue generation from ship registration. Also, with little job opportunities coming from the flag fleet, the country suffers a teeming seafarer unemployment and heavy reliance on foreign vessels for employment opportunities (Afful, 2016). Ajarfor (2016) indicated that, about 4000 Ghanaian seafarers were unemployed as at 2016, due to the unavailability of Ghanaian flagged merchant vessels.
1.2 Problem statement

The Ghana Maritime Authority also noted in a press briefing in 2021 that, about one thousand, one hundred and eighty-nine (1,189) Ghanaian seafarers were employed under an MoU with London and Brunei (Anaadem, 2022). On top of it all, the country's registration process is being condemned by shipowners for being hostile, especially to incoming shipowners because of its bureaucratic nature and costly (Afful, 2016). This research therefore, seeks to explore the prospects and barriers of adopting open ship registry and make recommendation on how the identified barriers could be overcome. Ship registration in Ghana would also be assessed in this research.

1.3 Research Objective

The study is guided by the following specific objectives:

i. To assess the current situation of ship registration in Ghana;
ii. To establish the benefit of adopting open ship registry in Ghana;
iii. To identify barriers of adopting open ship registry in Ghana;
iv. To recommend ways of overcoming the barriers of adopting open ship registry in Ghana

2.0 LITERATURE REVIEW

2.1 Concept of Ship Registration

Ship registration is the general mechanism for registering a ship/vessel in a particular State (IMO, 2019). This allows the inscription of a vessel into the public records (Rojas, 2019) and provides vessels with internationally recognised legal identity (Fast Capital, 2023). Generally, ships are registered under one of three systems; closed, open or hybrid system.

Closed Ship Registry (CSR) restricts ship registration to nationals or entities meeting a country's legal criteria. It typically requires ships to be owned and crewed by citizens, though restrictions vary by country. CSR allows for better fleet supervision, ensures compliance with safety and pollution standards, protects domestic shipping interests and promotes local employment. However, its strict requirements can limit fleet expansion, reduce tax revenue, and increase operational costs, as shipowners cannot access cheaper international labour markets. The economic pressures associated with this system often lead shipowners to re-flag under less restrictive systems. (Xiao, 2021)

The Open Ship Registry (OSR) system allows vessels to register under a country's flag regardless of the shipowner's nationality. Established during World War II, OSRs have become dominant in global shipping, holding over 70% of registered ships (Hung and Son, 2015; Shaheen, et. al., 2020). Major OSR countries like Panama, Liberia, and the Marshall Islands benefit from significant economic returns through fees and taxes, despite having low registration charges and offering incentives (Hung et al., 2015; UNCTAD, 2022). For instance, Panama generated $87.3 million in 2021. The fruitfulness of open ship registries over the years, is attributed to their attractiveness to shipowners due to flexible tax regimes and cost-saving opportunities, including hiring international crews at competitive rates (Rojas, 2019). The major drawback of adopting this system could be insufficient resources and surveillance capacity, both in terms of infrastructure and personnel for monitoring and controlling vessels, potentially leading to navigational safety and security issues (Petrossian et al., 2020; Negret, 2016). OSRs are also criticized for fostering unfair competition, violating collective agreements between labour and management and jeopardizing the interests of seafarers (Xiao, 2019).

The hybrid ship registration system consists of both closed and open registration features (Shaheen, et. al., 2020). States establish offshore "second registers" to attract shipowners, offering benefits similar to open registries, including financial incentives and reduced restrictions. Hybrid registries emerged as a response to the dominance of open registries, which had significantly reduced fleet sizes and revenues in traditional closed registry states (Shaheen et al., 2020; Xiao, 2021). The countries that adopt this system are mostly developed countries. They establish the second register mostly in former colonies and dependent states or territories, making this system unsuitable for developing countries like Ghana (Rhea, 2010).

2.4.4 Ship Registration in Ghana

As a prominent maritime and costal state, the country has a coastline of approximately 540 kilometres (270 nautical miles), stretching from Aflao in the Volta Region to Cape Three Points in the Western Region. It shares borders with the Gulf of Guinea and the Atlantic Ocean in the south (GMA, 2021, Maritime Page, marine insight). Ghana's location along the Gulf of Guinea offered a strategic advantage, leading to the establishment of the Black Star Line (BSL) in 1957. Initially supported in terms of finance and management, by ZIM Shipping, BSL became fully state-owned in 1960. Its purpose was to bolster trade, capture 40% of ocean traffic, create jobs, and prevent foreign dominance in Ghana's shipping sector. Operating under a closed registry system which was adopted to protect from foreign competition, the BSL owned vessels such as MV Keta and Lake Bosomtwe, transporting key exports like cocoa and timber. The company contributed to maritime development by influencing the establishment of the today Regional Maritime University and dry docks (Afful, 2016).

Despite these achievements, challenges led to BSL's collapse in the 1990s. The closed registry system has since struggled to achieve its objectives, with Ghanaian seafarers facing high unemployment. Approximately 4,000 seafarers remain jobless due to the lack of state-owned ships. While the closed registry system initially protected Ghana's shipping interests, its limited flexibility and reliance on BSL constrained its long-term effectiveness, particularly in fostering sustainable growth and employment in the maritime sector (Afful, 2016). Today, Ghana continues to grapple with these challenges, highlighting the need for a re-evaluation of its ship registration policies to maximize maritime sector benefits.
Seagoing vessels are registered, inspections and surveyed under the provisions of the Ghana Shipping Act, 2003 Act (645) which allows ship ownership by Ghanaian citizens, corporations, partnerships, and foreign entities in joint ventures with Ghanaians. According to Sawer (2024), Ghanaians involved in joint venture arrangement are in these arrangements through fronting schemes and using corporate structures to conceal the real ownership of foreign owned vessels. Ghana's Shipping Act, Section 99, empowers the Minister to regulate manning requirements for Ghanaian vessels, emphasizing nationality and crew qualifications of seafarers manning Ghanaian vessels. The 2021 Cabotage Regulations reserve 50% of officer positions and 75% of ratings for Ghanaian seafarers on foreign vessels that operate in the shores of the country, fostering local employment and safeguarding national shipping infrastructure (Kwofi, 2022; Dugbartey, 2023). The regulations also seek to protect the domestic shipping industry from foreign competition, preserve domestically-owned shipping infrastructure for national security purposes, and ensure safety in Ghana's territorial waters (Dugbartey, 2023.

The step-by-step process to get a ship registered under the flag of Ghana as outlined on the maritime administration's website *https://ghanamaritime.org/home/ship-registry/*, shows that the process takes up to five (5) working days. Afful (2016), indicated that Ghanaian ship owners find the registration process as demanding and discouraging for their business and to new entrance. This is because, the obligation that comes with the registration process is bureaucratic, laborious and cost intensive. The shipowners advocated that the registration process be reviewed to a more user-friendly, less bureaucratic and less costly.

According to Section 478 of Act 645, ship owners are required to remit fees to the Ghana Maritime Authority for certificates issued for registration, survey, inspection of a ship, or services provided in the engagement and discharge of seafarers. The minimum fees for registering a vessel with a gross tonnage of 150 and above in Ghana amount to approximately USD 3,695, equivalent to GHC 36,950.

Table 2: Ship Registration Fees and Charges

s/n	Fees and Charges Item	Approved Fees and Charges (USD)
1	Application Form for Vessel Registration	50
2	Examination of Importation Document	1,000
3	Processing of Application	1,150
4	Certificate of Survey of Registration	1,150
5	Ship Carving and Marking notes	115
6	Issue or re-issue of Certificate	230
	Total	**3,695**

Note: Fees and Charges (Miscellaneous Provisions) Act of 2022 (Act 1080).

There is limited study and literature on the specific ship registration tax system under Ghana's ship registration system. However, Afful (2016), established that, Ghanaian shipowners do not enjoy any tax discounts or incentives from the administration.

Ship registration policies that are enticing to ship owners, such as tax exemptions; lenient application of labour laws, social security systems, and regulations on ship operation and crew hiring; and financial incentives has significant and positive relationship with increased number of registered vessels, employment and taxable revenue to government (Godson, 2020) affirmed that The shipping business rides on the phenomenon of maximising profits while minimising cost of operations (Park, et. al., 2022). Consequently, by ship owners avoid registries with high taxes, low incentives and inflexible, given the capital intensiveness of the shipping business. Singapore, for instance mitigated unemployment with the policy of awarding vessels a 50% refund on the annual tonnage tax for recruiting a minimum of 25% Singaporean crew.

2.3.3 Overview of Some Prominent Open Ship Register

For the objective of this study, the subsequent subsections entail a review of Panama, Liberia and Singapore system of open ship registry. The review of the system of registry of these countries covers the registration procedures, conditions as well as ship registration policies adopted by them.

Table 3. Implementation of Open Ship Registry in Panama, Liberia and Singapore

	Panama	**Liberia**	**Singapore**
Period of Adoption	Open Ship Registry was adopted in the early 1920s	Adopted in 1948	Switched to Open registry in the 1969
Registration Condition	• No restriction on ship owners' nationality • Open to all types of ships • No prerequisite tonnage requirement for registration. • Pre-survey is required for vessel that are over 20 years old	• No restriction on ship owners' nationality • Open to all types of vessels that are 20 years of age and below	• No restriction on ship owners' nationality • All types of vessels for registration that are 17 years and below except fishing vessels, hydrofoils and wooden vessels. • Vessel classed by a recognised classification societies is considered for registration
Registration Process	Two major steps of registration, that is provisional registration and permanent registration	The Registration process comes with ease and its user friendly with no delay in operation	The procedure for registering a ship with the Singapore Registry has 5 major steps
Ship Registration Policies	• Merchant Marine Act (Law No. 57 allows indefinite renewal of vessel registration. • All the taxes are low and competitive. • Grants up to 50% special discounts on registration fees to ship-owners depending on the type, number, size and tonnages of ship. • No nationality restriction on crew recruitment. • The income of the Crew is not subject to income tax, just like the operations of the vessel. • No currency restrictions and limits on monetary transfers between countries	• Vessels registered are taxed annually with a fixed fee per the net tonnage of the vessel. • Ship operations and profit are not taxed. • Offers 3% annual tonnage tax discounts under Green Award program. • No nationality restriction on crew recruitment.	• Offers 50% reduction on the Initial Registration Fees to Ships that exceed the requirements of IMO's MARPOL Annex VI Phase 3 EEDI by 10% or more • Offers 80% discount under the Green Ship Programme (GSP), on the initial registration fee (IRF) to ship owners who register their ships fulfilling the BTS criteria. • Ship owners' profits and personnel income are exempt from Singapore income tax. • No nationality restriction on crew recruitment.

3.0 Research Methodology

The study applied a qualitative research approach to explore perspectives on Ghana's ship registry, prospects and barriers of adopting an open registration system in Ghana. This method allowed the research to examine the unique experiences and insights of participants regarding the characteristics and impacts of the various ship registration systems on nations and other key maritime players. According to Cleland (2017), qualitative research allows a researcher to appreciate situations, occurrences, and experiences by answering the 'how' and 'why' questions of a research. It also helps researchers to address question in a comprehensive manner that would be difficult to provide with numbers (Islam & Aldaihani, 2022). This method was utilised in this research for both data collection and analysis because of the nature of the research and questions that the research sought to address.

3.1 Data Collection: Both secondary and primary data sources were employed. Secondary data included literature reviews of ship registration systems worldwide, especially open registries in Panama, Liberia, and Singapore. Primary data involved first-hand insights gathered through interviews with some key stakeholders in Ghana's maritime industry. The interviews were conducted face-to-face or via digital platforms to accommodate participant preferences.

3.2 Data Analysis and Sampling: Using the interpretative phenomenological analysis (IPA), the study interpreted participants' lived experiences, aiming to provide an unbiased view of their perspectives. A purposive sampling technique was employed to target 23 maritime experts, including individuals from the Ghana Maritime Authority, shipowners, seafarers, ship managers and lecturers for their specialized knowledge. These participants offered valuable insights into Ghana's current ship registry and the possible advantages of an open registration system.

4.0 Results and Discussions

4.1 Current situation of ship registration in Ghana

This study revealed that currently, Ghana has a slow growing ship registry that contribute minimally to economy of the country. The data collected from GMA showed that the registry generate less than 1% of the administration's annual incomes. The seafaring profession in Ghana holds great potential but faces limited job opportunities, especially for cadets due to the unavailability of national vessels and limited Ghanaian beneficial ship ownership.

About 80% of the Ghanaian flagged vessels are owned under Ghanaian/foreign joint venture arrangement where the foreigners have the highest investment. The foreigners' high investment gives them dominance in management and operational decision making which consequently leads to high recruitment of foreign seafarers on Ghanaian vessels, especially for managerial roles. This situation defeats the purpose of job creation for Ghanaians bases that the closed registry was opted.

The findings on the registration process and procedures indicate that they would have a regressive impact on OSR if considered in Ghana. Panama, Liberia, and Singapore are renowned for their simplified registration procedures, automated processes, and short registration times. The primary data confirmed that shipowners associate the registration process with complexity, inconvenience, and delays that incur them financial costs. The service for ship registration is exclusively available at the headquarters of Ghana's Maritime Administration (GMA), lacking automation and digitalization of procedures and correspondence. The expensive cost of registration is exacerbated by exchange rate instability and delays in the registration process.

Ship operation in Ghana's domestic shipping industry is burdened by substantial tax obligations without corresponding tax incentives, fee reductions, or voluntary government initiatives to support Ghanaian shipowners. This challenging and hostile business environment negatively impacts Ghanaian shipowners. Ship registration policies influence a system's performance, attracting shipowners through tax benefits, discounted fees, and incentives. Ghana's lack of such measures diminishes its competitiveness for Open Ship Registry marketing.

4.2 Benefits of adopting open ship registry in Ghana

About 87% of respondents believe Ghana's closed ship registry inadequately benefits socio-economic development, citing limited Ghanaian shipping companies and exposure to foreign competition. They established that there are no major Ghanaian-owned shipping companies to protect from foreign shipping companies such as MSC and Maersk, especially after the collapse of the Black Star Line. Conversely, some argue CSR ensures maritime safety, security, and protects Ghanaian waters and emphasised that the country has limited capacity to manage alternative regimes while maintaining a good international maritime reputation.

- o Increase revenue for the Maritime administration and by extension contribution national income: Industry experts suggest adopting OSR could boost Ghana's revenue by increasing fleet registration fees and auxiliary income from seafarer training and certifications, inspired by successes in Panama and Liberia.
- o Create increased and wider range of employment opportunities in the seafaring profession and other maritime professions such as ship broking, insurance companies, just to mention a few: OSR adoption could create jobs for Ghanaians, particularly seafarers, and reduce youth unemployment, drawing lessons from Singapore's 1970s incentive policies. Additionally, maritime professions like ship management, broking, and insurance could benefit from expanded global market exposure.
- o Increased international recognition by giving Ghana a strong voice on influencing international maritime decisions at the International Maritime Organisation (IMO): The interviews established that States with significant gross tonnage on the register OSR has the potential of providing Ghana with the number of tonnages that would amplify the country's voice on influencing international maritime decisions. A few of the respondents from GMA also testified to this.

o OSR can contribute to Ghana's blue economy and green shipping: the participating experts in this research argued that ship registration policies like the Liberian Green Award program and the Green Ship Programme (GSP) scheme of Singapore which encourages shipowners to improve the safety and environmental performance of their vessels can be utilised in the Ghana's agenda to being among the blue economy and operating green shipping.

4.3 Barriers of adopting open ship registry in Ghana

o Somewhat cumbersome, inconvenient and expensive registration procedure. Given that OSR targets not only the domestic but also the foreign market, Ghana's current registration process, as described by respondents as included bureaucratic, lengthy and complex administrative procedures, slow digital communication, and frustration with multiple travels during the registration process could pose a barrier to the country benefiting from adopting OSR.

o Having nationality as a determining factor for registration. Overviews and assertions regarding OSR states reveal a negative correlation between nationality restrictions and the growth of a flag state register. While Ghana's nationality restriction is not overly stringent, it still poses a barrier to optimizing the benefits of OSR in the country. Therefore, a reconsideration of this condition is necessary for effective OSR adoption.

o Zero government incentives for shipowners coupled with huge tax burden. Huge tax burden coupled with zero tax reduction policies, like attributed to shipping business in Ghana can be considered as one of the significant obstacles to the national fleet expansion, thereby, negatively impact the growth of the country's register upon implementation of OSR.

o Inadequate resource capacity to regulate, manage and inspect vessels to ensure navigation. The shipowner respondents highlighted that, delays due to the limited number of survey and inspection surveyors available. Inadequate capacity can have a detrimental effect on the successful implementation of an OSR regime.

o Implementation Bottleneck as A Result of Bureaucracy and Policy Politicisation The interview brought attention to the politicization of public policies and bureaucratic procedures in policy implementation within Ghana's operational systems. This situation creates bottlenecks in the execution of many development projects and ideas in the country. The respondents highlighted that certain significant government policies and projects have experienced delays, if not outright abandonment, due to a lack of continuity resulting from changes in government or public officers. According to the respondents, if the adoption of an Open Ship Registry (OSR) is considered and any of these scenarios unfolds, the entire initiative of adopting OSR could face significant delays or even come to a complete halt

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4.4 Overcoming barriers that could hinder the benefit of open ship registry in Ghana

o Automated and simplified registration process coupled with increasing accessibility of the Maritime Administration to the shipowners, through 24hour service provision and visual correspondence. Accessibility to shipowners at all times promotes responsiveness and good customer relations, potentially contributing to the success of an OSR system. As noted by Shaheen et al. (2020), delays in registration due to complex processes frustrate and incur costs for shipowners considering flag state registration. Therefore, there is a need to simplify Ghana's registration process, introduce automation and digitization, and ensure 24/7 service provision to optimize the benefits of adopting OSR.

o Remove nationality restrictions as registration condition and utilise the Cabotage law and other enticing and incentive policies to secure jobs for Ghanian seafarers.

o Introduction of fee and tax incentives as well as supportive government initiatives targeting shipowners and promoting seafaring employment opportunities.

o Ship registration policies that are well defined, focused and attractive to shipowners and influence employment creation. using policies to encourage shipowners to adhere to safety, security, and environmentally friendly shipping initiatives can be gleaned from the initiatives undertaken by Liberia.

o Built Requisite Capacity and Take Lessons from Successful OSR Countries. The interviews indicated that the Maritime Administration should enlist and train additional skilled personnel, particularly surveyors, to effectively address the potential demand that may arise with an Open Ship Registry (OSR). It was also proposed that the GMA could consider temporarily outsourcing technical responsibilities to classification societies.

o Strong Dedication by the Maritime Administration to Prevent Implementation Bottleneck. Respondents argued that it would take strong dedication and will of GMA in the facilitation of the implementation process, in order to mitigate institutional delays and bureaucracy. Exhibiting time-consciousness and ensuring consistency in tracking the implementation progress can also play a significant role in mitigating delays and bureaucracy.

5.0 Conclusions and Recommendations

5.1 Conclusions of the study

Investing in shipping business is a significant undertaking, given the capital intensiveness and fierce competition in the shipping market therefore, shipowners try to take advantage of cost-effective alternatives in decision making, to achieve the highest possible returns on their investment in a long run. Knowing this, prominent OSR States, arrange flexible fee and business-friendly policy to entice shipowners. In return, OSR States today, hold remarkable share of the world's fleets and gain significant benefits from it.

Since time immemorial, the number of vessels under the flag of Ghana and the accrued socio-economic benefits have been insignificant. The findings of the research evidence that OSR system has the potential to increase the national fleet and essentially the contribution to +national revenue as well as increase employment prospects in seafaring. However, existence of factors such as cumbersome registration process, cost of registration, high tax burden, zero ship registration policies and limited capacity of the Maritime Administration, just to mention a few would hinder Ghana from benefiting to the optimum upon adopting open ship registration regime.

5.2 Recommendation

The analysis of the findings of the study clearly points out that there are some barriers and suggests some possible solutions have been identified to mitigate these challenges. To achieve optimal benefit of adopting open ship registration in Ghana, the study recommends the following:

- Developing Comprehensive Policy Framework for Implementation of Open Ship Registration

  The Maritime Administration should consider developing a comprehensive policy framework which defines the objectives, strategies, and stakeholder roles in the idea of adopting open ship registry. This would then influence decisions on suitable registration conditions, structures and procedures for the registration process and ship registration policies. This will also make the monitoring and tracking of progress easier. Easy tacking and monitoring of progress help in early and easy detection of policy or plan that might need revision or realignment.

- Automation and Digitalisation of Registration Systems

  GMA should consider an automated registration procedure coupled with digital correspondence in the form of online application platform on its website, emails for exchange of document, paperless payment system, and digital issuance of certificates and licenses to increase its administrative efficiency and promote productivity. To ensure the protection and verification of security details on vessel certificates and licenses, an automated system could incorporate a Bar Code Verification System. This will not only promote good customer service and enhance the Authority's productivity around the clock thereby increasing its attractiveness to shipowners, but would also save shipowners significant cost and time.

- Delegation of Some Functions to Recognised Organisation (RO)

  The Maritime Administration ought to engage the expertise of acknowledged classification societies to conduct surveys and inspections, particularly for foreign vessels that may be drawn to Ghana's registry under an Open Ship Registry (OSR) regime.

- Easing Tax Regimes and Introduction of Incentive Schemes

  Shipowners consistently favour a flag State that offers increased flexibility and economic advantages. To make Ghana's registry economically appealing to both domestic and foreign shipowners, it would be essential to eliminate taxes on the importation of vessels; and streamline fees discounts and tax discounts towards increasing employment opportunities for Ghanaian seafarers. Incentive schemes can also be utilised in promoting safety and environmentally friendly practices, thereby support the global blue economy agenda.

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Examining the Interplay Between Safety Delivery and Safety Awareness on Safety Behavior: Insights from Onboard Ferry Operations

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Abstract

This study explores the safety culture in ferry crossing, aiming to reduce accidents and fatalities by investigating how organizational safety culture influences accident-preventive behavior. This study examines the impact of safety delivery and awareness on passengers' preventive behavior during ferry crossings in Ghana, using a quantitative research approach. A cross-sectional design will be employed, allowing data collection from ferry passengers explore their views using structured questionnaires. This study revealed how safety awareness (safety information, safety equipment, vessel condition) and safety delivery (safety facilities, safety demonstration, safety enforcement) interact to foster accident-preventive behaviors in ferry transport in developing economies.This research contributes to safety literature by exploring the interactive effects of safety awareness and safety delivery on accident preventive behavior. It also extends the application of the Theory of Planned Behavior in the maritime context.

1.0 Introduction

Inland waterway transportation, particularly ferry crossings, is a vital mode of transportation worldwide, providing essential links between communities and facilitating economic activities (Smith, 2021). Despite its benefits, ferry travel presents inherent risks, with accidents and fatalities occurring frequently. For instance, the sinking of Eastern Star in 2015 resulted in the death of 442 people (Wang et al., 2020), and the Sewol ferry disaster in 2014 caused the deaths of 300 passengers and crew members (Woo et al., 2015). Additionally, from 2000 to 2014, Golden and Weisbrod (2016) recorded 232 ferry accidents with varying fatalities in 43 countries.

The situation is not different from Ghana as the water transportation accidents used to be very minimal but has seen a surge in the past few decades. Inland waterways in Africa, specifically in Ghana, have also experienced several recent accidents, incidents, and deaths. (Boadu et al., 2021), provided account of several accidents occurring on Ghana's Inland waterways. For instance, on 11th April, 2011, a ferry on the Volta Lake sunk due to overloading and poor weather conditions. In July 2012, the MV Juliana, which was also operating on Lake Volta, capsized during a heavy storm. The ferry was overloaded with passengers and cargo at the time of the accident, leading to a significant loss of life. In May 2016, the MV Dodi Princess II capsized on Lake Volta in the Brong-Ahafo Region of Ghana.

In the light of above, it is pressing to understand options to enhance accident preventive behavior in ferry crossing. Drawing inspiration from (Azmi et al., 2023) and Lau et al. (2021), they argued empirically that, both safety delivery and safety awareness positively associate with safety behavior. In contrast, Mikuličić et al., (2024) show that safety awareness and delivery are though fundamental in safety behavior conversations, however, they argue that safety awareness in isolation does not stimulate safety behavior. These mixed findings justify the need to further explore and develop clarity in understanding.

2.0 THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

2.0.1 Safety Delivery

Safety delivery has garnered attention and importance in recent years safety literature (Boysen et al., 2021). It has been argued that ensuring safety delivery is paramount to building trust and confidence among consumers (Bowen et al., 2014). Experts argue that safety delivery is not a one-size-fits-all approach in enhancing safety behavior (Hong & Cho, 2024a; Xi et al., 2023); rather, it takes on nuanced meanings depending on the context in which it is applied. In the context of ferry crossings, it refers to the comprehensive process and measures put in place to ensure the safety of passengers during their journey on a ferry (Popa & Strer, 2016). We argue that, safety delivery focuses on the meticulous orchestration of measures aimed at safeguarding passengers throughout their journey.

2.0.2 Safety Awareness

Safety awareness regarding ferry crossings is a paramount concern that involves passengers, crew, and operators being vigilant and informed about safety measures and protocols to ensure a secure and risk-free journey (Ali, 2020). It has been argued that fostering a culture of safety awareness is essential to minimize potential hazards and ensure safe travel over water. According to Hystad et al. (2016), safety awareness encompasses passengers' understanding of emergency procedures, such as the location of life jackets and lifeboats, and their adherence to safety instructions given by crew members. In the same line of argument, passengers need to stay within designated areas during the voyage to maintain a safe environment.

For passengers, safety awareness begins with understanding and following safety instructions provided by the ferry crew. These instructions, as highlighted by Ljung and Oudhuis (2016), to include the location of life jackets, lifeboats, emergency exits, and muster stations. Passengers' awareness of the importance of wearing life jackets properly, securing their personal belongings, and not obstructing aisles or access points is crucial for their safety. It has been argued that this awareness is vital in ensuring a safe journey (Yelgin & Ergün, 2022).

2.0.3 Passenger Preventive Behavior

Passenger preventive behavior refers to a set of actions, practices, and precautions taken by individuals traveling as passengers on various modes of transportation, such as ferries, airplanes, trains, or buses, with the primary goal of minimizing risks, ensuring safety, and contributing to a secure and smooth journey (Munawar et al., 2021). It consists of range of actions and precautions that passengers should take to minimize risks, respond to emergencies, and contribute to a safe and smooth voyage (Lau et al., 2021).

2.0.4 The Theory of Planned Behavior (TPB)

We use TPB to develop a conceptual model of how and when safety delivery and safety awareness affect accident preventive behavior. Earlier studies focused on using individuals as unit of analysis, but more recent applications have considered how organizations and ship operators can promote safety behavior. The theory's basic tenets hinges on attitudes, subjective norms, and perceived behavioral control. Husin & Ab Rahman, (2016) emphasize that attitudes toward a behavior significantly impact one's intention to engage in that behavior. For instance, positive attitude towards safety behavior is more likely to positively impact such individual in demonstrating safety attitudes. Subjective norms encompass the social pressure or influence an individual perceives from significant others, such as family, friends, or colleagues, regarding the behavior in question. These norms reflect whether an individual believes that others important to them would approve or disapprove of the behavior. In TPB, subjective norms contribute to the formation of intentions; if someone believes that their social circle supports a particular behavior, they are more likely to intend to perform it.

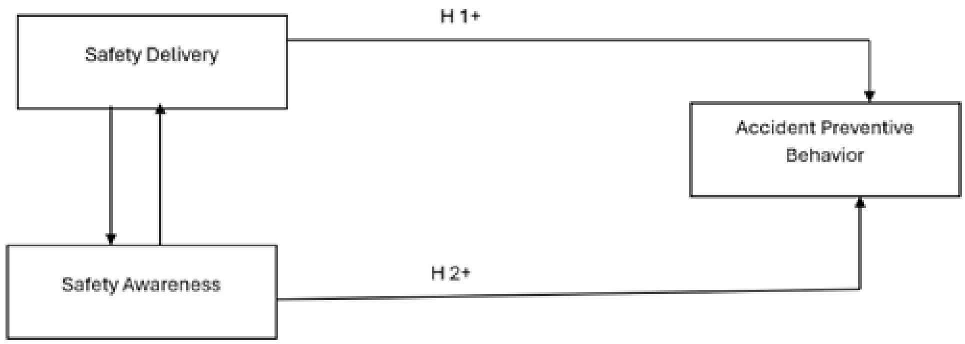

Figure 1. Conceptual Model

From the conceptual model, the following hypotheses were developed; (H1) -safety delivery positively affects ferry passenger behavior and (H2)- safety awareness positively affects ferry passenger behavior.

3.0 METHODOLOGY

3.0.1 Research Design

Previous research on safety in the context of inland waterway transport has been based primarily on cross sectional survey data (Lau et al., 2021; Lu et al., 2018a, 2018b; Xi et al., 2023). Following examples from such studies, we collected cross-sectional survey data to test our hypotheses. We sampled passengers who use the services of the ferries at Akosombo, Dambai, Yeji and Adawso. These are the major ferry stations operated by Volta Lake Transport Company Limited (VLTC) in Ghana. Ghana is a developing economy where it is difficult to obtain objective secondary data for the variables of interest. Though cross sectional data restrict the ability to make causal inferences (Kull et al., 2018). Rindfleisch et al. (2008) argue that such data can be used to test explanatory models grounded in relevant theories. We expect safety delivery and safety awareness to have positive relationship with safety behavior.

3.0.2 Measure development

We followed the measurement guidelines in MacKenzie et al. (2011) to generate and validate suitable indicators for the constructs. Prior to administering our questionnaire, three safety experts and two deck officers were asked to review the constructs' operational definitions and indicators. Based on their feedback, indicators with poor face validity and items found to be ambiguous were revised. We pretested our questionnaire by administering to 30 ferry passengers. Upon analyzing the pilot study, no major concerns were found in the questionnaire.

3.0.3 Substantive variables

Dependent variable

We developed seven measurement items from Weng (2018) and Lau et al., (2020) where respondents were asked to show their level of agreement for the measurement items which demonstrate accident preventive behavior. This was anchored on a five-point Likert scale from 1 = strongly disagree to 5 = strongly agree.

Independent variable

Two independent variables safety delivery and safety awareness were used to predict accident preventive behavior. Safety delivery was adopted from Lu and Yang (2011) and Lu and Tseng (2012). Three reflective dimensions of safety delivery were used namely: safety facilities, safety demonstration and safety enforcement.

3.0.4 Sample and data collection

We sampled passengers from Akosombo, Adawso, Dambai and Yeji ferry stations. We focused on only passengers who have consistently used the ferries for a period of 12 months or more with not less than 10 round trips. This is to understand their experience on the ferry in relation to safety and the extent of behavioral change. A total of 242 questionnaires were administered, over a period of 3 weeks, 210 was retrieved accounting for a response rate of 87%. 87 of the received questionnaires were discarded as they were incomplete with other not meeting the period of service utilization criteria, leaving 123 valid responses (i.e., 50.8 % effective response rate). Our sample size and response rate compare favorably with other studies in maritime transport safety (Hong & Cho, 2024c; Lau et al., 2021; Lu et al., 2018b; Xi et al., 2023)

4.0 DATA ANALYSIS AND RESULTS

4.0.1 Demographic Characteristics

The demographic characteristics of the respondents in the study on the among ferry service users offer insightful glimpses into the composition of the sample. Details on participants demographic features is shown below:

Table 1 Personal Characteristics of Respondents

Features	Description	Frequency	Percent
Gender	Male	78	63.4
	Female	44	35.8
Age	18–29 years	34	27.6
	30–40 years	71	57.7
	41–50 years	13	10.6
	51–60 years	2	1.6
	61+ years	2	1.6
Level of education	SHS	17	13.8
	Undergraduate	44	35.8
	Postgraduate	60	48.8
	Doctoral degree	2	1.6
Ferry stations mostly utilized	Akosombo	65	52.8
	Yeji	6	4.9
	Dambai	13	10.6
	Adawso	38	30.9

Source; Field data (2024)

4.0.2 Exploratory factor analysis of safety awareness attributes

The exploratory factor analysis delving into safety awareness attributes related to Safety Information, Safety Equipment, and Vessel Condition reveals several noteworthy details into the perceptions and behaviors of ferry service users. These attributes offer a comprehensive view of how individuals engage with safety protocols and their awareness of crucial aspects while utilizing ferry services.

	Variables	Safety Information	Safety equipment	Vessel condition
1	I am aware of ferry's relevant safety information while taking the ferry	777.		
2	I read information on the ferry's safety card in details	716.		
3	I am aware of the emergency evacuation .procedures on the ferry	859.		
4	I am mindful of the designated assembly points in case of an emergency	836.		
5	I pay attention to ferry's emergency exit routings	649.		
6	I pay attention to the position of life boats		568.	
7	I am aware of the ferry whether it has been overloaded		850.	
8	I am aware of the ferry whether it has been over speeded		811.	
9	I am concern about the captain's and crew member's mental conditions		651.	
10	I am aware of the location of fire extinguisher			760.
11	I am aware of the position of life jackets			730.
12	I comply with ferry's relevant safety regulations while taking the ferry			797.

Source; Field data (2024)

Under the category of Safety Information, the analysis indicates a strong association with various safety practices. Participants reported high levels of awareness regarding relevant safety information provided on the ferry, emergency evacuation procedures, designated assembly points during emergencies, and the presence of fire extinguishers. These findings suggest that ferry users are generally attentive to safety guidelines and protocols, as indicated by the significant factor loadings (0.777, 0.716, 0.859, 0.836, 0.760).

4.0.3 Exploratory factor analysis of safety delivery attributes

The exploratory factor analysis on safety delivery attributes, categorized into Safety Facilities, Safety Demonstration, and Safety Enforcement, provides valuable insights into the perceived effectiveness of safety measures and practices onboard ferry services.

Table 3: Safety Delivery attributes loadings

	Variables	Safety facilities	Safety demonstration	Safety Enforcement
1	The ferry has a sufficient supply of life-saving equipment	.870		
2	The fire-fighting equipment on the ferry is satisfactory for passenger safety	.813		
3	The medical facilities and equipment on the ferry are sufficient for potential emergencies	.810		
4	The safety demonstration and announcements provided to passengers are clear and comprehensive.		.723	
5	The safety initiatives effectively guide and alert passengers to potential risks.		.766	
6	The safety guidance and alertness communicated on the ferry is easily understandable to passengers.		.847	
7	The safety posters displaying emergency equipment are clear and easily comprehensible.		.794	
8	There are sufficient safety officers onboard			.742
9	The safety officers check on passengers to enhance safety			.829
10	The safety officers communicate clearly to inform			.853
11	The safety officers enforce all safety protocols onboard			.803

Source; Field data (2024)

Starting with Safety Facilities, respondents indicated a high level of satisfaction with the availability and adequacy of life-saving equipment and fire-fighting facilities on the ferry. The significant factor loadings (0.870, 0.813, 0.810) suggest that passengers generally perceive the ferry to be well-equipped to handle potential safety emergencies, with sufficient medical facilities and equipment available for emergencies.

4.0.4 Reliability test

The Cronbach alpha reliability test was conducted to offer comprehensive evaluation of the various constructs examined in the study. This was done to shed light on the internal consistency and reliability of the measurements. The Cronbach alpha reliability results are shown in Table 4.

Table 4 Cronbach Alpha Reliability

Variables	Constructs	Number of items	Cronbach's alpha
Safety awareness	Safety information	5	.920
	Vessel condition	4	.822
	Rescue equipment	3	.834
Safety delivery	Safety equipment	3	.910
	Safety demonstration	4	.909
	Safety enforcement	4	.903
Passenger Preventive Behaviour		7	.857
Understanding Ferry Crossing		3	.711

Source; Field data (2024)

Among the constructs related to Safety Awareness, it is evident that the items assessing Safety Information exhibit a very high level of internal consistency, as indicated by a Cronbach's alpha of 0.920. This suggests a strong reliability in gauging respondents' awareness of safety-related information provided onboard the ferry. Similarly, the construct concerning Vessel Condition demonstrates a good level of internal consistency with a Cronbach's alpha of 0.822, implying a reliable measurement of respondents' perceptions regarding the condition of the ferry. Moving on to Rescue Equipment, the construct maintains a commendable level of internal consistency with a Cronbach's alpha of 0.834. This indicates a reliable measurement of respondents' awareness regarding the availability of rescue equipment onboard.

4.0.5 Safety awareness

The study on safety awareness of ferry travel was examined and the results are shown in the model (figure 1) below. In this model, safety awareness was measured with safety information, vessel condition and rescue equipment.

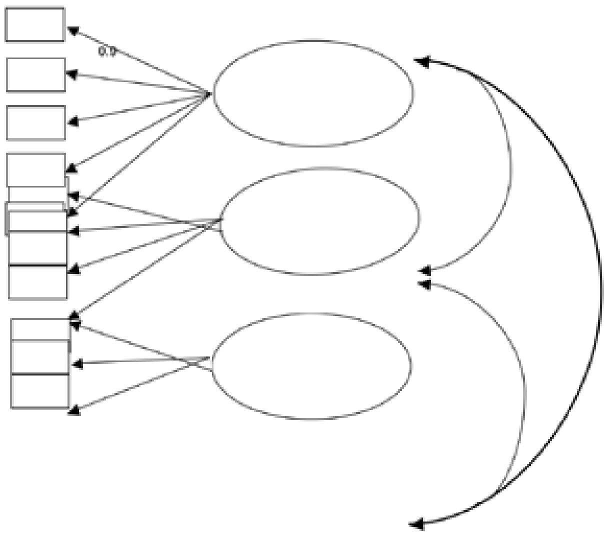

Figure 1: Safety Awareness Measure
Source; Field data (2024)

Examining safety information, which was assessed through five items, the results indicate a strong correlation among these elements. Each item, ranging from awareness of relevant safety information to attention to emergency evacuation procedures, shows a consistent correlation of 0.8 to 0.9 with the overall construct of safety information. This suggests a cohesive understanding among passengers regarding the safety protocols and emergency measures provided by the ferry service.

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4.0.5 Safety Delivery

The study assessed safety delivery measures aboard a ferry using three key constructs: safety facilities, safety demonstration, and safety enforcement. The analysis shown in the model (figure 2) revealed noteworthy correlations among these constructs. Details on the correlation between the various constructs is shown below;

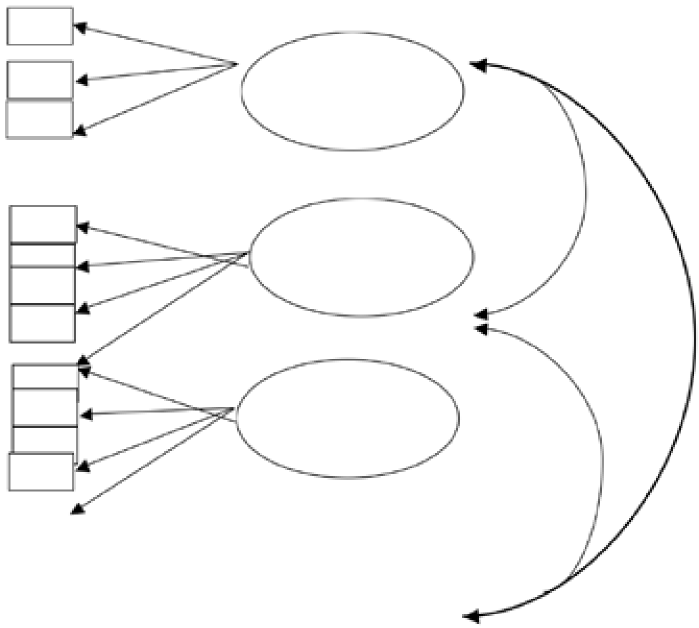

Figure 2: Safety Demonstration Measure
Source; Field data (2024)

From the model, it was observed that the study found a strong positive correlation of 0.7 between safety equipment and the effectiveness of safety demonstrations. This suggests that when a ferry is well-equipped with safety gear such as life-saving and fire-fighting equipment, the effectiveness of safety demonstrations tends to be notably higher.

The correlation of 0.6 between safety facilities and safety enforcement, as well as safety demonstration and safety enforcement, highlights an interplay between physical resources and procedural actions. When safety facilities, such as life-saving equipment and medical provisions, are in place (as indicated by the high 0.9 correlations within the safety facilities items), they support the enforcement of safety protocols by officers onboard. Moreover, effective safety demonstrations, which were positively correlated with all items at 0.9, likely aid in reinforcing the importance of these protocols to the enforcement officers.

4.0.5 Passengers Preventive Behavior

The results revealed notable correlations between passengers' preventive behaviors and the items used to measure these behaviors.

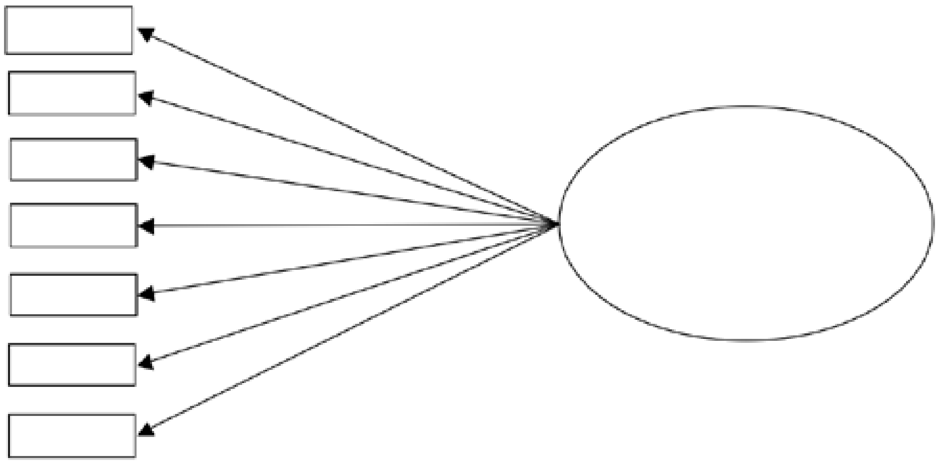

Figure 3: Passengers Preventive Behavior Measure
Source; Field data (2024)

From model (Figure 3), it was discovered that among the seven items assessed, correlations ranged from 0.5 to 0.8. These items captured a range of actions and attitudes related to safety while onboard. Passengers showed a moderate correlation of 0.5 with the item indicating their refrainment from engaging in behaviors that might jeopardize safety during the ferry voyage. This suggests that while a portion of passengers consciously avoids risky behaviors, there is variability in this aspect of preventive behavior.

In contrast, stronger correlations of 0.7 to 0.8 emerged with several other items. Notably, passengers displayed a robust correlation of 0.8 with items such as actively participating in safety drills, knowing how to use safety equipment like life jackets and fire extinguishers, refraining from obstructing emergency pathways, taking precautions against slips and falls, and consciously following safety instructions provided by the ferry crew.

4.0.6 Effect of safety delivery on passenger preventive behavior

The analysis aimed to investigate the impact of safety delivery components—safety facilities, safety demonstration, and safety enforcement—on the preventive behavior of passengers utilizing ferry services in Ghana.

Table 5a: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.700a	.489	.476	3.84487

a. Predictors: (Constant), Safety Enforcement, Safety Facilities, Safety Demonstration
Source; Field data (2024)

The model summary indicates that the safety delivery factors; safety facilities, safety demonstration, and safety enforcement collectively account for a substantial portion of the variance in passengers' preventive behavior, with an overall model fit of R=0.700 and an associated R2 of 0.489. This suggests that approximately 48.9% of the variability in passengers' preventive behavior can be explained by safety facilities, safety demonstration, and safety enforcement combined. The adjusted R2 of .476.476 suggests a reliable fit of the model, considering the included predictors.

Table 5b: ANOVA

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	1657.375	3	552.458	37.371	.000b
	Residual	1729.616	117	14.783		
	Total	**3386.992**	**120**			

a. Dependent Variable: Passengers Preventive Behavior
b. Predictors: (Constant), Safety Enforcement, Safety Facilities, Safety Demonstration
Source; Field data (2024)

The ANOVA results further support the significance of the model (F=37.371, p<0.001), indicating that the regression model as a whole is a strong predictor of passengers' preventive behavior.

Table 5c: Coefficients

Model	Unstandardized Coefficients	Standardized Coefficients			t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.882	1.334		9.655	.000
	Safety Facilities	.477	.155	.287	3.086	.003
	Safety Demonstration	.508	.134	.375	3.789	.000
	Safety Enforcement	.181	.123	.130	1.474	.143

a. Dependent Variable: Passengers Preventive Behavior
Source; Field data (2024)

The breakdown of the model into its components reveals that safety facilities (β=0.287, p=0.003) and safety demonstration (β=0.375, p<0.001) both have statistically significant positive effects on passengers› preventive behavior. This suggests that as perceptions of safety facilities and the quality of safety demonstrations improve, passengers are more likely to engage in preventive behaviors. However, safety enforcement (β=0.130, p=0.143) does not appear to have a statistically significant effect on passengers› preventive behavior at the conventional p<0.05 level. While the coefficient is positive, indicating a tendency towards increased preventive behavior with better safety enforcement, the lack of statistical significance suggests that this relationship may not be as strong as that of safety facilities and safety demonstration.

4.0.7 Effect of safety awareness on passenger preventive behavior

The analysis sought to explore the influence of safety awareness components—specifically, Rescue Equipment, Vessel Condition, and Safety Information—on passenger preventive behavior within the context of ferry services.

Table 6a: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.741a	.549	.538	3.59977

a. Predictors: (Constant), Rescue Equipment, Vessel Condition, Safety Information
Source; Field data (2024)

The model summary indicates a moderate-to-strong fit for the model, with an R value of 0.741 and an associated R2 of 0.549.549. This suggests that approximately %54.9 of the variability in passengers› preventive behavior can be explained by the combination of Rescue Equipment, Vessel Condition, and Safety Information. The adjusted R2 of .538.538 further indicates a reliable fit for the model, considering the included predictors.

Table 6b: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1861.844	3	620.615	47.893	.000b
	Residual	1529.082	118	12.958		
	Total	3390.926	121			

a. Dependent Variable: Passengers Preventive Behavior
b. Predictors: (Constant), Rescue Equipment, Vessel Condition, Safety Information

Source; Field data (2024)

The ANOVA results provide strong evidence for the significance of the overall model ($F=47.893$, $p<.001$), indicating that the collective impact of Rescue Equipment, Vessel Condition, and Safety Information significantly predicts passengers› preventive behavior.

Table 6c: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.778	1.263		10.118	.000
	Safety Information	.086	.101	.080	.847	.399
	Vessel Condition	-.012	.114	-.009	-.110	.913
	Rescue Equipment	1.184	.154	.689	7.704	.000

a. Dependent Variable: Passengers Preventive Behavior
Source; Field data (2024)

Considering the individual predictors, it is observed that Rescue Equipment ($\beta=0.689$, $p<0.001$) has a notably strong positive and significant effect on passengers› preventive behavior. This suggests that as the availability and quality of rescue equipment on ferries improve, passengers are more likely to engage in behaviors that prevent safety risks. However, the other factors, Safety Information ($\beta=0.080$, $p=0.399$) and Vessel Condition ($\beta=0.009–$, $p=0.913$), do not demonstrate statistically significant effects on passengers› preventive behavior at the conventional $p<0.05$ level. The coefficient for Safety Information is positive, indicating a tendency for increased preventive behavior with better safety information provision, yet this relationship lacks statistical significance. Similarly, Vessel Condition shows a non-significant and negligible effect on passengers› preventive behavior

5.0 Discussion of Findings

5.0.1 Effect of safety delivery on passenger preventive behavior

The analysis›s findings showed that the preventive behavior of passengers was significantly impacted by two of the three constructs: safety demonstration and safety facilities. This suggests that the availability and sufficiency of safety amenities onboard, as well as the efficiency and comprehensibility of safety demonstrations, are important factors that influence passengers› preventive behavior. Passengers are more inclined to take precautions to guarantee their safety during the river crossing when they are reassured by the availability of enough life-saving equipment, enough firefighting gear, and obvious safety demonstrations.

5.0.2 Effect of safety awareness on passenger preventive behavior

The study discovered that safety information did not approach statistical significance while having a favorable correlation with preventive behavior. Conversely, there was a weak and unfavorable correlation between vessel condition and preventive behavior. It›s interesting to note that rescue gear was found to be a major beneficial influence on travelers’ preventive behavior. When combined, the model indicates that passengers› behavior about taking safety precautions during ferry crossings is significantly influenced by their overall level of safety awareness.

5.0.3 Implications of the findings

Ferry operators should actively seek feedback from passengers regarding their perceptions of safety facilities, demonstrations, and overall safety measures. This feedback can help in continuous improvement and tailoring safety measures to passengers› needs.

Crew members should receive regular training on safety protocols and procedures. This ensures that they are well-equipped to handle emergency situations and effectively communicate safety information to passengers.

Ferry operators and policymakers should implement ongoing safety awareness campaigns targeting passengers. This includes distributing safety information pamphlets, displaying safety posters, and using digital platforms to communicate safety procedures effectively.

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MV Nyerere Tragedy or never again: Safety challenges in Ferry Transportation in Tanzania

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Abstract
Ferry transportation plays a vital role in connecting communities across inland water bodies which include Lake Victoria, Lake Tanganyika and Lake Nyasa. Ferry transport serves as a pivotal connection for both passengers and cargo, connecting remote communities to mainland markets and social services such as healthcare and educational opportunities. In addition, the transport provides access to essential services; ferries also support the tourism industry, allowing tourists to explore Tanzania's lakes and coastal areas. However, high-profile accidents such as MV Nyerere tragedy have highlighted persistent safety challenges in the maritime transport sector which include issues of overloading, inadequate maintenance and sufficient crew training.

The research investigates the current state of ferry transportation in Tanzania, examining regulatory frameworks, enforcement mechanisms and operational practices that impact overall safety. The research applies ISO 31000 risk management framework to systematically identify, analyse and evaluate current risks by focusing on the steps necessary to mitigate potential risks. Using accident data for the past 15 years (2009-2024), the study conducts a trend analysis of ferry-related incidents on Tanzania inland waters, with a focus on fatality rates, causes and geographic distributions of accidents in the Great Lakes region. Data was collected from the Ministry of Transport, Tanzania Shipping Agency Corporation (TASAC), Tanzania Meteorological Agency (TMA) and media archives. Key factors to be analysed include frequency, severity and main causes such as overloading, mechanical failure, bad weather and non-compliance to safety regulations at the time of each incident.

Through the interpretation of these trends with the ISO 31000 framework, the study aims to provide a comprehensive overview of the safety challenges facing Tanzania's ferry sector and assess the overall effectiveness of current regulatory and safety interventions. The findings will inform recommendations grounded in risk management principles focusing on improving safety standards and reducing the risk of future tragedies on Tanzania's inland waters.

Keywords: *Maritime safety, ISO 31000, Risk Management, Mv Nyerere*

1.0. Introduction

It has been conserved that boat transportation is becoming increasingly important to a nation's economic growth, particularly in those with lengthy coasts. More specifically, ferries offer a cost-effective way to carry goods and services while also making a significant contribution to regional accessibility and integration (Pham et al., 2024). Furthermore, cruise boats frequently provide tourists with an entertaining and picturesque form of transportation, which promotes the growth of tourism in coastal regions (Bergek, 2021). The domestic ferry sector is uniquely distinctive owing to its challenging navigation conditions and vulnerable accident records that have evoked endless calls for improving maritime safety. The recent adoption of IMO model safety regulations offers viable options for the Member States to standardize incorporation into national law. The operations of domestic ferries range from very large vessels with freight to small craft, which are often the only transport means for a large population of commuters in the developing world Baig et al, 2024).

However, this essential mode of transport has been marred by recurring safety challenges over the years, underscored by tragic incidents such as the sinking of MV Spice Islander I (2011), MV Skagit (2012) and MV Nyerere (2018). These disasters, often attributed to overloading, inadequate vessel maintenance, and insufficient regulatory oversight, have claimed hundreds of lives, raising serious concerns about the safety of ferry operations in Tanzania (Wambura & Kaduma, 2020; Mwakibete et al., 2022).

Despite its importance, the ferry sector in Tanzania faces persistent safety challenges, with numerous high-profile accidents exposing systemic weaknesses in the regulatory, operational, and enforcement frameworks. The tragic sinking of the MV Nyerere on September 20, 2018, which claimed over 200 lives on Lake Victoria, is a stark reminder of these vulnerabilities (Tanzania Shipping Agency Corporation [TASAC], 2019). Preliminary investigations attributed the disaster to overloading, mechanical failures, and inadequacies in crew training and safety preparedness (International Maritime Organization [IMO], 2019).

Safety on domestic ferries is hardly Tanzania's problem alone. Hundreds of people die every year in ferry accidents around the world and nearly 21,000 people have died in ferry accidents since 2000, Worldwide Ferry Safety Assn., (2018). While many of the fatalities take place on boats in the developing nations of the Philippines, Bangladesh, Indonesia and Tanzania, wealthier countries, like South Korea, have had deadly ferry incidents in recent years as well. In 2014, the Sewol ferry sank en route from Incheon on South Korea's northwestern coast to the resort island of Jeju, resulting in more than 300 deaths-many of them students.

Major Tanzanian Ferry Accidents

i. On 21 May 1996, MV Bukoba sank 30 nautical miles (56 km) off Mwanza city in 25 metres (14 fathoms) of water, killing up to 1,000 people. The official deaths record is 894. In January 2002, the ship's captain, two port managers and marine surveyor were found not guilty of negligence through lack of evidence. According to court ruling there was also no evidence of overloading on the vessel's instability.

ii. On 10 September 2011, the MV Spice Islander I sank off the coast of Zanzibar, resulting in the tragic loss of an estimated 1,573 lives. If accurate, this makes it the sixth-largest peacetime maritime disaster ever recorded, surpassing the death toll of the Titanic, which claimed 1,517 lives. In the aftermath of the tragedy, a Zanzibar minister stated that the government would take stern measures against those responsible. However, no significant punitive action or accountability measures were taken against individuals or entities involved (Zanzibar Government Report, 2011).

iii. On 18 July 2012, the MV Skagit sank near Chumbe Island, Zanzibar, resulting in the loss of nearly 300 lives. Early reports cited high winds and overloading of passengers as contributing factors to the disaster. In its report issued in November 2012, a Commission of Enquiry identified negligence, unprofessional conduct, and unaccountability as the primary causes of the accident. The Commission further recommended the prosecution of the vessel's owner for failing to adhere to safety regulations and ensuring passenger safety (Zanzibar Commission of Enquiry, 2012).

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v. On 20 September 2018, the MV Nyerere capsized in Lake Victoria, resulting in the tragic loss of 228 lives. In response to the disaster, a Commission of Enquiry was appointed on 23 September 2018 to investigate the causes of the accident; however, as of now, the findings of their investigations have not been made public. The immediate cause of the incident was attributed to poor navigation, while the underlying cause was identified as overloading, which significantly compromised the vessel's stability and safety (Tanzania Shipping Agency Corporation, 2018).

The Lake Victoria ferry transportation industry has several obstacles. In addition to a lack of adequate facilities and infrastructure, overloading and the usage of unlicensed vessels (local boats) to transport people are cited as the main causes of the frequent ferry accidents. According to various studies, ferry accidents on Lake Victoria occurred often between 1996 and 2012 (Mramba, 2012).

Accidents Waiting to Happen

Ferries are persistently and systematically overcrowded. For instance, a ferry with 200 passengers can accommodate 400 passengers. The 200 "official" passengers are listed on the ship's manifest, but the 200 "unofficial" passengers are not, and the officials in charge of the ship's safety and management pocket their fare. The overcrowding issue is made worse by frequent breakdowns and service suspensions caused by the similar pocketing of income that should be spent for upkeep and repairs. The "collateral damage" produced by rent-seeking government officials is represented by the unidentified bodies buried on the beach at Ukara. Ferry services continue to be a governmental monopoly because a privately owned and operated service would deny these officials their rents.

Would Private Ferry Services Reduce the Death Toll?

Would ferry services that are privately owned and operated be more effective and safe than the ones we now have? Without open and accountable contracting and regulation, private services can be just as vulnerable to inefficiency and rent-seeking. However, compared to state-run services, where all revenue streams are susceptible to self-destructive rent-seeking, private operators are more likely to maintain their vessels in order to maximize profit. Since private operators are more likely to be held liable for a significant accident than civil personnel, they are also more likely to take safety concerns seriously than a state-run service.

In Tanzania, both privately owned and government-owned ferries offer ferry services. Privately operated boats nevertheless offer comparatively superior services than government-run ferries, despite the fact that they are not given any subsidies. The majority of ferries held by the government are outdated (MoT, 2011). Because of their location and the infrastructure they have, certain places can only be reached by ferry. Most passengers cannot afford air and road transportation, despite the fact that they may be used as alternatives. Thus, as a component of Tanzania's overall transportation system, the ferry industry is crucial.

The MV Nyerere tragedy, in particular, which resulted in 228 confirmed deaths, stands as a stark reminder of the systemic vulnerabilities in ferry transportation (UNCTAD, 2019). Despite regulatory reforms and periodic interventions, accidents continue to occur, highlighting the need for a comprehensive evaluation of trends and persistent safety gaps. Over a 15-year period (2009–2024), these incidents have not only exposed the limitations of existing safety measures but also underscored the urgent need for sustainable solutions to enhance maritime safety (Mlay et al., 2023).

The IMO has issued safety standards for domestic ferries, which some countries have used in forming their own regulations, and the body has worked with individual governments on ferry safety, including the Tanzanian government to improve the safety of passengers traveling on Lake Victoria (Maritime Safety Committee at its 105th session in April, 2022).

This study seeks to analyze safety trends in ferry transportation across Tanzania over the past 15 years, focusing on the underlying causes of accidents, the effectiveness of regulatory frameworks, and the socio-economic impact of safety failures. By leveraging a detailed trend analysis, the study aims to identify recurring patterns and critical gaps, ultimately providing actionable recommendations to strengthen safety measures and prevent future tragedies. The overarching goal is to contribute to the realization of a safer, more reliable ferry transportation system, encapsulated in the vision of "Never Again" following the MV Nyerere tragedy (Tanzania Transport Authority, 2024).

2.0. Methodology

The methodology aims to explore safety challenges in ferry transportation in Tanzania with a focus on the MV Nyerere tragedy. It employs a comprehensive trend analysis of ferry accidents and incidents to identify underlying patterns, assess the effectiveness of existing safety measures, and propose actionable recommendations.
The methodology was structured to systematically examine regulatory frameworks, enforcement mechanisms, and operational practices influencing safety, using the ISO 31000 risk management framework to guide risk identification, analysis, and mitigation strategies.

The study employed a descriptive and analytical design to assess ferry transportation safety in Tanzania. It leveraged historical data, expert insights and trend analyses to evaluate safety challenges and propose actionable recommendations.

The Ministry of Transport provides official reports and documentation on ferry operations, safety inspections and regulatory frameworks, offering valuable insights into the governance and oversight of maritime activities. The Tanzania Shipping Agency Corporation (TASAC) contributes accident reports, operational records and enforcement data on inland water transportation, shedding light on the effectiveness of safety measures and compliance levels. The Tanzania Meteorological Agency (TMA) supplies weather data correlating with reported ferry accidents, enabling an assessment of environmental risks and their impact on ferry operations. Media archives, comprising news articles and reports on ferry-related incidents, capture public narratives and offer supplementary data to complement official records.

A main technique used in this study was document analysis, with an emphasis on a careful examination of official reports, the results of accident investigations and regulatory documents supplied by the Ministry of Transport and the Tanzania Shipping Agency Corporation (TASAC). This strategy seeks to reveal information about safety procedures, degrees of compliance and the efficacy of enforcement actions. In order to find trends, root causes, and the results of ferry-related accidents, archival study also entailed a thorough analysis of media archives, providing a more comprehensive background and a public viewpoint on the problems. Additionally, statistical data on ferry accidents, fatalities and their geographic distributions from 2009 to 2024 was extracted through secondary data collection. This information helped with a thorough trend analysis and provided specific recommendations.

2.1 Analytical Framework

The study applied the ISO 31000 risk management framework to ferry transportation risks. The ISO 31000 management provides a structure and systematic approach to identify, analyse and evaluate and treat risks associated with ferry transportation. The framework has been applied to evaluate the challenges faced by ferry transportation systems in Tanzania, specifically in light of the accidents such as the MV Nyerere tragedy.

2.2 Trend Analysis

A comprehensive trend analysis was conducted to identify trends in ferry-related accidents over a 15-year period, offering crucial insights into the mechanics of these incidents. The first step in the investigation was a frequency analysis, which examined the number of incidents reported annually and their temporal distribution. The objective of this stage was to identify periods of heightened activity or emerging trends across time.

The study then focused on Severity Analysis, evaluating the number of deaths and the extent of damage associated with each incident. This highlighted the most devastating events and improved understanding of the consequences of ferry mishaps.

3.0. Results and Discussion of Findings

This section presents the findings from the trend analysis of ferry accidents and incidents in Tanzania, specifically highlighting the MV Nyerere tragedy. The findings are analyzed within key thematic areas, referencing existing studies and reports to offer context and validation.

3.1. Application of the ISO 31000 Risk Management Framework to Ferry Transportation Risks

The systematic assessment of safety risks in ferry transportation can be categorized into risk identification, risk analysis, risk evaluation, and risk treatment. Each stage provides a comprehensive understanding of hazards, their causes, and appropriate mitigation strategies to enhance safety.

(i) Risk Identification

Risk identification is the foundational step where the key hazards contributing to ferry accidents are determined. Based on historical data and incident reports, the primary risks in ferry transportation include: Exceeding the passenger or cargo capacity of a vessel compromises stability and increases the likelihood of capsizing. Overloading is often motivated by financial incentives or limited enforcement of capacity limits.

Poor maintenance of vessels, aging infrastructure, and a lack of spare parts contribute to unexpected breakdowns, jeopardizing passenger safety.
Weak enforcement of safety regulations, such as the use of life jackets, adequate crew training, and vessel inspections, exacerbates risks. Additionally, safety awareness among passengers remains limited.

(ii) Risk Analysis

In this stage, the frequency and severity of ferry accidents are assessed the key aspects include:
Historical data indicate that ferry accidents occur frequently during peak periods, such as holidays or market days, when vessels are prone to overloading. For instance, the MV

Nyerere tragedy on Lake Victoria in 2018 was primarily caused by overloading, claiming over 200 lives.

Ferry accidents often result in catastrophic loss of life, significant economic costs, and psychological trauma. For example, the MV Bukoba disaster in 1996 led to over 800 fatalities, marking one of the deadliest maritime incidents in Africa.

Analysis revealed that mechanical failures, non-compliance with safety protocols, and adverse weather conditions are recurring contributors to ferry incidents. Poor enforcement of safety regulations exacerbates these challenges.

(iii) Risk Evaluation

Risk evaluation involves prioritizing the identified risks based on their likelihood of occurrence and severity of impact. A risk prioritization matrix was used to classify the hazards is shown in table 3:

Table 3: Risk Prioritization Matrix

Risk	Likelihood	Severity	Risk Level	Description
1. Overloading	High	High	High	Frequent occurrence during peak travel seasons leading to vessel capsizing.
2. Mechanical Failures	High	High	High	Aging vessels and poor maintenance result in breakdowns, increasing fatalities.
3. Adverse Weather Conditions	Moderate	High	Moderate	Sudden storms and strong winds on lakes, especially Lake Victoria.
4. Non-compliance with Safety Regulations	High	Moderate	Moderate	Weak enforcement of safety protocols, such as lack of life jackets.
5. Crew Incompetency	Low	Moderate	Low	Insufficient crew training impacts emergency response but occurs infrequently.

(iv) Risk Treatment

Risk treatment in ferry transportation involves strict enforcement of passenger and cargo limits, mandatory inspections for mechanical failures, replacement of aging vessels, specialized maintenance training, and advanced navigation tools. Strengthening safety protocols and public awareness campaigns are also recommended to create a safer and more reliable system.

3.2. Trend Analysis of Ferry Accidents/Incidents (2009–2024)

The trend analysis of ferry accidents in Tanzania from 2009 to 2024 reveals both progress and persistent challenges in ensuring maritime safety. The early years were characterized by regulatory gaps, weak enforcement of safety standards, and frequent overloading. A decline in incidents was observed between 2013 and 2016, signaling the initial impact of improved oversight and safety initiatives. However, systemic weaknesses such as aging vessels and adverse weather conditions remained significant contributors to incidents. The period from 2017 to 2018 marked a significant spike in accidents, with the tragic MV Nyerere disaster in 2018 being the most notable incident. The period 2019 to 2022 showed signs of stabilization, but low trend analysis values (and indicate that the overall variance in ferry accidents cannot be fully explained by time trend alone. This suggests the presence of random factors and unmonitored risks such as sudden weather changes, crew error and operational inefficiencies.

Table 4(a): Summary of the Nature of Accident/Incident

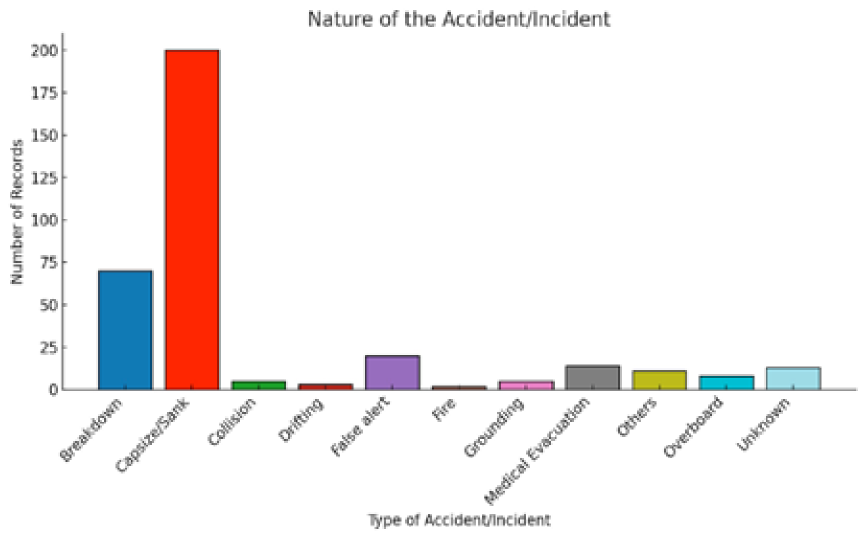
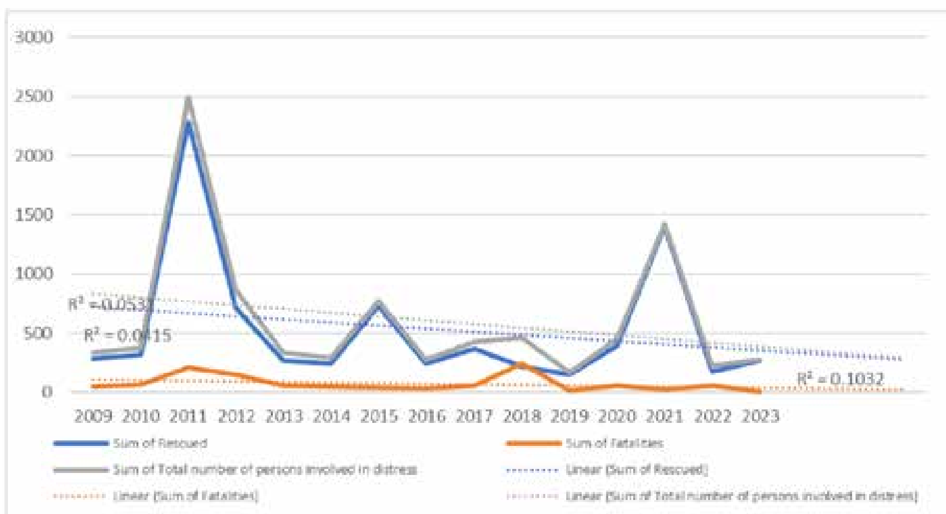
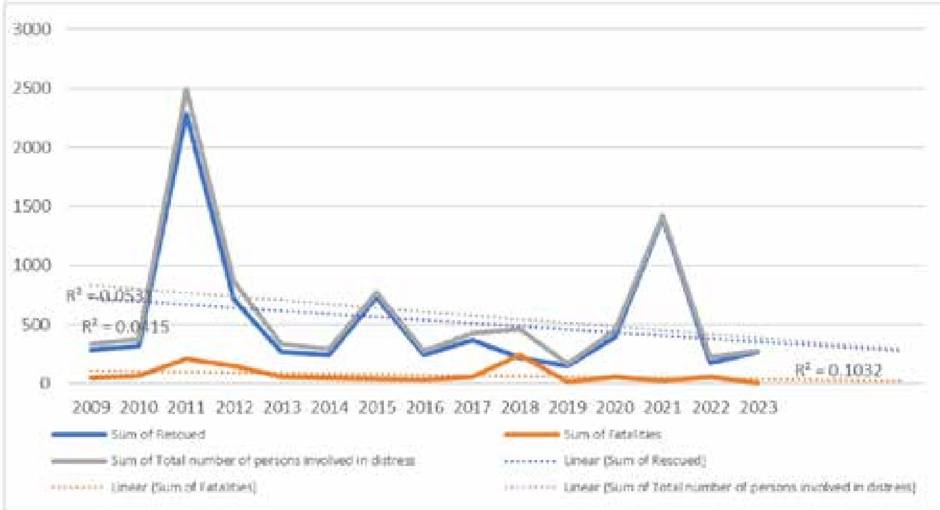


Table 4(b): Sum of Number of Records for each Nature of the Accident/Incident





Source: Authors' Report

4.0. Conclusion and Recommendations

In summary, despite considerable advancements in decreasing ferry accidents over the past 15 years, substantial challenges remain. The analysis highlights the necessity for ongoing initiatives to tackle overloading, enhance vessel maintenance, and reinforce the enforcement of safety regulations.

The MV Nyerere tragedy serves as a stark reminder of the consequences of systemic weaknesses in ferry operations and regulatory enforcement. Implementing the proposed recommendations, including strict enforcement of safety regulations, improved vessel maintenance, and enhanced public awareness, will be instrumental in ensuring safer and more reliable ferry transportation in Tanzania. Continuous monitoring and evaluation, supported by robust data collection, will enable policymakers to assess the effectiveness of interventions and make evidence-based decisions to prevent future incidents. Ongoing investment in safety technologies, including real-time monitoring systems and weather tracking tools, as well as enhanced public education and stricter oversight, is essential for achieving sustainable maritime safety in Tanzania.

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AI EFFECT ON CONTAINER TERMINAL OPERATIONS AND RESPONSIVENESS: EXPERIENCE FROM TANZANIA PORTS

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Abstract

Purpose: This study examined the moderating effect of artificial intelligence (AI) on links between container terminal operations and responsiveness of service delivery as constructs based on the empirical evidence drawn from Tanzania's port operations. Design/methodology/approach: Data came from structured questionnaires administered to 349 port stakeholders drawn from a population of 2,222 agents based in four selected Tanzania ports using simple random sampling. The sample size is 21 more respondents or 6.4 percent above the originally projected sample of 328, hence further enriching the quality of the study. The resultant data enabled hypotheses testing using Structural Equation Modelling (SEM) through Smart PLS 4.0 and SPSS version 27. Employing a positivist philosophy and deductive approach coupled with an explanatory design and quantitative method, the study used the Systems Theory (ST) to operationalize the interactions of the three constructs. The study proceeded from the assumption that there has been no extensive research model that had hitherto compounded the joint effects of this triad of constructs.

Findings: The results indicate that container terminal operations have a significant positive impact on the responsiveness of TPA services' delivery with the moderated relationship of AI accounting for higher positive significant effects. Moreover, the Importance-Performance Matrix Analysis (IPMA) results indicate that container terminal operations have the highest levels of both importance and performance in predicting TPA's responsiveness. As the study provides strong empirical evidence confirming that container terminal operations positively influence TPA's responsiveness. Additionally, the study expands the ST dimensions.

Practical implications: The results shed light on potential areas for further improvement by Tanzania Ports Authority and other Stakeholders from both public and private sectors to enhance TPA's responsiveness. Also, the study findings have implications for relevant policies including The Ports Act 2004, National Transport and Trade Policies of 2003, and the Agenda 2063 The Africa We Want which need further streamlining to be in sync with the demands of modern port operations.

Originality/value: This research has identified dimensions of container terminal operations and determined the moderating effects of AI in addition to examining their impacts on TPA's responsiveness.

Keywords: *container terminal operations, responsiveness, port service delivery, and supply chain.*

1.0 INTRODUCTION

Ports serve as vital nodes in the maritime shipping network and significantly contribute to the development of the multimodal transportation system (Pallis et al., 2011). Transportation systems and other technological innovations such as artificial intelligence (AI) and automation provide numerous opportunities that optimise processes, generate new business, and link effectively with global logistics and supply chains (Tsvetkova et al., 2021). In recent times, AI has gained popularity and relevance while presenting immense potential for transforming a wide range of sectors (Nagarajan et al., 2023). In fact, the consequent drastic changes in port operations in the twenty-first century have inevitably affected global logistics and services (Bassan, 2007). For international trade, transport services at port terminals including containers, efficient operations are essential (Ahmad et al., 2021). Some 50 years ago, containers entered the global maritime freight business as comparatively homogeneous boxes that facilitate quick and simple handling of cargo (Kara, 2016). These containers account for the hauling of a considerable and increasing proportion of about 35 percent of the total volumes and more than 60 percent of commercial value (WorldBank, 2024). Sea ports handle over 75 percent of the global trade and thanks to the economy of scale favouring maritime transport the rapid growth continues unabated (Ghazaleh, 2023). Apart from being effective at loading and unloading cargo, containers also facilitate scheduling and control essential in managing and offering weather and theft protection while enabling ports to serve as trans-shipment, distribution, and logistics hubs (Uzun, 2021; Zehendner, 2013).

Furthermore, the emergence of containerization has introduced significant changes regarding how and where goods are manufactured and processed, a trend set to continue with digitalization (World Bank, 2024). In fact, a combination of increased digitalization, new technologies, and the willingness of the industry to work collectively toward systemwide improvements now provides the capacity and opportunity to measure and compare container port performance robustly and reliably (World Bank, 2022). Also, the latest review of Maritime Transport highlights the poor performance of ports in southern Africa relative to other regions in the world (World Bank, 2022). Similarly, the World Bank's Container Port Performance Index ranked Dar es Salaam port of Tanzania at the 361st position out of 370 ports worldwide with other African ports such as Durban, Cape Town, Maputo, and Mombasa located further down the bottom of the list (World Bank, 2021).

In essence, the port performance in Tanzania including operations and service delivery has remained a rather neglected issue and, consequently, a lacuna for assessing how the TPA's performance can evolve in the face of a shift in national leadership has remained (Bassan, 2007; Issa & Masanja, 2022; Mwisila & Ngaruko, 2018). Moreover, studies on the significance of efficiency and innovation in attaining sustainable performance are pivotal (Issa & Masanja, 2022). Even though Tanzania is one of the least developed countries, its ports serve many land-locked countries through its numerous sea and lake ports (Bigg & Dodds, 2019; Issa & Masanja, 2022). The market share analysis for Tanzania and Kenya ports in East Africa for the 2017 – 2013 period shows that the average percentages of incoming cargo traffic from Burundi, Rwanda, the Democratic Republic of the Congo, and Uganda, 53.4 ,77.2 ,88 ,97.92, and 2.8 and 46.6 ,22.8 ,12 ,2.08 and 97.2 went through Tanzania and Kenya ports, respectively. Such market share and huge potentials amidst competition and future dynamic demand in the port industry signal the necessity to probe factors for enhancing the responsiveness of TPA service delivery to retain the existing and attract new customers through container terminal operations and examine the moderating effects of the AI on container terminal operations and how responsively TPA can provide services.

Empirical evidence on the relationships among study variables enhanced knowledge of and understanding at the local level. Container terminal operations and the responsiveness of TPA's service delivery happen to be competitive factors in setting port improvement priorities and strategies. The Important-Performance Map Analysis (IPMA) for Tanzania ports has been developed based on the study findings through variables and established relationships for management consideration. In this regard, the study objectives have addressed, firstly, the Ports Act 2004 No 17 on page 12 about port promotion and, secondly, the mission of the National Transport Policy of 2003 (Tanzania, 2003), and the vision of the National Trade Policy for a Competitive Economy of 2003 (Viwanda, 2003).

2.0 LITERATURE REVIEW

2.1 Theoretical Literature Review

To address its objectives, the study was informed by the Systems Theory (ST):
Systems Theory (ST)
Building on Von Bertalanffy (1951), Ashby (1956) further developed the system theory aimed to explain all systems in all fields of science by exploring interdependencies of relationships for managing complex entities. A system comprises frequently interrelating groups of activities and parts that form the subsequent whole entailing the exchange of input or output through processes linking subsystems mediated by the transfer of resources including decisions, support, and responsibility for four universal function aspects—adaptation, goal-attainment, integration and pattern maintenance. The following review covers studies that applied ST to inform the investigation the three (3) variables of this study:

2.1.2 Relationship between ST and container terminal operations

The utility of the container terminal has become quite remarkable all over the world, according to Mazouz et al. (2017). The study focused on optimising the staging of containers in a terminal gate system using a port within China. The analysis concluded that both the facility and the terminal gate applied the systems theory to make daily operation suited for the container terminal. Also, Nayak et al.›s (2024) study developed a unified port performance index (PPI) that considered container cargo among other haulage categories and the multi-dimensional nature of port performance indicators. The study used secondary data for 12 major Indian ports on five significant dimensions including container terminal operations. The results further affirm that the container terminal operations have a positive and significant impact on port financial performance. Furthermore, Kuo and Chen (2021), who examined the extent to which lean management practices could improve operational performance with the application of System Theory in Taiwan, associated the operational performance of the container terminal with business performance and affects the container shipping companies. The study had generated data from 212 respondents. The study had assessed the relationships between lean policy, lean practices, operational performance, and business performance in the context of container shipping.

2.1.3 Relationship between ST and AI

Yu et al.›s (2023) study found that the application of AI at the workplace to be on a steady rise. To enhance advancement, the study developed the antecedents of AI to capture the essence and consequences of its adoption for the workplace with ST application. The study concluded that AI adoption at the workplace would enable managers and practitioners to develop effective AI adoption strategies and achieve a competitive advantage for organisations. In this regard, Lima and Custodio›s (2004) study assessed the creation of efficient AI models without compromising environmental issues in line with the ST application. Its objective was to develop a tool for planning and performing task control execution in a distributed environment. The successful creation of efficient AI models can materialise without compromising environmental issues including planning and performing task control execution, concluded the study.

2.1.4 Relationship between ST and service delivery responsiveness

Israel (2023), who examined the mediating effect of an integrated health commodities procurement system on the relationship between responsiveness and health service delivery, collected data from 274 respondents employed in the28 government hospitals of six regions in the Southern Highlands of Tanzania. After confirmatory factor analysis (CFA) and structural equation modelling (SEM), the results revealed a positive relationship between responsiveness and service delivery with the ST application.

2.2 Empirical Literature Review

2.2.1 Container terminal operations and responsiveness of TPA's service delivery

In a global context, seaports—as centres for trade activities—contribute to strengthening the development of the multimodal transportation system by boosting cargo networks (Weerasinghe et al., 2023). International transportation draws special attention to competitive factors such as quality and spectrum services provided, the port's capacity to manage large cargo volumes promptly, and cost and efficiency (Rana, 2019). Moreover, hubs and transhipment terminals continuously improve their network to fulfil new roles in global supply chains due to the tremendous growth of containerised cargo at main transportation routes (Rana, 2019). Containers are relatively uniform boxes that allow for easy, fast handling of freight; moreover, they are strong enough for repeated use, and they are usually stackable and fitted with devices for transfer between modes (Jonker et al., 2021). Besides efficient discharging and loading processes, these containers also simplify scheduling and controlling cargo in addition to serving as protection against ravages of weather and pilferage (Zehendner, 2013). Recently, the connection of a container terminal to its hinterland gained significance, with terminals offering short and reliable delivery times having an advantage over their competitors (Notteboom & Rodrigue, 2008). The study treated these container terminal operations as contributing factors to the responsiveness of port service delivery, hence the generation of the following hypothesis:

H1: Container terminal operations positively influence the responsiveness of TPA's service delivery

2.2.2 Artificial intelligence, operations, and responsiveness of service delivery

The application of artificial intelligence (AI) technology has evolved into an influential endeavour in improving port performance, but little research has considered the relationship among AI capability (Chen et al., 2022). Industries including the port sector seek opportunities for integrating AI methods with traditional approaches, the concepts and technologies of the Internet of Things (IoT), and cyber-physical systems to convert real-time data into actionable decisions (Chen et al., 2022; Munim et al., 2020). In fact, AI is a crucial component of data-driven decision-making in the port industry, which is one of the oldest and most traditional industries that still rely more on intuition than on data due to the vast size of network and planning problems (Munim et al., 2020). The application of AI affects the relationship between terminal operations and responsiveness of service delivery. As such, we hypothesise:

H2: Artificial intelligence moderates the relationship between container terminal operations and responsiveness of TPA's service delivery.

3.0 METHODOLOGY

This study adopted a positivist philosophical stance to relate the natural scientist stance with an observable social reality in a bid to produce law-like generalizations (Saunders, 2019), and deductive reasoning for the study's hypotheses and observable consequences that should have occurred with new empirical data if the hypotheses were found to be true (Antwi & Kasim, 2015). Moreover, the study applied an explanatory design to explore a new universe based on the study variables, relationships, and associated objectives, which had hitherto not been studied earlier in terms of causes and reasons/factors behind some phenomenon related to study variables (Megel & Heermann, 1993). Also, the study applied the quantitative method to determine and support what is embedded in the positivism paradigm that focuses on fresh data (Rahi, 2017). Also, it integrates deductive, objective, and generalized purposes and procedures (Morgan, 2014). Furthermore, the study applied the Krejcie and Morgan›s (1970) formula, which Januszyk et al. (2011) and Minani (2019) had already applied as precedent, to a population of 2,222 to obtain a representative sample of n = 328.

3.1 Sample Selection, Unit of Analysis and Inquiry

The projected sample size—after applying Krejcie and Morgan›s (1970) formula—amounted to 328 port customers; however, due to extraordinary turnup, the size was expanded to 349 to include other key responders drawn from Other Government Departments and Tanzania Ports Authority. The sample covered five regions under review selected using simple random sampling, which had given everyone a fair chance of being drafted into the sample (Creswell, 2014). The participation of several stakeholder groups made the study present a more comprehensive analysis of the research issue (Kovacs & Moshtari, 2019). Clearing and Forwarding Agency Company (employer) were the study's unit of analysis and staff members (employees) of the firm who had adequate information about the Tanzania Ports Authority (TPA) services were the units of inquiry.

The study used a self-administered two-part questionnaire to collect data. The first part gathered the respondents' demographic information alongside the company profile whereas the second part contained -7point Likert-scale type statements with measures ranging from 'Strongly agree' to 'Strongly disagree'. Techniques to address the common method bias included reverse coding of the variable values applied in the questionnaire during data entry and the application of the -7point Likert scale for independent and dependent variables instead of the -5 or three -3point scale. The reliability of the responses on the former scale is better than on the latter lower scales owing to the construct defining items on the scale (Joshi et al., 2015).

4 RESULTS AND DISCUSSION

4.1 Respondents' Profile

The study generated data from an expanded size of 349 due to an extraordinary turnout beyond the expected 328 questionnaires distributed in the five regional ports under review, hence a response rate of 106.4 percent. The gender split of the final sample was 87.1 percent male and 12.9 percent female. The mean age of the sample was 35.5 years. The sample comprised 49.6 percent of respondents with University degrees, 27.2 percent with secondary school certificates, 20.92 percent with College certificates, 1.4 percent with non-formal education, and 0.88 percent with primary-level education. The majority (%40.7) had a mean work experience of five years.

4.2 Assessment of the Measurement Model

The assessment of the measurement model conducted by composite reliability, Cronbach alpha, rho_A, AVE, and HTMT yielded the following results:

Table 1: Measures of Construct Validity and Reliability

	Composite Reliability	Cronbach Alpha	rho_A	Average Variance	HTMT (HTMT < 1)		Decision
					AI	CO	
	(>0.7)	(>0.7)		**Extracted** (>0.5)			
AI	0.914	0.874	0.876	0.726			Good
CO	0.928	0.905	0.910	0.682	0.932CI0.95 [0.714;0.982]		Good
DR	0.910	0.874	0.884	0.671	0.876CI0.95 [0.722;0.954]	0.884CI0.95 [0.737;0.928]	Good

Source: Field Data (2024)

The results presented in Table 1 show that exogenous latent variables have good measures of validity and reliability for all the variables, including the endogenous variable, PCS.

4.2.1 Assessment of Common Method Bias

The CMV subjected to a simple Collinearity Test using VIF showed that all the constructs had variance inflated factor (VIF) values of less than the proposed threshold of 5. As such, CMV posed no threat.

4.2.2 Assessment of model's predictive power (PLSPredict) (out-of-sample)

The assessment of the model's predictive power found the RMSE of LM (i.e. prediction) to be greater than that of PLS-SEM (i.e. actual) in DR1, DR2, DR3, and DR4, implying lower prediction error. Also, the values of Q^2_predict in the four indicators of the endogenous variable are above 0, between 0.367 and 0.615 meaning a lower prediction error. As such, the model has higher predictive power.

4.2.3 Direct and Final Measurement Models

Figures 1 and 2 presents the direct and final measurement models and, significantly, with the indicator loadings that satisfied the criterion as indicated:

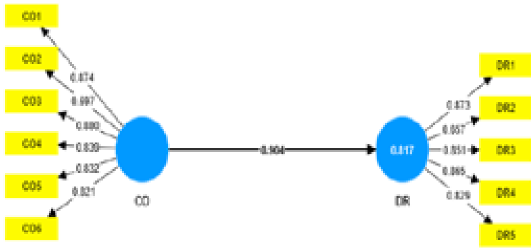

Figure 1: Direct Measurement Model.

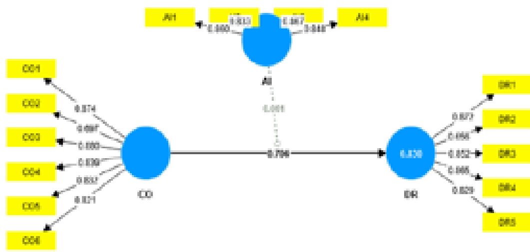

Figure 2: Moderated Measurement Model.

4.3 Evaluation Results of the Structural Model

The measuring of the VIF values indicates that both independent variables of 1.552, which are acceptable level of collinearity, hence the structural model has no collinearity issues. Also, the path coefficient value of 0.904 indicates a strong positive relationship, which explains a 90.4 percent increase in DR. Impliedly, if the CO construct increases by one standard deviation unit, the DR construct would increase by 0.904 standard deviation unit, assuming all other independent constructs remain constant. The result of the coefficient of determination of R2 stood at 0.817 for the direct model, which explains that an 81.7 percent change in DR can be accounted for one (1) exogenous construct. Also, the effect size of f2 yielded 0.716, which translates into a large effect size on R2. The measuring of the predictive relevance of Q2 produced a value of 0.542. Thus, the model has predictive relevance.

4.3.1 Model assessment

The structural model results reveal a significant relationship between CO and DR. In this regard, the study measured the direct model. The coefficient of determination of the R2 value was 0.817, implying that an 81.7 percent change in DR can account for two (2) exogenous constructs as follows:

4.3.2 Direct effect of container terminal operations on TPA service delivery responsiveness

The first hypothesis, H1 states that container terminal operations positively influence the responsiveness of TPA's service delivery. The study results indicate that CO has a significant impact on DR ($\beta = 0.904$, $t = 50.202$), i.e. one unit increase of CO raises DR by a path coefficient of 90.4 percent, ceteris Paribas (Hair et al., 2017). Also, the confidence intervals [0.933 ;0.862] do not include 0, indicating the existence of a direct effect (Hair et al., 2017). Furthermore, the t-value of 50.202 is above the critical value for the z-test of 1.645. These results support and validate H1.

4.3.3 Moderation analysis results

The measurement of moderated model reveals that the coefficient of determination of R2 value improved from 0.817 to 0.830, hence an 83.0 percent change in DR for the two (2) exogenous constructs.

Effect of AI and container terminal operations on TPA service delivery responsiveness
The second hypothesis, H2 states that the higher (lower) the artificial intelligence, the weaker (stronger) the influence of container terminal operations on the responsiveness of TPA's service delivery. The results indicate that AI*CO has a significant bearing on DR (β = 0.061, t = 3.014). Implicitly, if one unit increases (or conversely decreases) of the artificial intelligence, then the influence of container terminal operations and responsiveness of TPA's service delivery increases (or decreases) based on the size of the path coefficient (%6.1), ceteris Paribas (Hair et al., 2017). In other words, there is a weakening or reduction of the t-value from 50.202 to 3.014, which nevertheless remains above the critical value for the z-test of 1.645. These results, therefore, support and validate H2 .

4.4 Simple Slope Analysis

A typical moderator analysis results in representation using simple slope plots (Hair et al., 2021). This study has one simple slope plot delineated in Figure 3.

Moderation effect of simple slope analysis between CO, AI, and DR

The relationship between CO and DR is positive. Hence, lower levels of CO represent lower levels of DR. The upper line (in green), which represents a higher level of the moderator AI with standard deviation above the mean, has a steeper slope, hence representing a weaker positive effect. Also, the bottom line (in red), which represents a lower level of moderator AI with a standard deviation below the mean, has a flatter slope, thus depicting a stronger positive effect. The simple slope plot shows the positive interaction terms that enhance AI levels, hence signalling a slightly stronger relationship between CO and DR and vice-versa, which are acceptable.

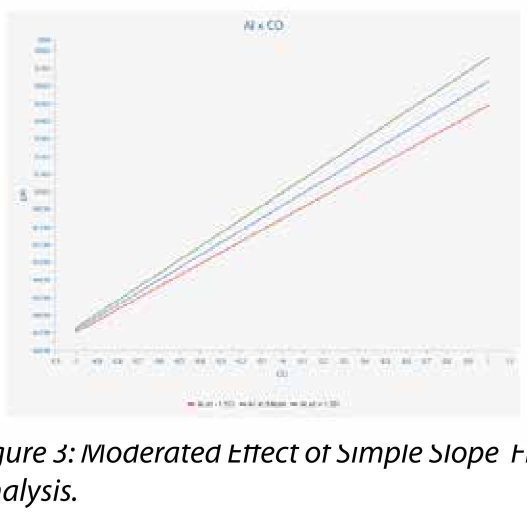

Figure 3: Moderated Effect of Simple Slope Analysis.

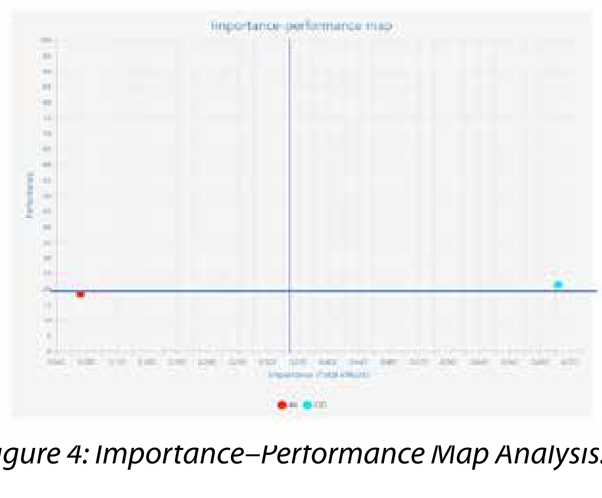

Figure 4: Importance–Performance Map Analysis.

4.5 Importance-Performance Map Analysis (IPMA)

Ringle and Sarstedt (2016) contend that multiple moderators in a total or moderated effect complicate the interpretation of IMPA's importance dimension. As such, it is advisable to exclude moderators in an IPMA (Hair et al., 2017; Ringle & Sarstedt, 2016). This study conducted IPMA using Smart PLS, with the results based on the total effect of one exogenous variable (CO) on the endogenous variable (DR). The findings confirm that CO, the exogenous variable, has high levels of importance and performance in Quadrant I with 'Concentrate Here' status as in Figure 4.

5 CONCLUSION, IMPLICATIONS, AND RECOMMENDATIONS

5.1 Effect of container terminal operations on PTA service delivery responsiveness

To begin with, the study findings uphold hypothesis H1, by confirming that container terminal operations positively influence the responsiveness of TPA's service delivery. The findings provide empirical support to the ST, by showing that TPA service delivery the responsiveness, specifically its container terminal operations has a significant and positive relationship with the responsiveness of TPAs' service delivery. These findings are consistent with finding by Jonker et al. (2021), Kuo and Chen (2021), Mazouz et al. (2017), Notteboom and Rodrigue (2008), Rana (2019), Weerasinghe et al. (2023), and Zehendner (2013), who have associated container terminal operations with some aspects of responsiveness of service delivery.

5.2 Moderating Effect of AI on Container Terminal Operations in service delivery responsiveness

The study findings also validate hypothesis H2 by ascertaining that artificial intelligence moderates the relationship between container terminal operations and the responsiveness of TPA's service delivery. Moreover, the study findings support the findings of Chen et al. (2022), Lima and Custodio (2004), (Munim et al., 2020); Yu et al. (2023), whose studies have associated container terminal operations and AI with some aspects of responsiveness of service delivery. Also, the study found all the measurements of the container terminal operations variable reliable and valid. Nevertheless, the container terminal should prioritise the following three operations: i) vessel tallying activities during discharge operations, ii) execution of container cargo transfer, and iii) receiving processes of container cargo at the yard and positioning prompt updates for enhancing TPA's service delivery responsiveness. Furthermore, application of AI in port operations should be enhanced to ensure: i) less frequent stoppages of Information Systems that affect port service delivery, ii) adequate tools for information and data gathering for data-driven decision-making, and iii) consistent running of information systems to let port users predict with certainty the time to be spent on cargo clearance to further boost TPA service delivery responsiveness.

5.3 Conclusion and Implications

Overall, the IPMA findings indicate that amongst the exogenous variables, the ones with high levels of importance and performance were CO and, subsequently, AI with the lowest performance measure among all. As such, the TPA Management ought to maintain the productive commitment, initiatives, and resources dedicated to CO. To further strengthen the TPA service delivery responsiveness, enforcing vessel tallying activities during discharge operations, execution of cargo transfer and receiving processes, and position updating in the container terminals are crucial. Moreover, terminal managers should ensure that the planning and distribution of equipment and technical resources are fully and effectively integrated at each stage of the cargo clearance processes and supply chain generally. After all, the TPA Ports Act 2004, No 17 aim to promote efficient seaport management and operations, ensure the provision of services related to the loading and unloading of cargo and passengers, and the provision of suitable and effective maritime and port services and facilities. The study findings further indicate that CO has significantly positive high levels of importance and performance in TPA service delivery responsiveness. Thus, corporate policymakers must check the container terminal operations policies and procedures to further enhance and optimise the potential of TPA's service delivery responsiveness. As such, policymakers should prioritise container terminal operations to enhance service delivery, which is currently not the norm in the TPA Ports Act objectives.

5.4 Recommendations for future studies

Even though this study found AI container terminal operations to positively influence TPA service delivery responsiveness, future studies could apply these variables in other terminals with different settings such as Ro-Ro and Oil Jetty for comparative purposes. Moreover, future studies could use other terminal operations attributes on TPA's service delivery responsiveness to bring more insight into the two interfaces. Also, collaborative research studies covering the same or similar objectives could be undertaken with other international ports and institutions for comparative analysis and experiences.

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ENHANCING OIL SPILL RESPONSE THROUGH ADVANCED TECHNOLOGY AND INNOVATION

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Abstract

Oil spills pose significant risks to marine ecosystems, coastal communities, and the global economy, necessitating efficient and rapid response solutions. This paper explores innovative approaches to improve oil spill response capabilities, focusing on advancements in robotics, artificial intelligence (AI), and bio-based materials. Autonomous underwater and surface drones equipped with AI-driven sensors are designed to detect and track oil spills in real time, even in remote or hazardous areas, allowing for faster identification and containment. Machine learning algorithms analyze environmental data to predict spill spread patterns, enabling responders to deploy resources strategically and minimize ecological damage. Additionally, bio-based absorbents, derived from materials like algae and cellulose, offer eco-friendly alternatives for oil cleanup, reducing the environmental impact of traditional chemical dispersants. Collaborative networks that integrate these technologies with satellite monitoring and cloud-based data-sharing platforms enhance coordination between agencies, fostering a more effective and timely response. By combining innovative tools and sustainable materials, this approach represents a significant advancement in mitigating the adverse effects of oil spills on marine life and coastal regions, contributing to a resilient and sustainable blue economy.

1. Introduction

Oil spills are catastrophic events that occur due to accidents during oil extraction, transportation, or storage. These events release vast quantities of crude oil into marine environments, leading to severe consequences for ecosystems, marine biodiversity, and coastal livelihoods. In addition to ecological damage, oil spills have long-term economic impacts, such as loss of fisheries, tourism revenue, and cleanup costs, which can reach billions of dollars.

Traditional oil spill response methods often face challenges like slow response times, limited reach in remote or hazardous areas, and environmental consequences of certain techniques, such as the use of chemical dispersants. These challenges underscore the need for innovative solutions that harness the power of emerging technologies and sustainable materials to revolutionize oil spill detection, containment, and cleanup. This paper focuses on three critical innovations:

1. Autonomous drones equipped with AI for real-time detection and monitoring.
2. Machine learning algorithms for predictive modeling of spill trajectories.
3. Bio-based absorbents for eco-friendly cleanup operations.

2. Innovative Technologies in Oil Spill Detection and Containment

2.1 Autonomous Drones with AI-Driven Sensors

The use of drones in oil spill management represents a paradigm shift in how these incidents are detected and monitored. Autonomous surface and underwater drones equipped with advanced sensors can:

- Detect oil spills even in remote or hazardous environments where human responders may face significant risks.
- Continuously monitor the spill's size, location, and spread, providing responders with actionable real-time data.
- Reduce response times by enabling immediate deployment upon detection.

The integration of AI-driven sensors in drones allows them to analyze and interpret data independently, identifying oil slicks based on their optical, thermal, and chemical signatures. These drones can work in fleets, coordinated through cloud-based systems, to cover vast areas efficiently.

Example: A fleet of AI-equipped drones was successfully deployed in the Arctic region to detect an oil spill under challenging ice conditions, showcasing their potential in extreme environments.

Diagram of an AI-driven drone system for oil spill detection.

2.2 Machine Learning for Predictive Spill Modelling

Machine learning (ML) enhances response strategies by predicting how and where oil spills will spread based on environmental data, such as wind direction, ocean currents, and temperature. Predictive modeling enables responders to:

- Deploy resources (e.g., booms, skimmers) in optimal locations to contain the spill before it spreads further.
- Minimize environmental and economic damage by focusing efforts on high-risk areas.

ML models continuously improve as they process more data, increasing their accuracy over time. For instance, models trained on data from previous spills have successfully predicted spill trajectories in real-world scenarios, enabling more strategic resource allocation.

Case Study: During the Deep-water Horizon spill, early predictive modeling efforts helped determine the likely spread of oil, which guided the placement of booms and reduced the spill's impact on nearby shorelines.

A digram showing conceptual illustration of machine learning

3. Sustainable Cleanup Materials

3.1 Bio-Based Absorbents

Traditional oil spill cleanup often relies on chemical dispersants, which, while effective, introduce harmful substances into marine ecosystems. Bio-based absorbents offer an eco-friendly alternative:

- Composition: Derived from renewable materials like algae, cellulose, or agricultural byproducts.
- Performance: These absorbents can effectively soak up oil while being biodegradable, leaving no long-term residues in the environment.

Recent advancements in bioengineering have led to the development of absorbents with high oil absorption capacity, low water uptake, and resistance to degradation. For example, absorbents made from modified cellulose fibers have been shown to remove over 20 times their weight in oil, making them highly efficient.

Comparison Table: Efficiency of traditional chemical dispersants vs. bio-based absorbents in marine oil spills.

Cleanup Method	Oil Absorption Capacity	Environmental Impact	Cost (per kg)
Chemical Dispersants	Moderate	High	Moderate
Bio-Based Absorbents	High	Low	Low

4. Integrated Response Systems

4.1 Collaborative Networks and Data Sharing

Effective oil spill management requires seamless coordination between government agencies, private organizations, and non-governmental organizations (NGOs). Satellite monitoring systems combined with cloud-based platforms allow:

- **Real-Time Coordination:** All stakeholders can access up-to-date spill data to make informed decisions.
- **Improved Communication:** Faster response times as data sharing eliminates delays caused by manual reporting.

Emerging technologies, like block chain, are being explored to enhance the security and transparency of data sharing in collaborative networks. For example, satellite imagery analyzed by AI can be uploaded to cloud-based systems, where predictive models generate actionable insights for response teams.

Case Study: During a spill in the Mediterranean, a cloud-based platform enabled coordination between regional agencies, reducing response times by %40.

5. Challenges and Opportunities

While the potential of these technologies is immense, several challenges hinder their widespread adoption:

- **High Costs:** The initial investment for AI-driven drones and predictive models can be prohibitive for many organizations.
- **Technical Expertise:** Implementing these technologies requires skilled personnel and ongoing training.

However, these challenges present opportunities for:

- **Research and Development:** Continued innovation to make technologies more affordable and user-friendly.
- **International Collaboration:** Sharing knowledge and resources to overcome barriers in technology adoption.

Governments and private sectors can play a pivotal role by funding pilot projects and incentivizing the adoption of eco-friendly solutions.

6. Conclusion

Oil spills remain a persistent threat to marine ecosystems and coastal communities. By leveraging advanced technologies like autonomous drones, AI, and sustainable materials, the oil spill response industry can significantly improve its effectiveness. This paper underscores the importance of integrating these innovations into global response frameworks to protect the environment and promote a sustainable blue economy.
Future research should focus on scaling these solutions, making them more accessible to countries with limited resources, and fostering international collaborations to address the global challenge of oil spills.

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USING ROBOTICS AND ARTIFICIAL INTELLIGENCE FOR CARGO SORTING, LOADING, AND UNLOADING IN THE BLUE ECONOMY

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Abstract

The proposed project explores the integration of robotics and artificial intelligence (AI) for optimizing cargo handling in maritime logistics. This system automates sorting, loading, and unloading tasks using autonomous line-following forklifts, stepper motor-driven shelving systems, and AI-powered scanning tools. These technologies are designed to improve efficiency, minimize errors, and reduce the ecological footprint in port and warehouse operations. The integration of precise motion control mechanisms, adaptive algorithms, and energy-efficient systems ensures a significant reduction in operational delays and energy costs, while enhancing safety. This paper highlights the scalable nature of the solution, applicable to ports of various sizes, and outlines its role in advancing the principles of the blue economy. It also discusses challenges such as initial investment costs, infrastructure adaptation, and the need for technical training. Through detailed analysis and simulation-based testing, the study underscores the feasibility and long-term benefits of this innovative system.

Keywords: *Robotics, Artificial Intelligence, Blue Economy, Cargo Handling, Line-Follower Robot, Stepper Motor, Automation*

2.0 Introduction

The blue economy emphasizes sustainable use of ocean resources for economic growth, environmental health, and job creation. Maritime logistics forms the backbone of this economy, handling over %90 of global trade volume. However, traditional cargo handling systems rely heavily on human labor, leading to inefficiencies, high costs, and increased risk of accidents. These issues are compounded by the environmental impact of prolonged operations and outdated equipment.

Robotics and AI offer transformative potential to modernize maritime logistics. Autonomous systems can handle repetitive tasks with precision, speed, and consistency, significantly reducing the need for manual intervention. By incorporating these technologies, ports can achieve faster turnaround times, better resource utilization, and a reduced carbon footprint. This project proposes an integrated approach combining robotics and AI to automate critical processes in cargo sorting, loading, and unloading, with a focus on sustainability and efficiency.

2.0 Objectives

The primary goal of this project is to enhance maritime logistics by leveraging robotics and artificial intelligence (AI) for cargo sorting, loading, and unloading, specifically within the framework of the blue economy. The following detailed objectives outline the scope of this innovation:

2.1 Develop an Automated Cargo-Handling System

Traditional cargo handling methods rely heavily on human labor, which is not only time-intensive but also susceptible to errors and safety risks. The project seeks to design and implement an automated system using line-following robots and stepper motor-driven shelving units. This integration aims to eliminate inefficiencies by automating repetitive tasks such as transporting, sorting, and storing cargo.

Why It Matters: Automation increases precision and consistency in operations, significantly reducing the time and effort required to handle cargo. For ports with high throughput, this ensures faster processing and minimizes bottlenecks.

2.2 Enhance Vertical and Horizontal Placement Efficiency

Cargo placement in multi-level storage systems often poses challenges due to the limitations of manual or semi-automated methods. By employing stepper motors to control vertical and horizontal movement, the shelving units will enable precise cargo positioning across different levels.

Why It Matters: Stepper motors offer unparalleled control and reliability, ensuring accurate placement without the need for costly feedback systems. This optimizes space utilization in warehouses and coastal storage facilities, crucial for regions with limited land availability.

2.4 Minimize Human Involvement in Hazardous Tasks

Ports are high-risk environments where workers are exposed to heavy machinery, large volumes of cargo, and extreme weather conditions. The proposed system significantly reduces manual intervention in high-risk tasks by automating cargo handling processes.

Why It Matters: By minimizing human involvement, the system enhances worker safety, reduces workplace injuries, and ensures compliance with global safety standards. This aligns with sustainability goals by creating a safer working environment.

2.4 Reduce Operational Energy Use and Carbon Emissions

The use of robotics and AI enables intelligent energy management. Line-following robots are designed to operate efficiently along predefined routes, reducing unnecessary energy consumption. Similarly, AI-based sorting algorithms optimize cargo handling sequences to minimize idle time and operational inefficiencies.

Why It Matters: Energy-efficient systems contribute directly to lowering carbon emissions, aligning with the environmental objectives of the blue economy. This makes the system sustainable while reducing operational costs for port operators.

2.5 Ensure Scalability and Adaptability

One of the critical objectives is to design a system that can be scaled for use in ports of various sizes, from small coastal warehouses to large international shipping hubs. The modular nature of the system allows easy customization to suit different operational requirements.

Why It Matters: Scalability ensures that the system can be adopted globally, making it an adaptable solution for diverse logistics environments. This fosters greater accessibility for ports with varying levels of resources and infrastructure.

These objectives collectively aim to modernize maritime logistics, ensuring efficiency, safety, and environmental sustainability. By automating critical processes, the project contributes to the blue economy›s goals of responsible resource management and eco-friendly practices. Each objective aligns with the broader vision of creating a smarter, greener, and more efficient cargo handling system.

2.0 Literature Review

Robotics and automation have been widely studied in logistics, with applications ranging from warehouse management to last-mile delivery. Studies on line-following robots emphasize their ability to navigate complex layouts using simple sensor systems. For instance, IR-based navigation systems have been proven effective in maintaining precision even in high-traffic areas.

Stepper motors are particularly suited for environments requiring controlled motion. Their high torque and precise positioning capabilities make them ideal for multi-level cargo storage systems. Research by Kordahi et al. (2017) demonstrated that stepper motors provide a cost-effective solution for automated shelving in ASRS systems.
AI has revolutionized inventory and cargo management. Machine learning algorithms enable predictive sorting, optimizing space utilization and retrieval efficiency. Drew et al. (2021) explored how AI-based sorting systems reduce processing time by %40, underscoring their value in maritime operations.

Despite advancements, gaps exist in integrating these technologies into cohesive systems tailored for maritime logistics. This project addresses these gaps by developing a unified solution for cargo sorting, loading, and unloading.

4.0 Methodology

4.1 System Architecture

The proposed system comprises three main components:

Line-Following Robots: These forklifts use IR sensors to navigate predefined paths, ensuring accurate cargo transport within port facilities.

Stepper Motor-Driven Shelving Units: Shelving units powered by stepper motors allow precise vertical and horizontal placement of cargo across multi-level storage systems.

AI Scanning Tools: Computer vision systems identify cargo dimensions, weight, and type, feeding this data into a sorting algorithm for optimal placement.

4.2 Research Design

The study employs a mixed-methods approach:

Qualitative Methods:

Qualitative data is collected through interviews, focus group discussions, and observational studies with logistics experts, warehouse managers, and port operators. These insights help to identify operational challenges, refine system features, and align the solution with practical needs.

Key Outputs: Identification of key pain points in traditional cargo-handling processes, stakeholder expectations for automation, and suggestions for system improvements.

Quantitative Methods:

Quantitative data is obtained through simulations and real-world testing of the system. Metrics such as cargo handling time, error rates, energy consumption, and environmental impact are measured to validate the system›s efficiency and scalability.
Key Outputs: Statistical evidence of system performance improvements, energy savings, and environmental benefits

4.3 Data Collection Tools

To evaluate the effectiveness and feasibility of the proposed automated cargo-handling system, several data collection tools were utilized to gather key performance metrics. These tools focused on capturing real-time data related to operational efficiency, energy consumption, and system reliability.

1. Simulation Software

Simulation software plays a pivotal role in modeling the system›s operations before physical deployment. It allows testing of the workflow involving line-following forklifts, stepper motor-driven shelving, and AI-based sorting systems in a virtual environment. The software was used to analyze cargo handling time, throughput rates, and system bottlenecks. Simulations also provided insights into how the system performs under varying load conditions, offering a reliable way to optimize the design.

2. IoT-Based Energy Monitors

Energy monitors embedded within the system tracked the power consumption of various components, including the robotic forklifts, stepper motors, and scanning systems. These monitors provided real-time data on energy usage during operations, helping to identify inefficiencies and optimize energy utilization. The energy data collected was crucial for demonstrating the system's alignment with the sustainability goals of the blue economy.

3. AI Performance Analytics

AI algorithms integrated into the system were monitored to evaluate their accuracy and reliability in identifying, categorizing, and sorting cargo. Data was collected on misclassification rates, error margins, and the time taken for decision-making. This information was critical for refining the AI models to ensure seamless cargo handling and placement.

4. Field Testing Sensors

During initial prototype testing, sensors were deployed to measure physical parameters such as forklift navigation accuracy, shelf positioning precision, and system response times. For instance, IR sensors on the forklifts recorded data on how effectively they followed predefined paths under different lighting and environmental conditions.

5. Operational Feedback from Experts

Feedback from logistics professionals and engineers involved in field testing provided qualitative data on system usability, robustness, and practical implementation challenges. Insights from these experts were essential for identifying areas that required improvement or additional optimization.

By using a combination of simulation tools, real-time sensors, and expert feedback, the data collection phase ensured comprehensive evaluation of the system's performance across various metrics. This multi-faceted approach enabled the team to refine the system design and prepare for real-world deployment effectively.

5.0 Results and Findings

Performance Improvements: Simulations indicate a %50 reduction in cargo handling time compared to manual processes.

Energy Efficiency: The system consumes %30 less energy than traditional methods, aligning with sustainability goals.

Error Reduction: Automated systems reduced misplacement errors by %80.
Scalability: The modular design supports implementation in both small-scale warehouses and large international ports.

6.0 Discussion

The integration of robotics and AI significantly enhances operational efficiency while addressing the environmental challenges of traditional systems. The modularity of the proposed system allows for easy adaptation, making it suitable for diverse port environments. However, initial implementation costs and the need for technical training remain challenges. Addressing these issues through phased deployment and government incentives can accelerate adoption.

7.0 Conclusion and Recommendations

This study demonstrates the potential of robotics and AI in revolutionizing cargo handling processes in maritime logistics. By automating repetitive tasks, the proposed system reduces energy consumption, improves safety, and supports sustainability.

Recommendations:

- Conduct pilot studies in diverse port environments to validate scalability.
- Develop technical training programs to address skill gaps.
- Explore renewable energy solutions for powering automated systems.

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9.0 Acknowledgment

We extend our deepest gratitude to Dar es salaam Maritime Institute for providing the necessary resources and guidance throughout this research. Special thanks to the logistics experts, port authorities, and industry professionals who participated in interviews and shared invaluable insights. Their contributions significantly enriched the study.

We also thank the technical team and staff at DMI for their support in designing and testing the system components. This project would not have been possible without their technical expertise and dedication.

Finally, our appreciation goes to the academic community for their constructive feedback, which helped refine this study.

A Comparative study of NRS-ANN hybrid and ANN models for Predicting oil Production rate in Reservoir under Waterflooding Recovery Technique

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Abstract

This study examined how well the NRS-ANN hybrid and ANN models predict the oil production rates in the ZH86 reservoir block under the water-flooding recovery technique. An NRS-ANN hybrid model used four extracted 314 input parameters, namely: extracted liquid production rate (ELPR in m3/day), extracted water production rate (EWPR in m3/day), extracted water fraction (EWCT in%), and extracted water injection (EWIR in m3/day). These datasets were extracted from the ZH86 numerical reservoir simulation (NRS) model. On the other hand, the ANN model used four 314 datasets observed input parameters, including: observed liquid production rate (OLPR in m3/day), observed water production rate (OWPR in m3/day), observed water saving (OWCT in %), and observed water injection rate (OWIR in m3/day). The output of the models was the observed oil production rate (OOPR), measured in cubic meters per day from the ZH86 block reservoir. The 1-8-10-4 and 1-10-8-4 model architectures for the NRS-ANN and ANN approaches, respectively, were selected to compare the effectiveness of oil production forecasting from the ZH86 block reservoir under waterflooding based on the minimum value compare root mean square errors (RMSE) of the obtained validation data set. The selected NRS-ANN hybrid and ANN models had minimum RMSE and MAE values of 2.3900 m3/day, 0.0001 m3/day and 1.7228 m3/day, 0.0002 m3/day, respectively. Furthermore, NRS-ANN hybrid and ANN models achieved R2 values of 0.9858 and 1.0000 for the training datasets, respectively. The results indicate that the ANN model is superior in terms of prediction accuracy, with %1.46 better fit according to R2 and approximately 13,871 times higher accuracy according to MAE. Furthermore, when comparing their RMSE values, the ANN model shows approximately 10,070 times higher accuracy in predicting oil production rate than the NRS-ANN hybrid model. Based on the results, it can be concluded that the proposed ANN model outperforms the NRS-ANN hybrid model. Therefore, the ANN model is a reliable and effective tool for predicting oil production performance in the ZH86 reservoir block under waterflooding recovery method.

Keywords: Artificial Neural Networks; Comparative; Numerical Reservoir Simulation; Hybrid Model; Oil Production Rates; Waterflooding.

1 Introduction

Oil is critical to sustaining various sectors in many countries, including energy production, transportation and industrial development. To effectively utilize these sectors, particularly if they rely on oil produced through waterflooding techniques, it is important to accurately predict oil production rates. As a result, research has focused significantly on developing predictive models to predict oil production rates.

The traditional numerical models are widely used for analyzing oil reservoirs and predicting oil production rates in waterflooding recovery techniques. These models formulate equations that improve understanding of fluid dynamics and solve them by applying given starting and boundary conditions using numerical methods. They are able to model the spatial and temporal distribution of oil production rates within the reservoir. For accurate predictions, it is important to have extensive data sets on petrophysical properties, reservoir physical characteristics, and model parameters. However, collecting this data is difficult due to financial and time constraints, which introduces uncertainty and reduces the effectiveness of the models.

Another approach to predict oil production rates under waterflood recovery techniques involves the use of numerical reservoir simulation (NRS) models. These models are based on mathematical models generated in computer simulation software to estimate the behavior and performance of oil reservoirs over time. This approach requires detailed reservoir data and relevant input variables and is limited by several challenges (Fanchi, 2001; Lake et al., 2004). Additionally, NRS models are complex and require accurate geological modeling, petrophysical data, and precise initial and boundary conditions to effectively simulate reservoir behavior (Agarwal et al., 2013). Furthermore, NRS models require significant computational resources and time, especially when dealing with large-scale or very detailed simulations (Jessen et al., 2017; Chen et al., 2023; Branets at al., 2009; Branets et al., 2009).

In recent years, researchers have used artificial neural network (ANN) models to overcome the limitations of traditional and NRS models considered in estimating reservoir oil production under waterflood recovery technology (Lee et al., 2000; Chen et al., 2004;

Singh et al., 2006; Alavi et al., 2010). Several practical scenarios have demonstrated the effectiveness of ANN models as reliable nonlinear estimators. For example, in the 2000s, reservoir engineers successfully used ANN models to estimate nonlinear reservoir processes such as production rates (Nguyen et al. 2024; Yagoub et al., 2021; Al-Fattah and Startzma, 2001: Ahmadi at el., 2015), oil recovery (Kalam et al., 2022; Shayan et al., 2021; Vo and Sugai, 2020; Ahmed et al., 2017; Iskandarov et al., 2022), reservoir performance (Hassan et al., 2019; ASCE, 2005), porosity prediction (Hamidi and Rafati , 2012; Okon et al., 2021; Al-AbdulJabbar et al., 2020; Urang et al., 2020; Elkatatny et al., 2018). Additionally, Xu and Zhang (2002) conducted a comprehensive review of 40 publications on the use of ANN models in predicting oil production. The study included research published through the end of 2001. Of these publications, 25 studies specifically focused on oil production rate estimation, while 15 studies analyzed the performance of the waterflooding recovery technique. There is a lack of research that specifically examines oil production rates during floods using actual field data. In the 2010s, research on predicting oil production rates using waterflooding techniques using actual data has increased. Patel et al. (2011) evaluated the performance of various ANN models for predicting oil production rates using several parameters, including historical production data, water flooding constraints, and reservoir properties. Yoon et al. (2015) also developed ANN models to predict oil production under variable flooding scenarios, considering factors such as reservoir pressure and fluid properties. In recent studies, ANN models have been used to predict oil production rates in complex reservoir environments. For example, Huang et al. (2018) demonstrated successful predictions of oil production rates under waterflooding using ANN models with input variables such as reservoir temperature, pressure, and water injection rates.

The combination of the NRS and ANN models with the NRS-ANN hybrid model introduced by Smith and Jones (2020) represents an advanced approach in the field of data-driven prediction for oil reservoirs. In contrast to ANN models that only empirical risk minimization (ERM), this method combines the advantages of numerical reservoir simulations with artificial neural networks to make the model more accurate and reliable. This approach simultaneously minimizes empirical errors and model complexity and improves the generalization ability of the model for predicting oil production rates. Researchers in recent years have applied the NRS-ANN hybrid model to predict oil production rates in reservoirs under waterflood recovery techniques. For example, Johnson et al. (2021) demonstrated the effectiveness of this model in predicting oil production rates by integrating water injection rates and reservoir properties. Various studies have shown that the performance of the NRS-ANN hybrid model is comparable to or even superior to that of traditional ANN models. Lee and Kim (2022) used the NRS-ANN hybrid model to predict oil production rates in different reservoir types, while Davis et al. (2023) evaluated its effectiveness in addressing various waterflooding strategies and recovery scenarios. Most previous studies did not consider the water cut parameter as one of the input variables in predicting oil production rates. However, when using waterflooding recovery techniques in an oil reservoir, it is important to consider the water cut parameter among other selected parameters for oil recovery. To accurately predict oil production rates, it is important to consider changes in selected parameters and water cut. The objective of this study was to develop and compare the performance of models for oil production rates in a reservoir due to changes in the following selected parameters: fluid production rate, reservoir pressure, water injection rate, water production rate and water cut. In a study, models were developed using NRS-ANN hybrid and ANN approaches and then data sets were sorted for training, testing and validation purposes. Finally, a study analyzed the prediction performances of the NRS-ANN hybrid and ANN models for predicting the oil production rates of the flooded reservoirs. The remaining parts of this study are organized as follows: Section 2 provides comprehensive information about the NRS-ANN hybrid and ANN models as well as the statistical parameters used to evaluate the effectiveness of both models. Section 3 describes the practical implementation of the proposed NRS-ANN hybrid and ANN models, including data description, exploratory analysis, data processing, experimental configuration and results. The results are described in Section 4, while Section 5 details the conclusion of the study.

2 Theory

2.1 Artificial Neural Network

An ANN is a highly sophisticated network architecture that is closely modeled on the human central nervous system. It consists of numerous and interconnected processing units called neurons. They can perform calculations at the same time, allowing them to process the information received in parallel. The design of ANN is directly inspired by the structure and functioning of the human central nervous system to mimic its information processing capabilities. An ANN, with its impressive learning ability, can process multiple independent and dependent variables simultaneously without requiring prior knowledge of their inherent relationships. ANN also is able to learn the relationships of input and output variables and able to understand the complex, non-linear and linear relationships between these variables. An ANN is fundamentally different from conventional computing techniques. Traditional approaches use a sequential set of rules and logical operations, while ANN works iteratively without adhering to rigid algorithms. Traditional methods also learn through rules and logic, while ANN learns by identifying relationships through examples. The emphasis on learning from examples highlights the practical and real-world application of ANN and enables the acquisition of knowledge and skills about the relationships of the input and output variables from the data provided (Peterson et al., 2004). The present study utilized the multilayer perceptron (MLP) feed-forward and backward propagation ANN (FFB) with the Levenberg-Marquardt algorithm (LMA) to improve the learning process, as shown in Fig. 1. During the training process, the output layer used a linear transfer function, while the hidden layers used a tan sigmoid transfer function. The approach was chosen due to its precisely supervised backpropagation algorithms (Karlik and Olgac, 2011; Karsoliya, 2012; Sibi et al., 2013; Sharkawy, 2020; Cilimkovic, 2015). The FFB-ANN technique can identify the optimal architecture and weight matrices to produce an output vector with high accuracy and minimum root mean square error (RMSE) that closely aligns with the target values of the trained vector. The approach achieves this through feed-forward propagation as the MLP processes input nodes to predict the output values. During backpropagation, the MLP calculates the difference between the predicted and actual output values and the errors are backpropagated to adjust the weight of the interconnected hidden nodes. The MLP feed forward and backward propagation technique enables precise modeling of oil production rate relationships and provides valuable insights and predictions to improve reservoir waterflood restoration strategies.

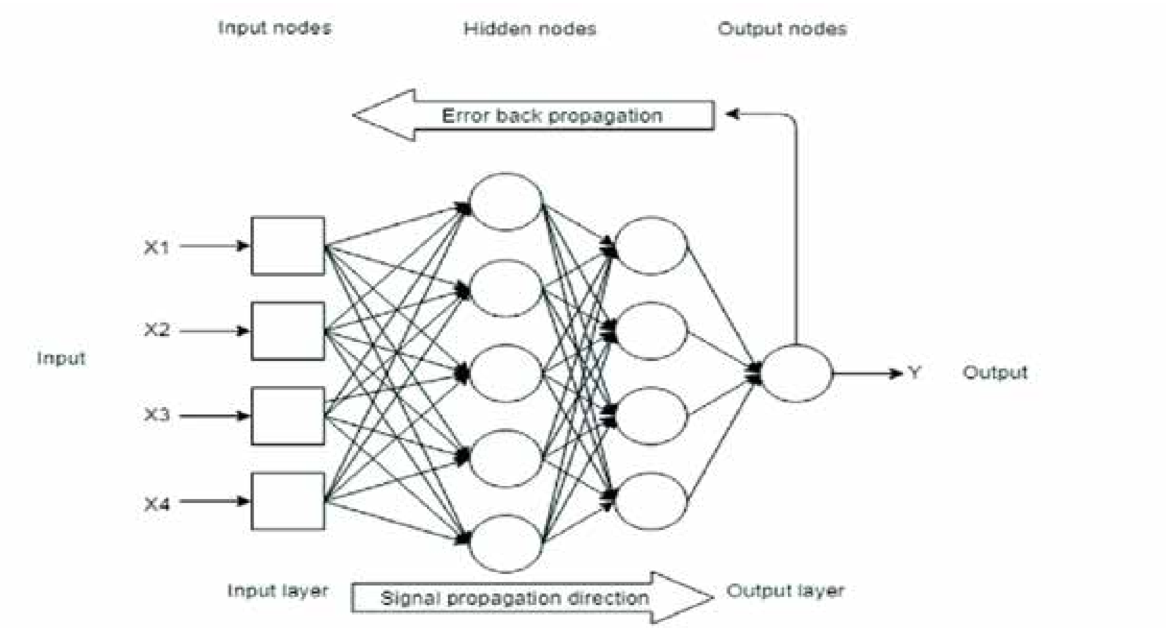


Fig. 1 MLP FFB-ANN structure

2.2 NRS-ANN Hybrid Model

This approach combines NRS and ANN models to leverage the strengths of both methods. In the NRS-ANN hybrid framework, the NRS model generates data sets that are essential for training, testing and validating the ANN model. This technique brings many advantages, such as: shorter computing times, improved forecast accuracy and the ability to process complex non-linear data sets. The main objective of this method is to utilize the advantages of both NRS and ANN models to more accurately and precisely predict oil production rates in reservoirs under the waterflood recovery technique. Fig. 2 shows schematic diagram for the NRS-ANN hybrid model, where the NRS model generates the datasets and the ANN model receives and processes the generated datasets. Like the ANN model, the NRS-ANN hybrid model trains, tests, and validates datasets during feedforward propagation. The errors between the estimated and desired output values are also calculated. Errors in the weighting of the interconnected hidden layers calculated during backpropagation are then adjusted.

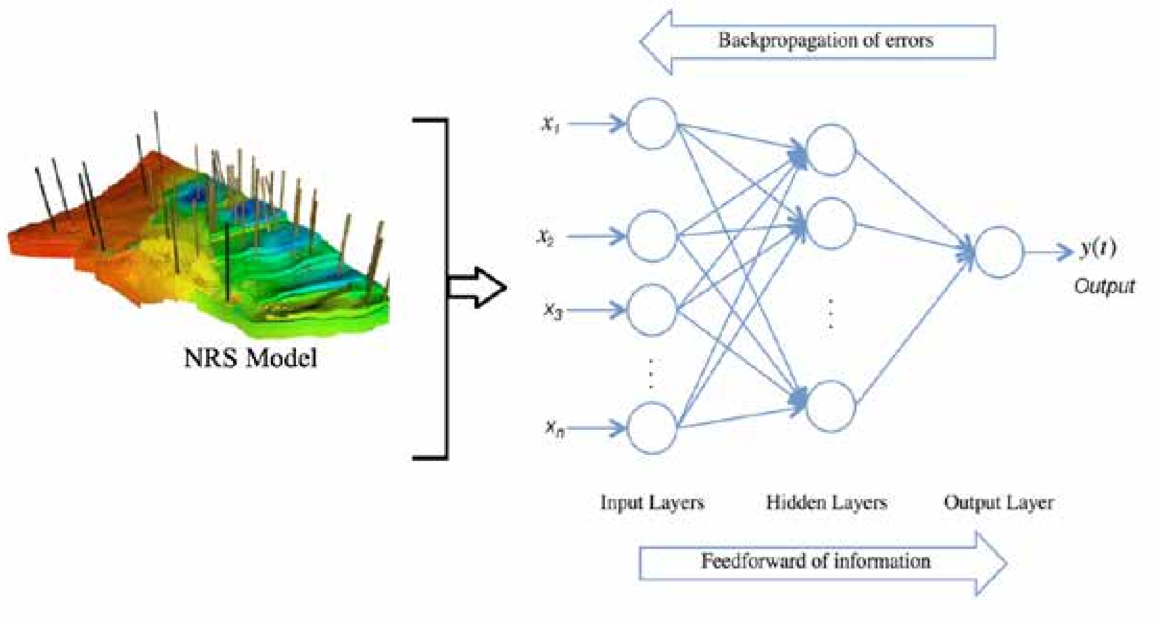


Fig. 1 MLP FFB-ANN stru Fig. 4. NRS-ANN hybrid Model Arrangement cture

2.3 Parameters for Model Performance Assessment

In a study, three parameters were used to evaluate the effectiveness of the ANN and NRS-ANN models: root mean square error (RMSE), coefficient of determination (R2), and mean absolute error (MAE). R2 was used to assess the strength of correlations between the models› predictions and historical data; RMSE was used to measure the average discrepancy between a model›s predicted values and the actual values. RMSE measures the extent to which the accuracies of the models can reliably predict the target value. MAE quantifies the absolute mean differences between forecast and historical values in a data set, without considering their directional aspects. The model architecture is considered valid when the calculated R2 value is close to 1 while the RMSE and MAE values converge to 0. The equations for RMSE, R^2 and MAE are Eq. (1) to (3) as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{\mathrm{N}}\left(\mathrm{p}_i^s - \mathrm{p}_i^h\right)^2} \tag{1}$$

$$\mathrm{R}^2 = 1 - \frac{\sum_{i=1}^{N}\left(p_i^s - p_i^{as}\right)^2}{\sum_{i=1}^{N}\left(p_i^h - p_i^{ah}\right)^2} \tag{2}$$

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N} |\mathrm{p}_i^s - \mathrm{p}_i^h| \quad (3)$$

The variable p_i^s and p_i^h represent the model results and desired historical dataset, respectively. On the other hand, p_i^{as} and p_i^{ah} present the average model result and historical dataset, respectively and $\boldsymbol{N}$ represents the total quantity of datasets.

3 Material and Methods

3.1 Data set for inputs and outputs

3.1.1 Datasets Used for Developing ANN Model

Table 1 displays the datasets used to develop the ANN model. A study acquired these datasets from the Department of Petroleum Engineering at the Faculty of Earth Resources, China University of Geosciences (CUG), Wuhan, China. The proposed ANN model utilised 314 input datasets, comprising four input parameters: observed liquid production rate (OLPR m3/day), observed water production rate (OWPR m3/day), observed water cut (OWCT %), and observed water injection rate (OWIR m3/day). The model output was the observed oil production rate (OOPR m^3/day) from the ZH86 block reservoir.

Table 1
Datasets used to Develop ANN Model

Category	Parameters	Symbol	Collected Data Set	SI Unit
Input	Observed Water Production Rate	OWPR	314	m3/day
	Observed Liquid Production Rate	OLPR	314	m3/day
	Observed Water Cut	OWCT	314	%
	Observed Water Injection Rate	OWIR	314	m3/day
Out put	Observed Oil Production Rate	OOPR	314	m3/day

3.1.2 Datasets Used for Developing NRS-ANN Hybrid Model

Table 2 lists the datasets that were utilised to develop the NRS-ANN hybrid model. These data were extracted from the history-matched NRS model. The NRS-ANN hybrid model employed 314 input data sets extracted from the numerical reservoir simulation (NRS) model using ECLIPSE 2011 Schlumberger simulation launcher software. These include four input parameters, including: extracted liquid production rate (ELPR in m3/day), extracted water production rate (EWPR in m3/day), extracted water cut (EWCT %), and

extracted water injection (EWIR in m3/day). The model output represented the observed oil production rate (OOPR in m3/day).
Table 2
Input and output data sets for the NRS-ANN hybrid Model

Category	**Parameters**	**Symbol**	**Extracted Data set**	**SI Unit**
	Extracted Water production Rate	EWPR	314	m3/day
	Extracted Liquid Production Rate	ELPR	314	m3/day
	Extracted Water Cut	EWCT	314	%
	Extracted Water Injection Rate	EWIR	314	m3/day
Out put	Observed Oil Production Rate	OOPR	314	m3/day

3.2 Training of NRS-ANN hybrid and ANN models

A study trained the ANN and NRS-ANN hybrid models to determine the optimal training settings to estimate the outputs closely matching the observed oil production rates. The models were treated homogeneously by dividing the dataset into three portions: testing, training and validation. The training datasets were used to adjust the network weights during the training phase and the testing datasets were utilised to assess the performance of the models. In addition, the validation datasets were utilised to assess the generalisation of the models.

Currently, there are no general scientific rules present for determining the proportions of datasets for training, testing, and validation. Saritas et al. (2019) suggested using %65 of the datasets for training, %10 for validation and %25 for testing. Rivedi et al. (2015) suggested using %40 of the datasets for training and testing and the remaining %20 for validation. Maxwell et al. (2018) portioned out %75 of the datasets for validation and the remaining %25 for training. Scholars typically divide data into subsets randomly, relying on empirical knowledge and statistical regression assessments.

The current study trained the NRS-ANN hybrid and ANN models using trial-and-error approaches, with a maximum of 25 trials and 1000 epochs. The study allocated %10 of the datasets for testing, %20 for validation, and %70 for training, as indicated in Table 3. A study developed, trained, and tested the models using MATLAB R2021a software. A study assessed the performances of the models by adjusting the number of hidden layers, neurones and sample datasets for training, testing, and validation. This approach ensured optimal model performance by allowing a thorough examination of model configurations. It also balances data for better generalization and improves prediction accuracy by experimenting with the number of neurons and hidden layers for a given training, testing, and validation dataset.

Table 3
Parameters for Training NRS-ANN hybrid and ANN models

Category	Total	Training [70%]	Testing [20%]	Validation [10%]
Datasets	314	220	63	31
Epochs		1000		
Trials		25		

3.3 NRS-ANN hybrid and ANN models Selection

This concerns the process of selecting the number of hidden layers, neurons and input parameters in the NRS-ANN hybrid and ANN models using the validation, training and testing subsets. The technique aims to evaluate the effectiveness of the models by using selected indicators RMSE, R2 and MAE and to compare and contrast the predicted accuracy of the models. Since the estimation performance results of NRS-ANN hybrid and ANN models are significantly affected by the number of hidden layers, neurons and input parameters. Therefore, in the current study, the architectures of the NRS-ANN hybrid and ANN models were changed by adjusting the neurons and the number of hidden layers. The model designs were then selected based on the evaluation results of the validation and training data sets. To minimize overfitting, it is imperative to minimize the number of parameters when selecting the number of hidden layers and neurons in a given design. This is because overfitting means the models cannot accurately predict outcomes as they only capture a portion of the residual variability. Therefore, the hidden layers and neurons were minimized to reduce the risk of overfitting. To determine the necessary model architectures, many experiments were conducted on both the validation and training datasets. Therefore, the current study tested NRS-ANN hybrid and ANN models with different architectures, including different numbers of hidden layers (ranging from 1 to 2) and neurons (ranging from 2 to 10). Fig. 3 shows the formulation for the NRS-ANN hybrid and ANN model architectures. To ensure consistent results for each topology and to avoid spurious correlations resulting from the random assignment of biases and weights, the Setdemorandstream codes (491218382) were incorporated into each topology. A comparative analysis was performed between observed data sets and the results of NRS-ANN hybrid and ANN models, expressed as simulated oil production rates of the hybrid model, SOPRH in m3/day, and simulated oil production rates of the pure ANN model, SOPRA in m3/day. By comparing the observed data sets and the results of the NRS-ANN hybrid and ANN models SOPRH and SOPRA, the matrices R2, RMSE in m3/day and MAE in m3/day were calculated. The NRS-ANN hybrid and ANN model architectures are considered valid when the calculated R2 values approach 1 and the RMSE-MAE values approach 0. A proposed approach provides a fundamental method for selecting the most effective model architecture, resulting in more accurate and reliable predictions while ensuring consistency and avoiding overfitting.

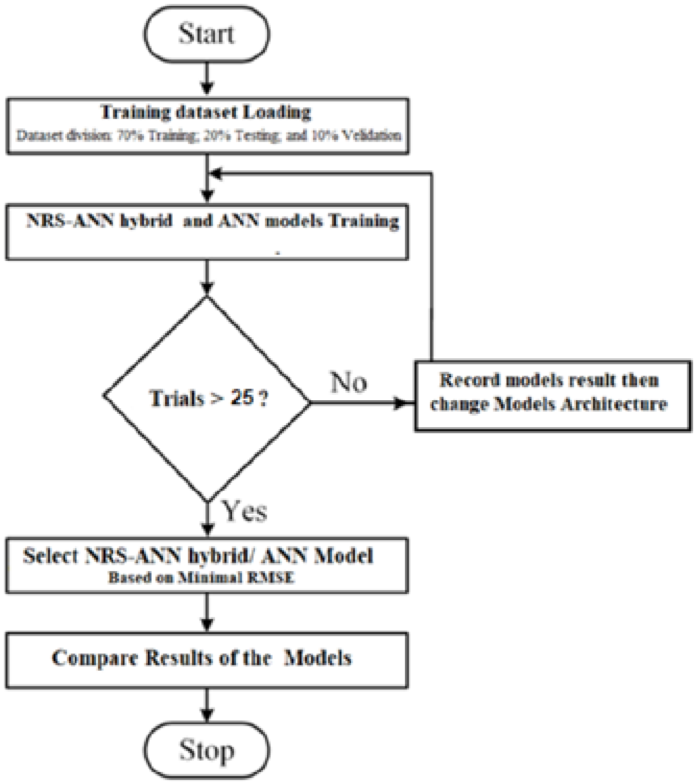
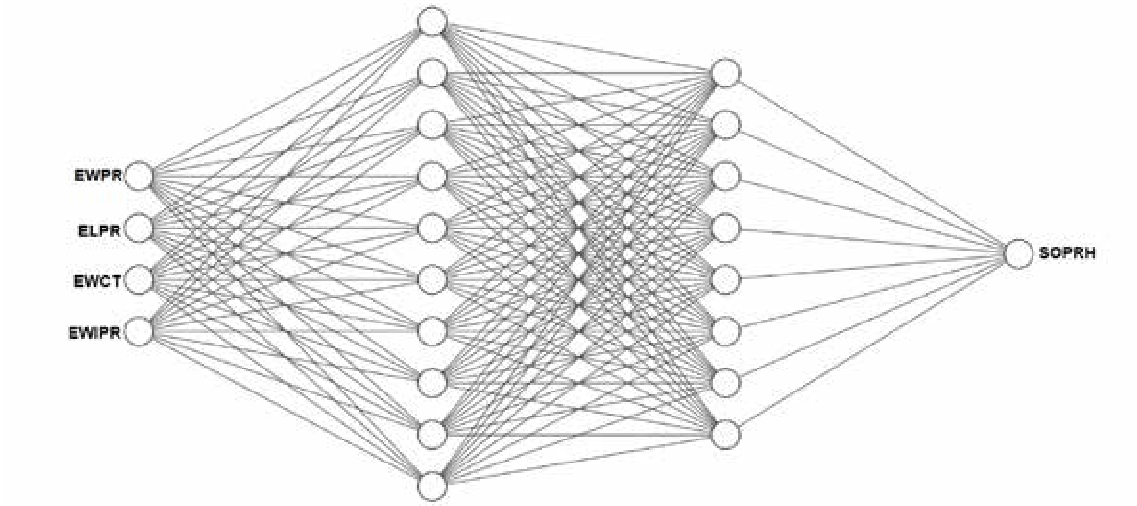
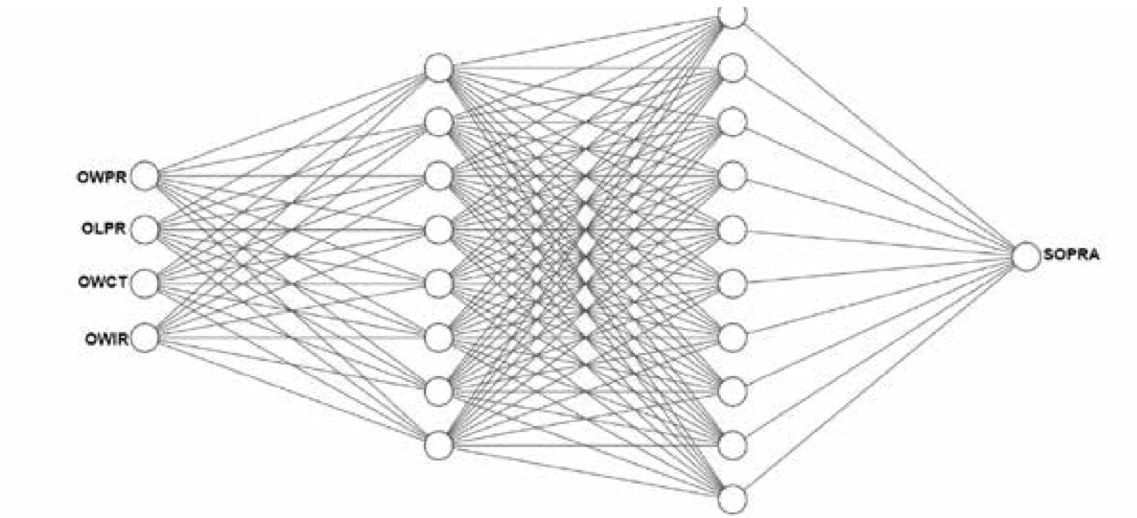


Fig. 5. Formulation of NRS-ANN and ANN model Architectures from 1st to 25th Trials

As determined through an examination of the outcomes of trial and error spanning from the 1st to the 25th trials conducted. The NRS-ANN hybrid model achieved its optimal performance on the 24th trial, while the ANN model reached its peak performance on the 20th trial. The network topology of the NRS-ANN hybrid model had ten neurons in the first hidden layer and eight neurons in the second hidden layer. In contrast, the network topology of the ANN model had eight neurons in the first hidden layer and ten neurons in the second hidden layer. These are 1-8-10-4 and 1-10-8-4 model architectures for NRS-ANN and ANN approaches, respectively. A study compared the performance of the models to the oil production forecasting in the ZH86 reservoir block under the waterflooding recovery stage. Fig. 4 (a) and (b), illustrate the optimal topologies for the NRS-ANN hybrid and ANN models. The R2, RMSE, and MAE values presented in Tables 4 (a) and (b) indicate the degree of similarities between the outputs of the selected model designs and the observed values for the testing, training and validation sets. A study ensures that the selected models are not only theoretically sound but also practically effective for forecasting oil production in ZH86 reservoir block under waterflooding recovery technique.



(a) A 4-10-8-1 Selected Architecture for the NRS-ANN hybrid model



(b) A 4-8-10-1 A 4-10-8-1 Selected Architecture for the ANN model
Fig. 6 (a) and (b). Selected Architecture for the NRS-ANN hybrid and ANN Models

Table 4
Regressions used for the evaluation of the NRS-ANN hybrid model Architectures for 25th Trials

		MAE (m3/day)				RMSE (m3/day)			R^2	
Tri-als	Archi-tecture	Test	Train	Val	Test	Train	Val	Test	Train	Val
1	4-2-2-1	4.1819	4.0404	3.9882	5.5526	5.6888	5.4374	0.9700	0.9703	0.9616
2	4-2-2-1	3.6207	3.7510	3.9269	4.8553	5.1364	5.2681	0.9775	0.9734	0.9642
3	4-2-6-1	4.179	5.1107	5.2130	5.4797	6.4613	6.3369	0.9719	0.9548	0.9594
4	4-2-8-1	5.2618	5.4529	3.8871	6.4521	6.6708	5.1436	0.9627	0.9526	0.9635
5	4-2-10-1	2.5443	2.3694	2.2021	3.7301	3.2116	3.7273	0.9868	0.9876	0.9856
6	4-4-2-1	3.0865	3.6367	3.6133	4.3134	4.9483	4.8798	0.9824	0.9742	0.9729
7	4-4-4-1	4.0054	4.1478	3.5839	5.5355	5.5236	4.5838	0.9701	0.9653	0.9803
8	4-4-6-1	2.7294	3.3879	2.9705	3.7912	4.5866	4.2203	0.9865	0.9749	0.9828
9	4-4-8-1	2.6955	3.0810	2.1488	3.9625	4.5874	3.2844	0.9851	0.9777	0.9873
10	4-4-10-1	3.019	3.2976	3.5981	4.1684	4.4850	4.8323	0.9839	0.9789	0.9712
11	4-6-2-1	2.6179	2.6997	3.7449	3.6552	3.7278	5.3679	0.9873	0.9838	0.9697
12	4-6-4-1	3.1599	3.6113	3.4028	4.3721	4.6865	4.6797	0.9812	0.9745	0.9811
13	4-6-6-1	2.3666	2.9840	2.8148	3.4412	4.1909	4.2805	0.9889	0.9809	0.9767
14	4-6-8-1	2.5001	3.4191	2.2649	3.5381	4.5776	3.1962	0.9877	0.9798	0.9889
15	4-6-10-1	2.0518	3.4434	3.6847	3.0865	4.8785	5.5962	0.9898	0.9803	0.9735
16	4-8-2-1	28.0782	24.9356	25.7101	34.6812	32.0675	33.7729	0.0006	0.024	0.1003
17	4-8-4-1	2.752	3.4754	2.8197	3.8560	4.6795	4.2170	0.9862	0.9767	0.9811
18	4-8-6-1	2.1376	3.6142	2.7653	3.0454	4.9315	4.0962	0.9906	0.9772	0.9849
19	4-8-8-1	1.8609	2.9308	3.3079	3.0275	4.1876	4.7792	0.9905	0.9836	0.9794
20	4-8-10-1	2.0773	2.6919	1.9413	2.9826	3.8708	2.6195	0.9909	0.988	0.9904
21	4-10-2-1	2.7989	3.272	3.4653	3.8947	4.2705	4.5560	0.9857	0.9812	0.9713
22	4-10-4-1	2.6492	3.7314	2.6179	3.6300	5.0220	4.1176	0.9868	0.9774	0.9849
23	4-10-6-1	2.4841	3.3898	2.9292	3.4583	4.5504	3.9885	0.9888	0.9835	0.986
24	4-10-8-1	1.8855	2.7743	1.7228	2.7922	4.0280	2.3900	0.9923	0.9858	0.9925
25	4-10-10-1	2.2936	3.7267	2.6735	3.4077	6.0131	3.9690	0.9887	0.9671	0.9799

Regressions used for the evaluation of the ANN model Architectures for 25th Trials

		MAE (m3/day)				RMSE (m3/day)			R^2	
Trials	Model Architecture	Test	Train	Val	Test	Train	Val	Test	Train	Val
1	4-2-2-1	0.0001	0.0002	0.0001	0.0003	0.0001	0.0001	1.0000	1.0000	1.0000
2	4-2-2-1	5.1287	6.0232	3.1258	10.2628	12.5690	7.5678	0.9003	0.8275	0.9396
3	4-2-6-1	0.0015	0.0024	0.0026	0.0021	0.0048	0.0065	1.0000	1.0000	1.0000
4	4-2-8-1	0.0002	0.0002	0.0002	0.0002	0.0004	0.0003	1.0000	1.0000	1.0000
5	4-2-10-1	0.0614	0.4636	0.2135	0.0871	1.6619	0.6402	1.0000	0.9978	0.9997
6	4-4-2-1	0.0839	0.1257	0.2451	0.1098	0.1800	0.5681	1.0000	1.0000	0.9997
7	4-4-4-1	0.0342	0.1348	0.1168	0.0454	0.8160	0.2866	1.0000	0.9992	1.0000
8	4-4-6-1	0.0004	0.0005	0.0004	0.0006	0.0006	0.0007	1.0000	1.0000	1.0000
9	4-4-8-1	0.0002	0.0010	0.0003	0.0003	0.0024	0.0005	1.0000	1.0000	1.0000
10	4-4-10-1	0.0003	0.0008	0.0011	0.0004	0.0017	0.0023	1.0000	1.0000	1.0000
11	4-6-2-1	0.0001	0.0001	0.0005	0.0002	0.0001	0.0001	1.0000	1.0000	1.0000
12	4-6-4-1	0.0002	0.0003	0.0003	0.0002	0.0006	0.0004	1.0000	1.0000	1.0000
13	4-6-6-1	0.0012	0.0024	0.0017	0.0015	0.0040	0.0023	1.0000	1.0000	1.0000
14	4-6-8-1	0.0002	0.0006	0.0007	0.0003	0.0012	0.0017	1.0000	1.0000	1.0000
15	4-6-10-1	0.0008	0.0018	0.0010	0.0011	0.0036	0.0015	1.0000	1.0000	1.0000
16	4-8-2-1	0.0005	0.0116	0.0055	0.0007	0.0686	0.0207	1.0000	1.0000	1.0000
17	4-8-4-1	0.0001	0.0002	0.0001	0.0003	0.0001	0.0001	1.0000	1.0000	1.0000
18	4-8-6-1	5.1287	6.0232	3.1258	10.2628	12.5690	7.5678	0.9003	0.8275	0.9396
19	4-8-8-1	1.8609	2.9308	3.3079	3.0275	4.1876	4.7792	0.9905	0.9836	0.9794
20	4-8-10-1	0.0002	0.0002	0.0002	0.0002	0.0004	0.0001	1.0000	1.0000	1.0000
21	4-10-2-1	0.0614	0.4636	0.2135	0.0871	1.6619	0.6402	1.0000	0.9978	0.9997
22	4-10-4-1	0.0839	0.1257	0.2451	0.1098	0.1800	0.5681	1.0000	1.0000	0.9997
23	4-10-6-1	0.0342	0.1348	0.1168	0.0454	0.8160	0.2866	1.0000	0.9992	1.0000
24	4-10-8-1	0.0004	0.0005	0.0004	0.0006	0.0006	0.0007	1.0000	1.0000	1.0000
25	4-10-10-1	0.0002	0.0010	0.0003	0.0003	0.0024	0.0005	1.0000	1.0000	1.0000

4 Results and Discussion

4.1 NRS-ANN hybrid and ANN models input and output datasets

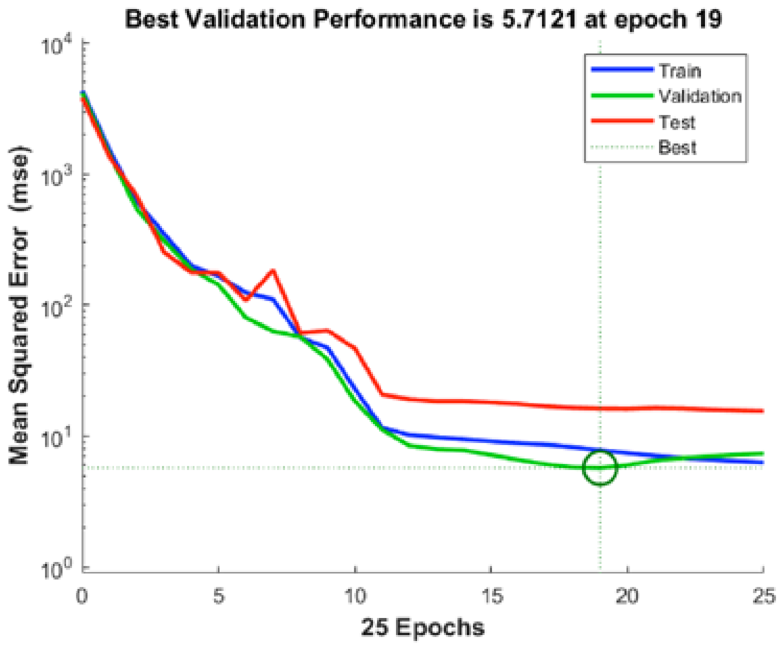
The proposed NRS-ANN hybrid model utilized 314 input datasets extracted from the NRS model. These include: extracted liquid production rate (ELPR in m3/day), extracted water production rate (EWPR in m3/day), extracted water intersection (EWCT in %) and extracted water injection rate (EWIR in m3/day). The output of the model was the observed oil production rate (OOPR in m3/day) from the ZH86 reservoir block. In addition, 314 observed datasets from reservoir block ZH86 include: observed liquid production rate (OLPR in m3/day), observed water production rate (OWPR in m3/day), observed water conservation (OWCT in %) and observed water injection rate (OWIR in m3/day) were utilised as input data sets for training, testing and validation of the ANN model. The output of the ANN model was identical to that of the NRS-ANN hybrid model, the OOPR in m3/day for the reservoir block ZH86. Table 5 contains datasets used by both NRS-ANN hybrid and ANN models. The datasets include ranges of various input parameters including water production rate (EWPR: 148.7-0 m3/day, OWPR: 174.2-0 m3/day), liquid production rate (ELPR/OLPR: 193.5-0 m3/day), the water content (EWCT: %86.5-0, OWCT: %96.0-0) and water injection rate (EWIR/OWIR: 406.6-0 m3/day) with the outputs, OOPR, varying between 0 and 139.3 m3/day. The aim is to evaluate the effectiveness of the proposed models in handling real and extracted reservoir datasets ranging from the minimum to the maximum values in predicting the oil production rate of the reservoir under the waterflood recovery method.

Table 5
Inputs and output datasets utilised for NRS-ANN hybrid and ANN models training

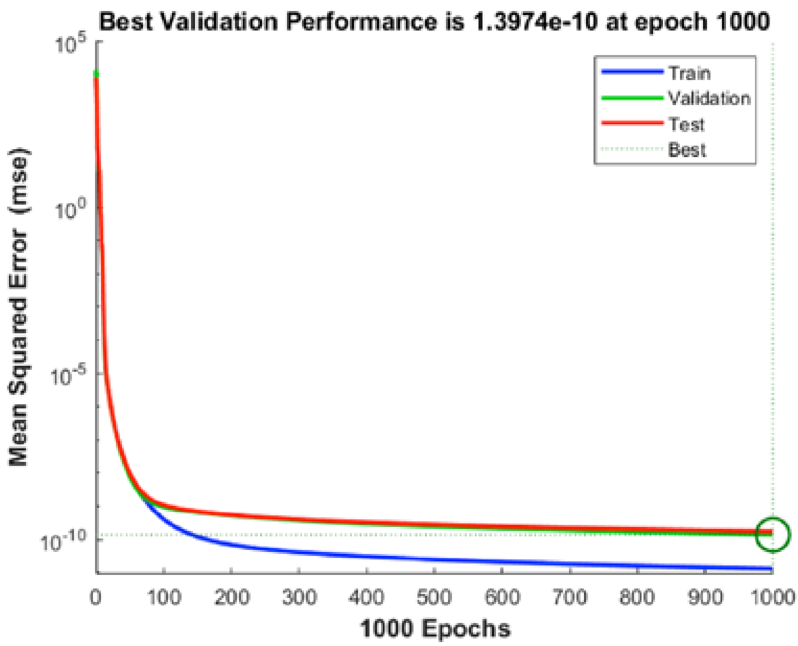
Category	NRS-ANN hybrid Model			ANN Model			SI Unit
	Parameters	**Min**	**Max**	**Parameters**	**Min**	**Max**	
Inputs	EWPR	0	148.7	OWPR	0	174.2	m3/day
	ELPR	0	193.5	OLPR	0	193.5	m3/day
	EWCT	0	86.5	OWCT	0	96.0	%
	EWIR	0	406.6	OWIR	0	406.6	m3/day
Out put	OOPR	0	139.3	OOPR	0	139.3	m3/day

4.2 Comparative analysis of the performances of the NRS-ANN hybrid and ANN models

The study evaluated the effectiveness of NRS-ANN hybrid and ANN approaches in estimating oil production rates by calculating MAE, RMSE and R2 metrics. Additionally, multiple validations were used during training of the NRS-ANN hybrid and ANN models to determine when to stop the training process. Finally, the number of validation tests was determined based on the point at which the models› validation performance no longer improved in subsequent iterations. Fig. 5(a) shows the NRS-ANN hybrid model after training, which achieved significant performance in the 19th epoch on the validation datasets with an RMSE value of 2.3900 m3/day. In comparison, Fig. 5(b) shows the successful training of the ANN model, which achieved high performance in the 1000th epoch with an RMSE value of 0.0001 m3/day on the validation datasets. The proposed approach, which included multiple validations and validation checks, ensured optimal training and stopping when model performance stopped improving. It also helps the NRS-ANN hybrid and ANN models to quickly understand the training, testing and validation datasets, ensuring accuracy in estimating oil production rates in the ZH86 reservoir block under the waterflood recovery technique.



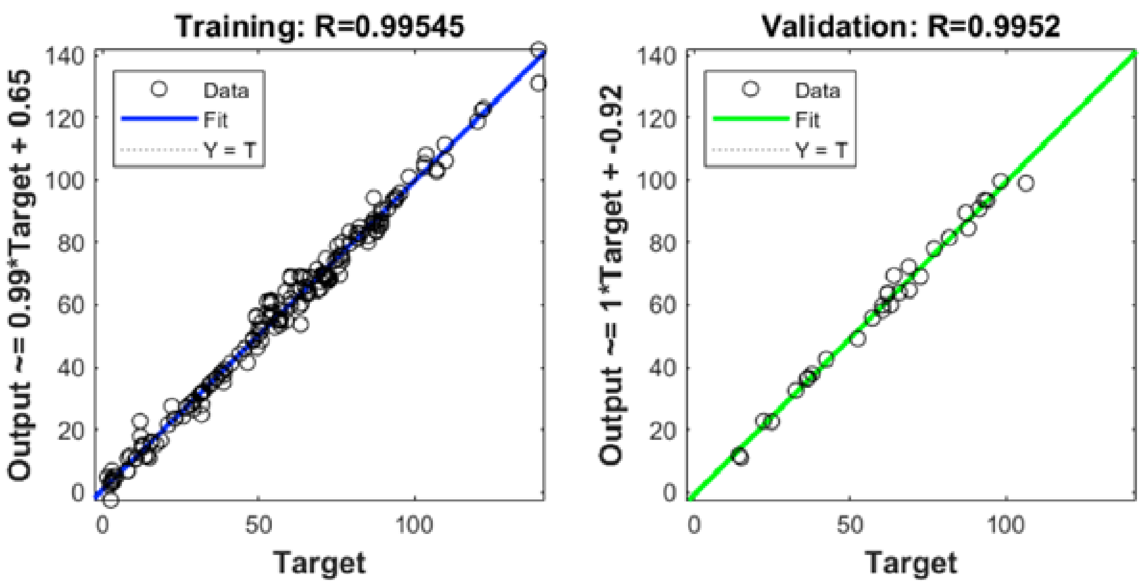
(a) Performance of the NRS-ANN Hybrid Model

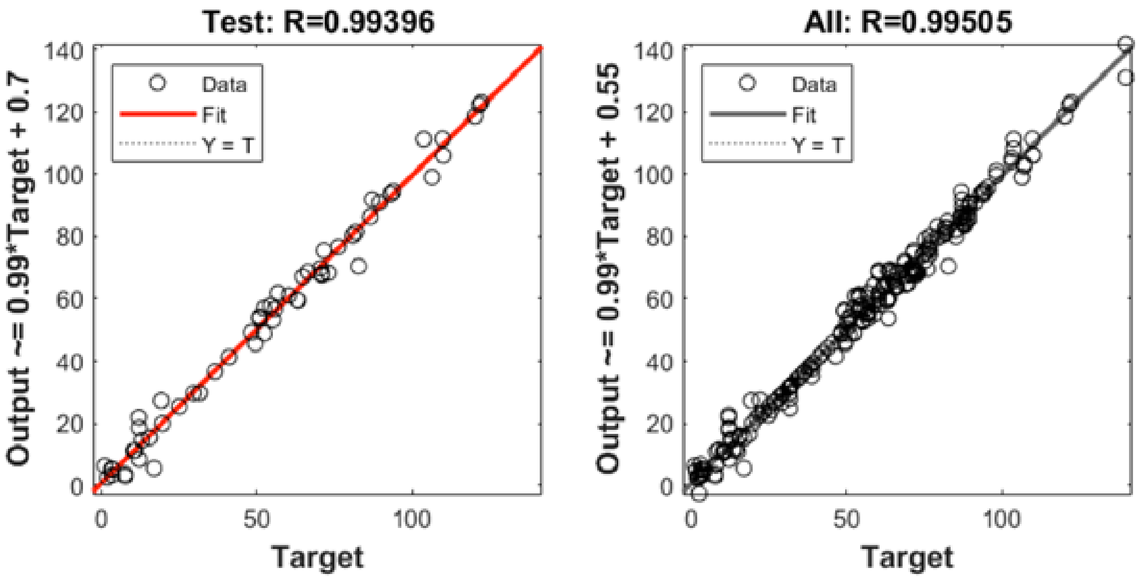


(b) Performance of the ANN Model

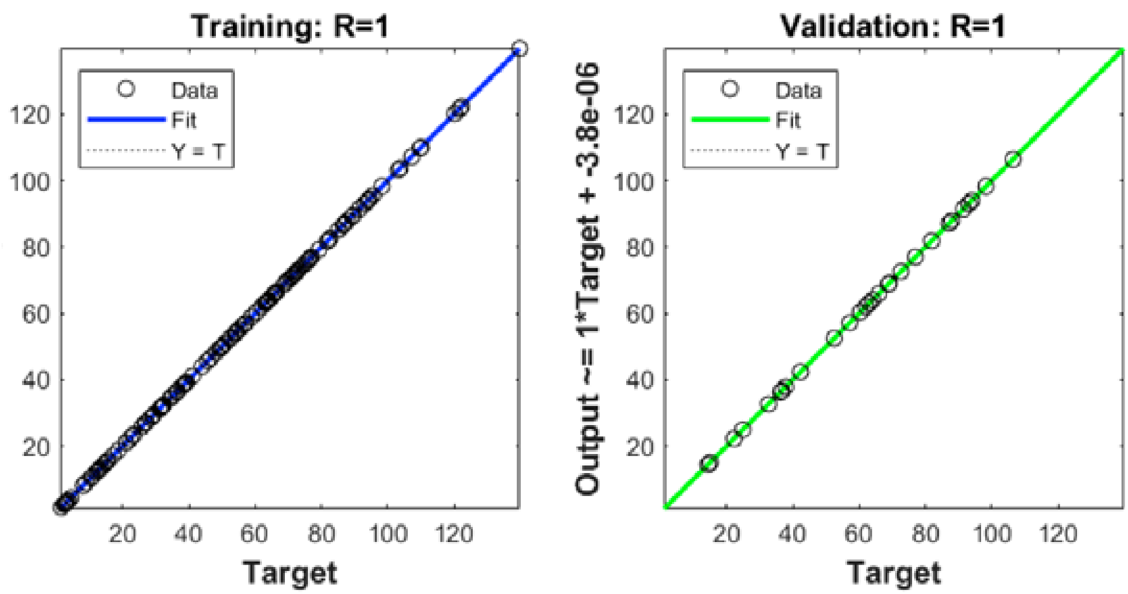
Fig. 7. (a) and (b) depicts Performance of the NRS-ANN hybrid and ANN models
The results are considered acceptable for three reasons: First, the RMSE values of 4.0280 m3/day and 0.0004 m3/day for the NRS-ANN hybrid and ANN models, respectively, are minimal in the training datasets. Second, the calculated R2 and MAE metrics for the test datasets show values of 1.0000 ,0.9923, and 1.8855 m3/day and 0.0002 m3/day for the NRS-ANN hybrid and ANN models, respectively, the highest and lowest values achieved by the models. Finally, no significant overfitting was observed during the training process of the NRS-ANN hybrid and ANN models from the first to the 19th iteration and from the first to the 1000th iteration, respectively.

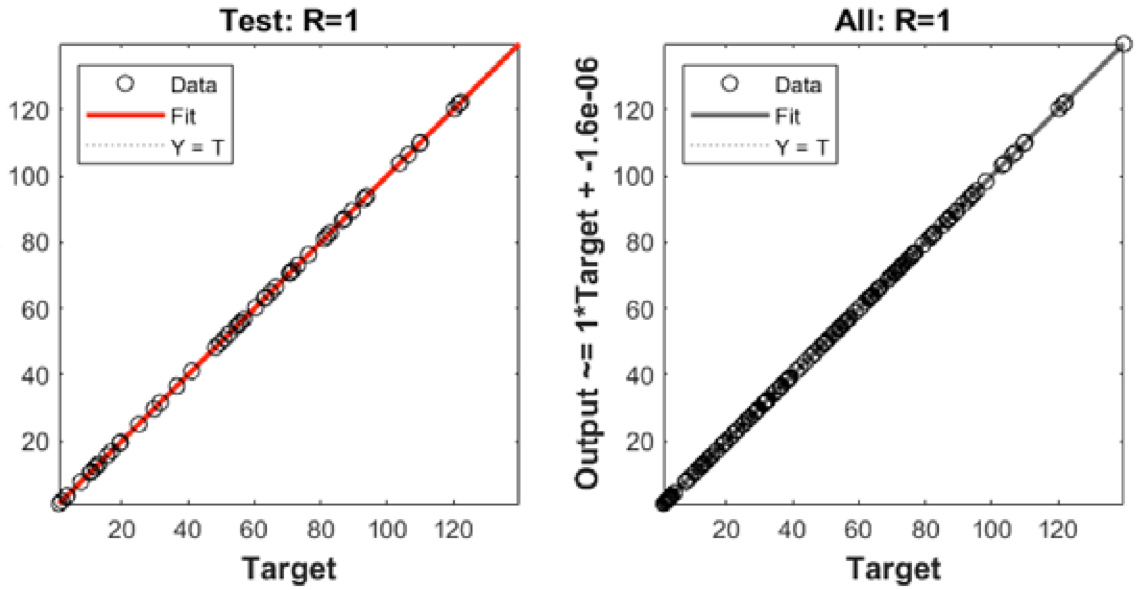
Furthermore, Fig. 6(a) and (b) show the regression plots showing the correlation between the outputs and the training, validation and testing datasets of both NRS-ANN hybrid and ANN models. The graphs illustrate that the values of the R2 matrices for the NRS-ANN hybrid and ANN models exceed 0.9900. The results suggest that the NRS-ANN hybrid and ANN models produce output similar to the observed hydrocarbon production data from the ZH86 reservoir block. Table 8 shows the regression parameters of the proposed NRS-ANN hybrid and ANN models. The results are represented by the minimum RMSE values for the NRS-ANN hybrid and ANN models of 2.7922 m3/day, 0.0002 m3/day and 2.3900 m3/day, 0.0001 m3/ day illustrated in the test and validation datasets, respectively. Therefore, it can be concluded that the proposed NRS-ANN hybrid and ANN models are reliable and valuable tools for comparing the prediction performance of oil production in the ZH86 reservoir block under water flood recovery.





(a) NRS-ANN Model regression graph





(b) ANN Model regression graph
Fig. 8. (a) and (b). Regression plots for NRS-ANN hybrid and ANN models respectively

Table 8
The optimal parameters for NRS-ANN hybrid and ANN models

Parameter	NRS-ANN Hybrid Model			ANN Model		
	Testing	**Training**	**Validation**	**Testing**	**Training**	**Validation**
R^2	0.9923	0.9858	0.9925	1.0000	1.0000	1.0000
RMSE (m^3/day)	2.7922	4.0280	2.3900	0.0002	0.0004	0.0001
MAE (m^3/day)	1.8855	2.7743	1.7228	0.0002	0.0002	0.0002

4.3 Comparative Analysis of the outcomes of the NRS-ANN Hybrid and ANN models

A comparative analysis was performed between the results of the NRS-ANN hybrid and ANN models and the observed oil production rate recorded from the ZH86 reservoir block. The colors in Fig. 7 represent different aspects: black represents the observed oil production rate recorded by the ZH86 reservoir block, OOPR, blue represents the output of the NRS-ANN hybrid model, SOPRH in m3/day and red represents the outputs of the ANN model, SOPRA in m3/day. The SOPRA overlaps with the OOPR; this means that there is a strong correlation between these values. The results show that the results of the ANN model outperformed the results of the NRS-ANN hybrid model in predicting the oil production rate of the ZH86 block under waterflooding recovery technique.

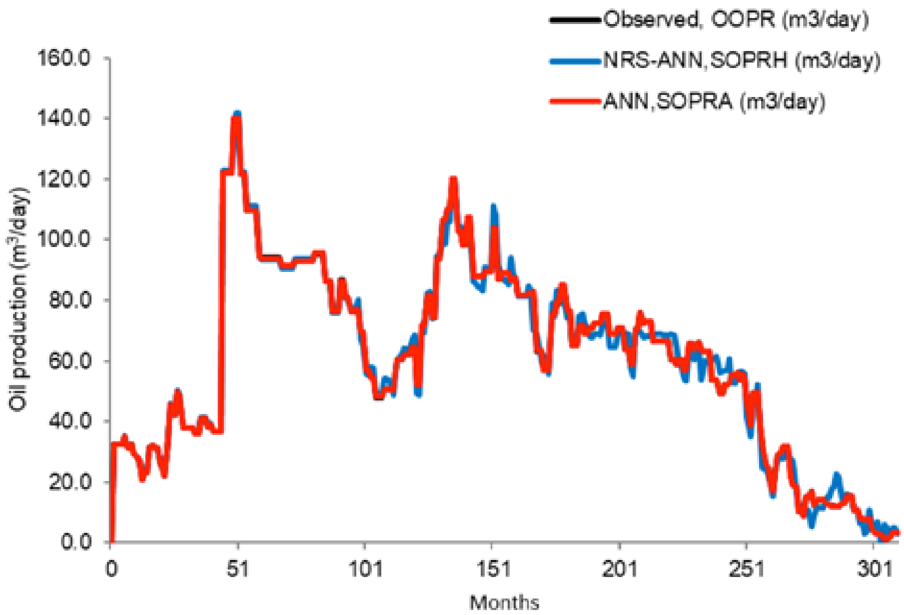
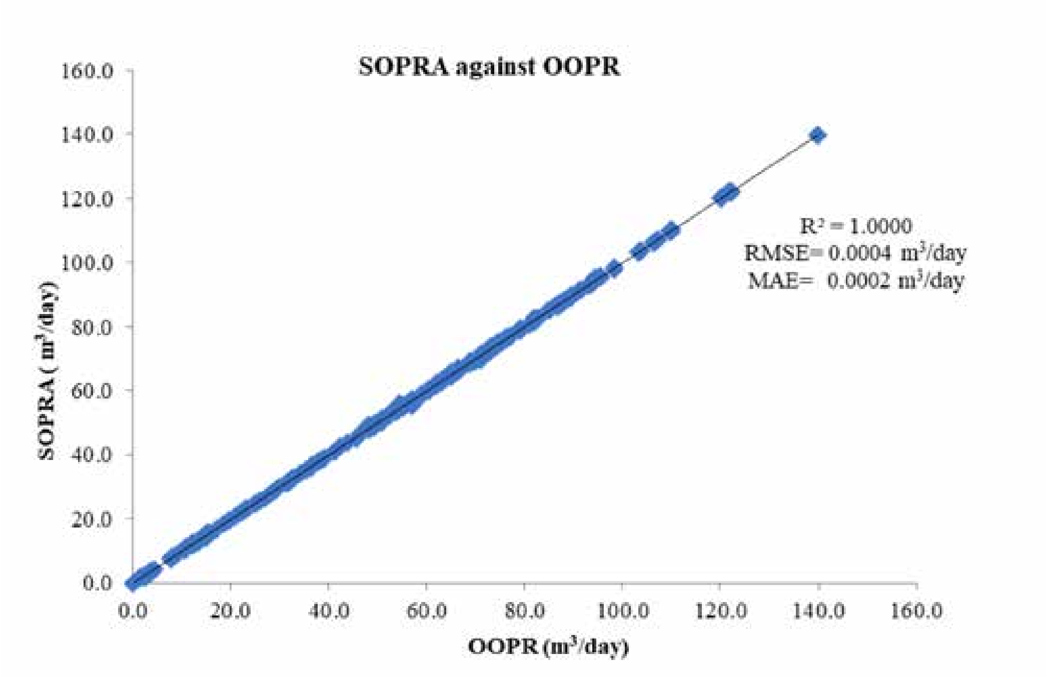
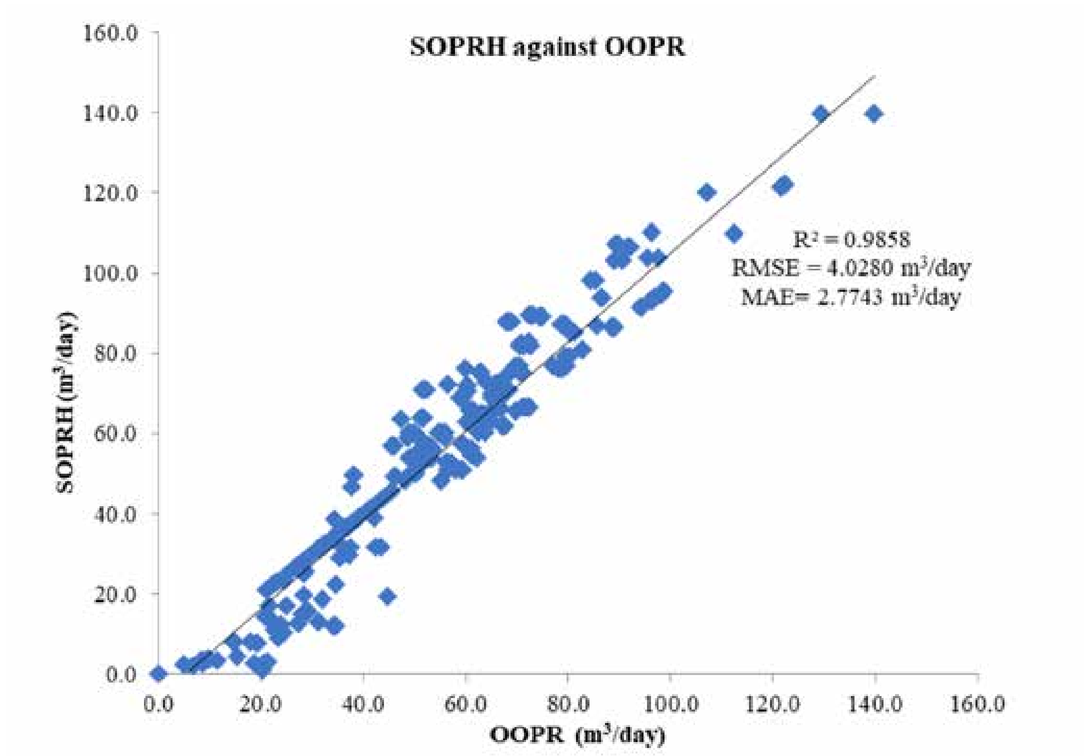


Fig. 9. Comparison of the outputs of the NRS-ANN hybrid and ANN models with Observations datasets

Additionally, a study compared the effectiveness of these models using scatterplots. Fig. 8 (a) and (b) illustrate regression plots showing statistical indicators such as R2 and MAE for comparing the performance of the NRS-ANN hybrid and ANN models in predicting oil production. The results of the NRS-ANN hybrid model SOPRH were compared with the observed oil production rate OOPR, as shown in Fig. 8 (b). A figure shows that SOPRH had R2 and MAE values of 0.9858 and 2.7743 m3/day, respectively. The ANN model in Fig. 8 (a) showed excellent prediction results and achieved a high level of performance with R2 and MAE values of 1.0000 and 0.0002 m3/day, respectively. Based on these findings, it can be examined that the ANN model has perfect prediction performance with %1.46 better fit based on R2 and about 13,871 times higher accuracy in terms of MAE.





(b) Scatter Graph of the Selected Optimal Structure of the NRS-ANN hybrid model

Fig. 10. Scatter plots for NRS-ANN hybrid and ANN models trapping indices R2, RMSE and MAE

In addition, the figures represent a comparison of the RMSE of the NRS-ANN hybrid and ANN model with respect to the observed oil production rate. It is observed that the results of the ANN model SOPRA are in close agreement with the observed oil production rate OOPR, with an RMSE of 0.0004 m3/day compared to 4.0280 m3/day of the NRS-ANN hybrid model. According to this analysis, the ANN model is about 10,070 times more accurate than the NRS-ANN hybrid model in predicting the observed oil production rate based on their RMSE values. The results of the comparative analysis show that the proposed ANN model, which utilizes the four input variables OLPR, OWPR, OWIR and OWCT, is more accurately in predicting oil production performance. Therefore, the proposed ANN model can be considered to be a reliable and valuable tool for predicting the oil production performance in the ZH86 reservoir block under waterflood recovery techniques.

5 Conclusion

A comparative analysis was conducted to evaluate the accuracy of oil production rate forecasts for the ZH86 block during waterflooding using the NRS-ANN hybrid and ANN models. The models were trained, tested and validated. An NRS-ANN hybrid model was developed using four input 314 datasets namely: ELPR, EWPR, EWCT and EWIR, which were derived from the NRS model. In contrast, an ANN model was developed using four observed input 314 datasets including: OWPR, OLPR, OWCT and OWIR, obtained from the ZH86 reservoir block. The OOPR was used as output data for the proposed models. The models were trained, tested and validated using a trial-and-error approach with a maximum of 25 iterations and a fixed number of 1000 epochs. RMSE, R2 and MAE were parameters used to evaluate the performance of the proposed models. The architecture of the models was determined based on the minimum value of the RMSE of the validation dataset. Due to their exceptional estimation capabilities, the study selected the model architectures 1-8-10-4 and 1-10-8-4 for the NRS-ANN and ANN techniques, respectively. The oil production forecast performances of the NRS-ANN hybrid model were compared with those of the ANN model. The results showed that the proposed NRS-ANN hybrid and ANN model achieved R2 and MAE values of 1.000 ,0.9858 and 2.7743 m3/day and 0.0002 m3/day for observed oil production data, respectively. Furthermore, the results indicate that the RMSE for the NRS-ANN hybrid model and the ANN proposed models decreased to values of 2.3900 m3/day and 0.0001 m3/day for the validation datasets, respectively. The results show that the ANN model can make better predictions, with a %1.46 better fit as measured by R2 and approximately 13,871 times higher accuracy as measured by MAE. Furthermore, when comparing their RMSE values, the ANN model is about 10,070 times more accurate than the NRS-ANN hybrid model in predicting oil production rate.

Funding

The Department of Petroleum Engineering at China University of Geosciences (Wuhan), Hubei provided funding for this research, which was sponsored by the China Scholarship Council (CSC). Also the National Natural Science Foundation of China grants no. 41972326 and 51774258.

Declaration of competing interest

The authors affirm that the research conducted in this study was not impacted by any identifiable conflicting financial interests or personal relationships.

Acknowledgements

The authors express their gratitude to Prof Guan Zhen Liang for supplying comprehensive geological and petrophysical data. The authors further acknowledge Prof. Guan for his insightful remarks, which have significantly enhanced this paper.

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Empowering Marine Technology: Ocean Plastic Waste Tracking and Reduction Portal for Ghana

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Abstract

Plastic waste in Ghana presents a significant threat to coastal regions and marine biodiversity, particularly highlighted by the accumulation of debris along beaches and infrastructure, such as the main bridge at the Regional Maritime University during heavy rains. In response, the proposed Ocean Plastic Waste Tracking and Reduction Portal for Ghana (OPWTRP) offers an innovative, web-based solution to track, report, and mitigate marine plastic waste through real-time data collection, geospatial mapping, and community engagement. Leveraging technologies including HTML, CSS, PHP, SQL, Java, and Google Maps, the OPWTRP provides an interactive platform for managing extensive environmental data. Users can report plastic debris by uploading geolocated images, which helps identify pollution hotspots. Integration with environmental sensors such as water quality monitors and satellite data from sources like Sentinel2- enhances the visualization of plastic waste distribution. All data is securely stored in an SQL database to ensure data integrity and accessibility. Predictive analytics utilize historical data, ocean currents, and wind patterns to forecast future plastic accumulation, allowing local authorities to proactively target high-risk areas. This information informs policy decisions and optimizes cleanup scheduling, maximizing resource efficiency.

Effectiveness will be assessed through metrics like reductions in plastic density in targeted zones and increased community involvement in cleanup initiatives. Community engagement is emphasized through coordination with NGOs, volunteers, and local businesses via the Ministry of Sanitation and Water Resources. Educational programs and incentive systems, such as eco-points redeemable at local businesses, will foster ongoing participation. Training local communities in data reporting will instill a sense of ownership in marine conservation efforts. Additionally, partnerships with international campaigns like the United Nations' Clean Seas initiative could extend the portal's reach and impact. Given the reliance on geolocation data and community reporting, robust data security measures—including user consent protocols, data encryption, and anonymized reporting—will be essential to build trust and encourage widespread adoption. Addressing the need for stable internet access, GPS-enabled devices, and training local personnel in data management is critical for the OPWTRP›s successful

implementation and scalability. The OPWTRP represents a scalable model for sustainable marine management, positioning Ghana as a leader in combating ocean plastic pollution in Africa. By integrating technological innovation, community involvement, and data-driven policy, this portal could serve as a benchmark for similar initiatives across the continent, significantly contributing to global marine sustainability efforts.

Keywords: *marine pollution, plastic waste, web portal, geospatial mapping, predictive analytics, google maps, community engagement, Ghana*

1. Introduction

Plastic waste has become one of the most pressing environmental challenges of the 21st century, particularly in developing countries like Ghana, where rapid urbanization and inadequate waste management systems exacerbate the problem. Coastal areas of Ghana are severely impacted by plastic pollution, which poses significant risks to marine biodiversity and local livelihoods. Evidence of this crisis is starkly visible at locations such as the beaches and around key infrastructure like the Regional Maritime University bridge, where plastic debris accumulates during heavy rainfall, spilling into the ocean through lagoons and storm drains.

The critical problem at hand is the lack of an integrated system to monitor, report, and manage plastic waste effectively. Traditional cleanup efforts often fail to address the issue systematically, leading to recurring pollution hotspots. The aim of this article is to propose the Ocean Plastic Waste Tracking and Reduction Portal (OPWTRP) as a potential solution that leverages technology for real-time data collection and community engagement to combat marine plastic pollution in Ghana.

Objectives of the Article:

1. To present the OPWTRP concept as an innovative approach to track, report, and reduce plastic waste in Ghana›s marine environments.
2. To outline the key technologies, methodologies, and data validation techniques proposed for the portal›s development.
3. To address the technical and infrastructural challenges of implementing the portal in underserved coastal communities and propose strategies to overcome these limitations.
4. To highlight the potential for long-term community engagement, stakeholder collaboration, and sustainable funding mechanisms in reducing plastic waste.
5. To propose expanded evaluation metrics that include biodiversity impact, economic benefits, and additional environmental data for a holistic assessment of the portal’s effectiveness.
6. To explore opportunities for scaling the project regionally and integrating it with global efforts to combat marine pollution.
7. To identify potential funding sources, partnerships, and detailed cost estimates for implementing and maintaining the portal, ensuring its financial sustainability and scalability.

Problem Statement

Ghana›s coastline faces a growing threat from plastic waste, which severely harms marine biodiversity and disrupts the livelihoods of communities reliant on fishing and tourism. Coastal areas, including urban hubs like Titanic Beach at the Regional Maritime University, frequently accumulate plastic debris due to inadequate waste management, urban runoff, and storm drainage systems. These challenges are further exacerbated by limited technological infrastructure.

Traditional approaches to waste management and cleanup have proven insufficient to address this issue systematically, resulting in recurring pollution hotspots. This underscores the urgent need for a comprehensive and adaptable platform that integrates real-time monitoring, predictive analytics, and community engagement. Such a system would enable stakeholders to make informed decisions based on reliable data while promoting sustainable practices for managing marine pollution.

3. Literature Review

Marine Plastic Pollution and the Role of Community Engagement

Marine plastic pollution has emerged as a critical environmental crisis, with recent estimates suggesting that approximately 8 million tons of plastic waste enter the world›s oceans annually (Jambeck et al., 2015). This influx is attributed to factors such as increased global plastic production and inadequate waste management practices, particularly in developing countries. Coastal nations like Ghana are disproportionately affected, given their limited waste management infrastructure, rapid urbanization, and increasing plastic consumption (Lebreton et al., 2017). These challenges are further exacerbated by urban runoff during the rainy season, which transports substantial amounts of plastic debris from inland areas to coastal environments (UNEP, 2021).

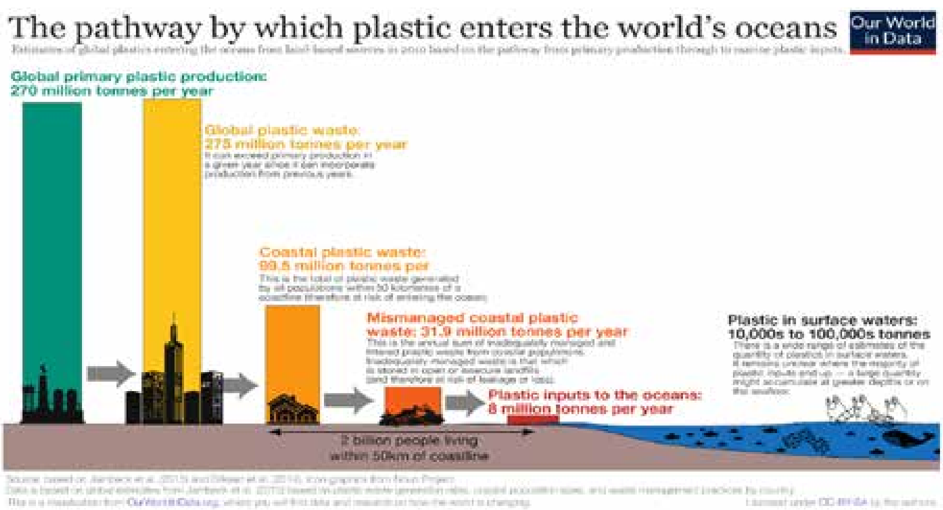

Figure 1: A bar chart showing the impact of plastic on the world›s oceans (source: World Economic Forum).

The Ghanaian Context

In Ghana, the problem of marine plastic pollution is visibly evident in coastal areas, particularly around urban centers and critical infrastructure such as the Regional Maritime University. During heavy rains, plastic waste accumulates along beaches and waterways, underscoring the interplay between urban runoff and ineffective waste disposal practices. Studies have highlighted that rivers and urban drainage systems are significant conduits for plastic waste, contributing to the pollution of the Gulf of Guinea and other marine ecosystems (Jambeck et al., 2015; Lebreton et al., 2017).

Efforts to address this issue are hindered by several factors, including inadequate waste collection systems, limited public awareness, and insufficient government policies. The lack of comprehensive data on plastic waste generation and its distribution further complicates efforts to develop effective mitigation strategies. There is therefore an urgent need for innovative, data-driven solutions that leverage technology and community involvement to tackle the growing plastic waste crisis in Ghana.

The Role of Community Engagement in Plastic Waste Management

Community engagement has been widely recognized as a critical component in addressing marine plastic pollution effectively. Global initiatives have demonstrated that involving local populations in monitoring, data collection, and cleanup efforts leads to more sustainable outcomes (Thompson et al., 2009). For instance, citizen science initiatives have proven effective in enhancing the accuracy and scope of marine debris data collection, providing valuable insights into pollution patterns and informing targeted interventions (Fischer et al., 2019).

One notable example is the Marine Debris Tracker project, which allows individuals to report plastic debris sightings via a mobile app. This initiative has significantly improved the spatial and temporal coverage of marine debris data, demonstrating the potential of citizen science to complement traditional scientific research (Fischer et al., 2019; Jamieson et al., 2019). Similar approaches could be applied in Ghana to empower local communities, particularly in coastal areas, to actively participate in tracking and reducing plastic waste.

Technological Innovations for Plastic Waste Management

Emerging technologies, such as geospatial mapping, environmental sensors, and predictive analytics, offer new opportunities to address marine plastic pollution more effectively. Geospatial mapping tools, such as Google Maps and Sentinel2- satellite data, provide a comprehensive view of plastic waste distribution, enabling stakeholders to identify pollution hotspots and prioritize cleanup efforts (Jamieson et al., 2019). Integrating these tools with environmental sensors, such as water quality and motion detectors, can enhance the accuracy of pollution assessments and provide real-time data on waste accumulation.

Predictive analytics, leveraging historical data on ocean currents, wind patterns, and rainfall, can be used to forecast future plastic waste accumulation, enabling proactive interventions. Such technologies could play a crucial role in the development of the OPWTRP.

The Potential of OPWTRP in Ghana

The OPWTRP aims to bridge the gap between technology and community engagement by providing an interactive platform for reporting plastic debris, visualizing pollution patterns, and coordinating cleanup efforts. By involving local communities, NGOs, and policymakers, the portal seeks to foster a sense of ownership and responsibility for marine conservation. Additionally, the platform›s ability to integrate with international initiatives such as the United Nations' Clean Seas campaign could further enhance its impact and scalability (UNEP, 2021).

However, at the pilot stage, based on the availability of resources, strategic areas in Accra could be tackled first, and then extended later to cover other coastal regions with a similar approach.

4. Technologies and Methodologies

Web Technologies: HTML, CSS, PHP, and Java

The OPWTRP is proposed to be developed using a combination of HTML, CSS, PHP, and Java. These technologies provide the foundation for a robust, responsive, and interactive web application.

- HTML and CSS are utilized to structure and style the user interface, ensuring that the portal is accessible and user-friendly on multiple devices.
- PHP serves as the backend server-side scripting language, handling data collection, processing, and integration with databases.
- Java is intended to enhance interactivity and real-time reporting, integrating external datasets like satellite imagery and sensor data into the platform.

System Overview

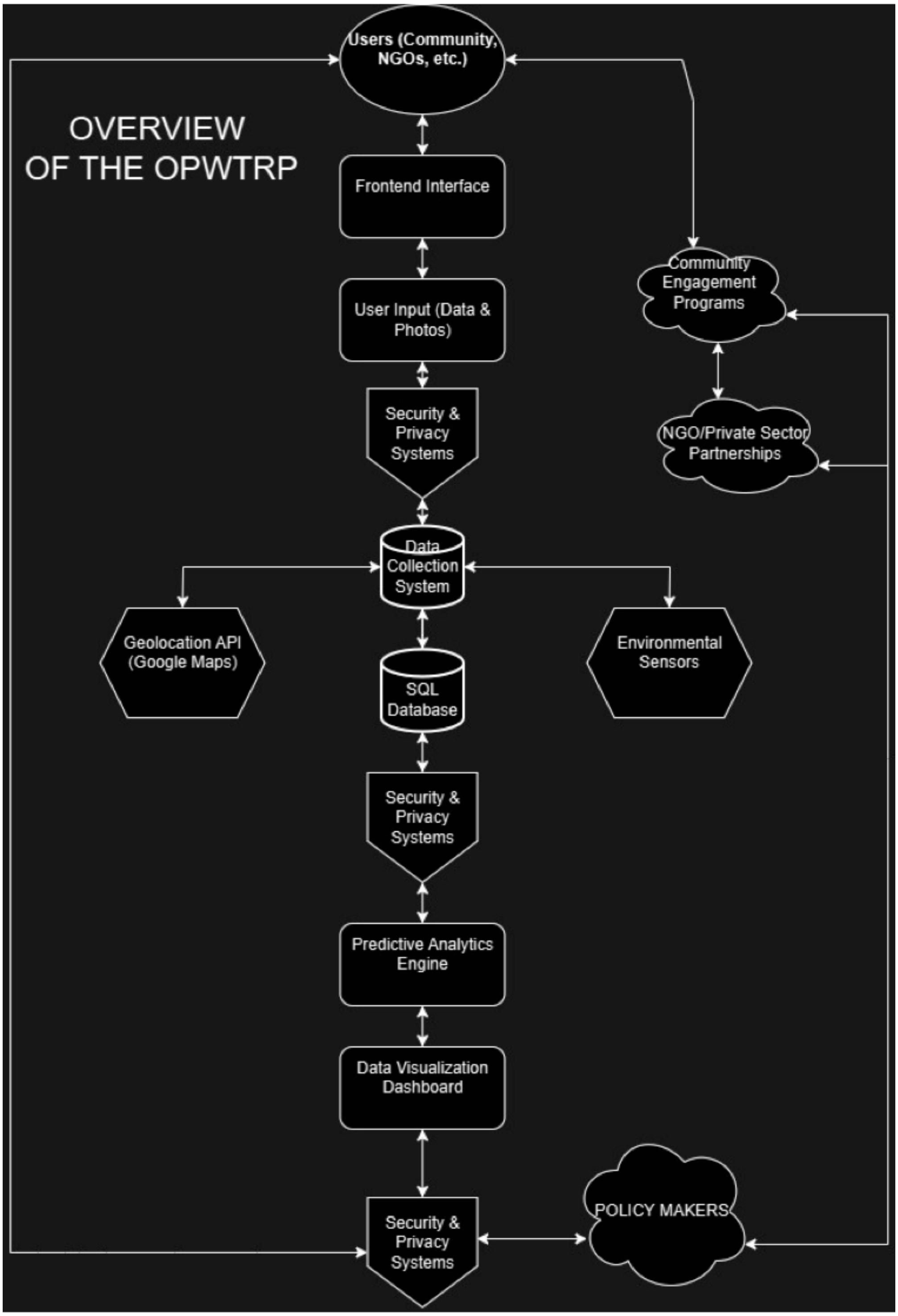

Figure 2: Block diagram showing an overview of the OPWTRP

Google Maps Integration

Google Maps will play a crucial role in visualizing plastic waste distribution. By integrating Google Maps with environmental sensors, such as water quality and motion sensors, users will be able to interact with a real-time map of pollution hotspots. This integration ensures a user-friendly platform that allows stakeholders to zoom into specific areas, monitor changes, and coordinate cleanup efforts efficiently. Google Maps› geospatial capabilities enhance the platform›s ability to provide actionable insights, ensuring accessibility for both communities and policymakers.

Data Collection and Reporting

The portal aims to enable users to report plastic debris they encounter in real time by uploading geolocated photographs. This crowdsourced data would be analyzed and displayed on an interactive map (Google Maps), visualizing pollution hotspots across Ghana›s coastline.

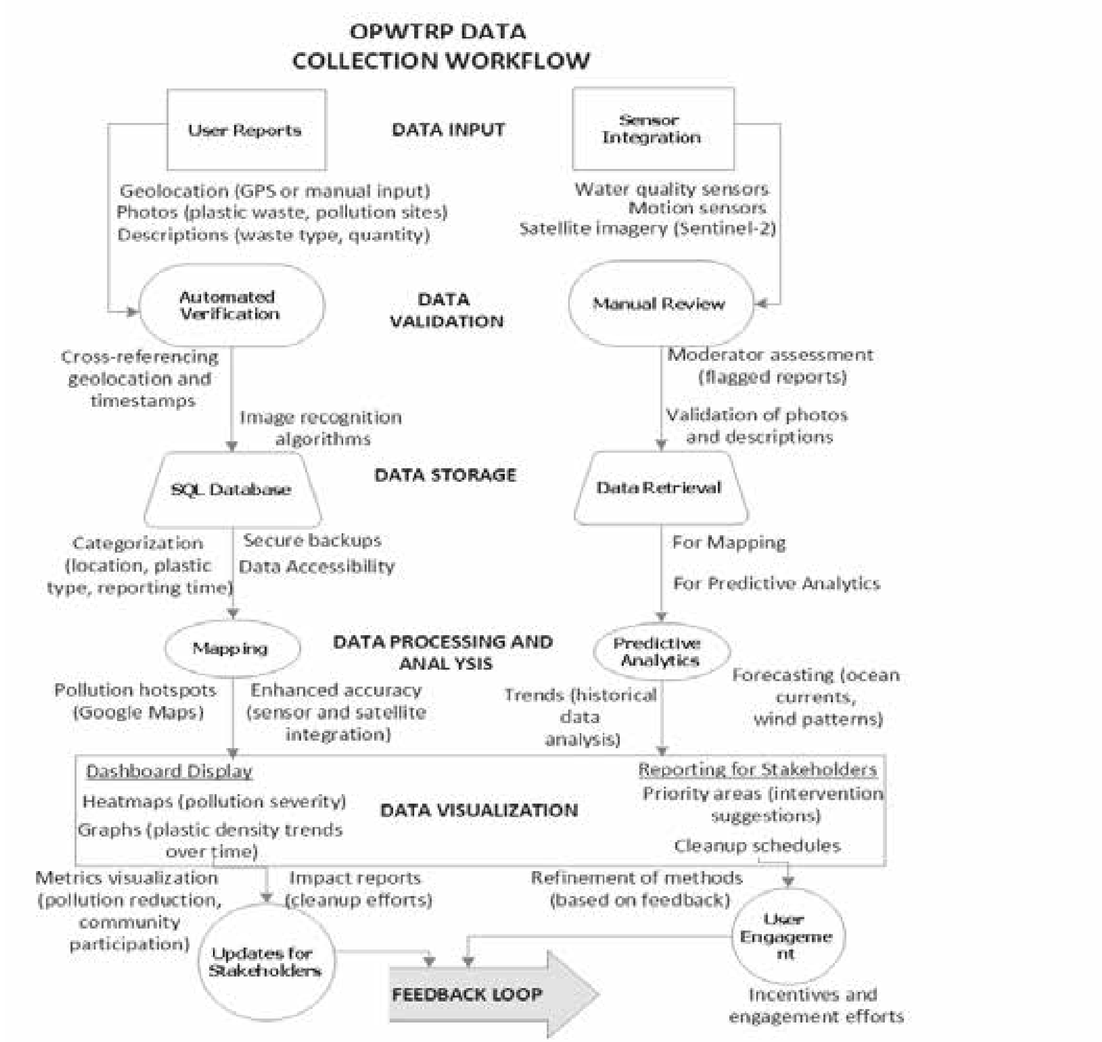

Figure 3: Data Collection Workflow (from user reports to data visualization).

Data Security and Privacy Measures

Given the reliance on user-generated geolocation data, implementing robust data security and privacy measures is essential. The OPWTRP will incorporate consent forms, secure data encryption, and anonymized reporting to protect user privacy and build trust. These measures ensure compliance with data protection laws and foster broader participation, particularly among communities wary of data misuse.

Data Ownership and Transparency Policies

To enhance transparency and foster trust, the project will adopt clear privacy policies on data ownership and usage. All data submitted by users will remain their property, with the portal acting as a steward. Aggregated, anonymized data will be used for analysis, ensuring individual submissions remain confidential. Policies will be published publicly, detailing data storage, sharing, and deletion rights.

Geospatial Mapping and Satellite Integration

Geospatial mapping will form the backbone of the portal's visualization capabilities. By integrating data from marine sensors and satellite imagery, the OPWTRP would provide a comprehensive view of plastic waste distribution (Lebreton et al., 2017).

Predictive Analytics

A key feature of the OPWTRP would be its predictive analytics engine, forecasting future plastic accumulation based on a combination of ocean currents, wind patterns, and historical pollution data (Jamieson et al., 2019).

The predictive analytics feature will not only forecast future plastic accumulation based on ocean currents, wind patterns, and historical pollution data but will also generate actionable insights for local authorities. These insights will highlight high-risk areas, enabling authorities to allocate resources effectively and schedule cleanup operations proactively. For example, predictive models could prioritize interventions in areas with seasonal surges in pollution, optimizing the impact of resource use.

Data Validation Techniques

To ensure data reliability, the OPWTRP will employ robust validation techniques. User-submitted photos will be analyzed using AI for debris type verification. Cross-referencing data from environmental sensors with user submissions will further confirm accuracy. Additionally, community moderators trained in data validation will review submissions to identify inconsistencies or inaccuracies before adding data to the system.

Community and Institutional Engagement and Collaboration

Community participation is envisioned as central to the success of the OPWTRP. The platform would encourage individuals and groups to report plastic waste, participate in cleanup efforts, and engage in educational initiatives aimed at reducing plastic consumption. To ensure sustained participation, the portal could offer incentives like badges for frequent users and social media integration to celebrate local achievements (UNEP, 2021).

In addition, the OPWTRP will incorporate educational programs that train local communities on proper data reporting techniques and the importance of marine sustainability. To further incentivize participation, an eco-points system will be introduced, where users earn points for consistent reporting and cleanup participation.

These points could be redeemed at partner community businesses or NGOs, creating a win-win scenario for economic and environmental growth.

Effective implementation of the Ocean Plastic Waste Tracking and Reduction Portal for Ghana (OPWTRP) will require robust collaboration between local communities, NGOs, academic institutions, and private sector stakeholders. This subsection highlights potential partners and their roles in ensuring the success of the project.

Key Partners and Roles

1. Ministry of Sanitation and Water Resources: The Ministry will assist in ensuring the integration of OPWTRP with national waste management policies and infrastructure. Additionally, the Ministry will be instrumental in facilitating public awareness campaigns and in promoting the involvement of local authorities and stakeholders in the cleanup efforts along the coastline of Ghana.
2. Non-Governmental Organizations (NGOs): Organizations such as Plastic Punch, Environment360, and Green Africa Youth Organization (GAYO) can lead community education, organize clean-ups, and mobilize volunteers. Advocacy groups like the Ghana Youth Environmental Movement (GYEM) could drive awareness campaigns and policy support.
3. Community-Based Groups and Clubs: Rotary Clubs and Beach Management Committees (BMCs) can assist with local clean-up operations and grassroots outreach. Fisherfolk Associations offer insights into pollution impacts and can contribute to reporting marine waste. Environmental clubs in schools and universities can engage youth in reporting and mitigation efforts.
4. Educational and Research Institutions: Institutions like the Regional Maritime University (RMU), Cape Coast Technical University, and University of Ghana can provide technical expertise in data collection, geospatial mapping, and analysis. Collaboration with these universities can also enhance research and training programs.
5. Private Sector Entities: Zoomlion Ghana Limited and the Recyclers Association of Ghana can support waste collection and recycling infrastructure. Partnerships with private companies could offer sponsorships and funding for sustained operations.
6. International Organizations: Agencies such as UNDP Ghana, UNESCO Accra, and USAID-Ghana can provide technical support, funding, and global visibility for the portal.

Collaborative Opportunities

These partnerships will enable:

- Volunteer Mobilization: Leveraging networks for active participation in plastic waste reporting and clean-ups.
- Capacity Building: Training programs for communities on reporting tools and waste management techniques.
- Funding and Infrastructure Support: Engaging private and international stakeholders for financial and logistical resources.

This integrated approach will ensure that the OPWTRP not only tracks and reports plastic waste but also builds a coalition of stakeholders committed to addressing marine pollution in Ghana effectively.

Capacity Building for Local Personnel

Building local capacity is critical for the portal's success. Training programs will focus on developing technical skills in geospatial mapping, database management, and environmental monitoring. Workshops on community engagement strategies, data privacy policies, and reporting standards will also be provided. Collaborations with local universities could offer certification programs, creating a skilled workforce capable of managing the portal and expanding its scope.

Technical and Infrastructural Requirements (Challenges)

For the OPWTRP to succeed, certain technical and infrastructural requirements must be addressed. These include ensuring access to stable internet in coastal areas, equipping community members with GPS-enabled devices for accurate reporting, and providing consistent access to electricity and training programs for local personnel to handle data and manage the platform effectively. Further to addressing these limitations, the project will incorporate offline-first capabilities, allowing data to be stored locally on devices and synced with the server once connectivity is restored. For areas lacking GPS-enabled devices, the portal will include manual location reporting with community mapping exercises to validate submissions. Partnerships with telecom companies can provide subsidized internet access, and low-cost solar-powered devices can be distributed in underserved areas.

Evaluation Metrics

The effectiveness of the OPWTRP will be measured through the following metrics:

1. Pollution Reduction: Tracking changes in plastic density in targeted zones or the decrease in plastic waste observed over time in hotspot areas. Plastic density metrics would involve assessing the amount of waste collected from hotspot areas compared to initial levels.
2. Community Participation: Monitoring engagement levels from local communities in reporting plastic debris and participating in cleanups; monitoring trends in volunteer engagement over time.
3. Cleanup Effectiveness: This can be gauged by tracking the achievements

of goals set for various cleanup exercises. The success rate of the cleanup operations can be recorded, and the data utilized to improve future strategies.

Additional Impact Metrics

In addition to pollution reduction and community engagement, the portal will track impacts on biodiversity and economic benefits. Metrics like species population recovery, improvements in water quality, and increased eco-tourism revenues will provide a comprehensive picture of the platform's success. Regular assessments of these indicators will inform updates and expansions, ensuring alignment with sustainability goals.

Long-Term Maintenance and Funding

Ensuring the portal's long-term maintenance requires a sustainable funding model. The project will establish a combination of government support, private sector sponsorships, and grant funding. Revenue streams such as subscription fees for advanced analytics tools and licensing data for research purposes could also contribute. Additionally, comprehensive routine maintenance could be funded through community-based eco-tourism or local business partnerships to oversee hardware and software updates, ensuring the platform remains operational and relevant.

Potential Partnerships and Expansion

To maximize the impact of the OPWTRP, partnerships with international initiatives like the United Nations' Clean Seas campaign are being explored. These collaborations could enhance data sharing and global awareness of the plastic waste issue in Ghana (UNEP, 2021), including policy changes and public engagement efforts to curb pollution along its coastline and waterways. Leveraging one of the campaign's objectives to partner with businesses and industries to find innovative solutions for plastic reduction and recycling, the project could attract some funding.

Expanded Funding and Partnerships

Beyond the UN Clean Seas campaign, the project will seek funding from private sector entities such as multinational corporations committed to environmental sustainability. Partnerships with eco-conscious brands, crowdfunding campaigns, and local businesses could provide financial and logistical support. International grants from organizations like the Global Environment Facility (GEF) or the World Bank could offer additional resources for scaling the platform.

Scalability and Regional Replication

The OPWTRP's flexible design will ensure scalability and potential replication across Africa. By addressing key technical and infrastructural requirements such as ensuring stable internet connections, GPS-enabled devices, and trained local personnel, the platform can serve as a replicable model for sustainable marine management. As these infrastructures improve, the portal could expand its operations, setting a benchmark for similar initiatives on the continent.

Future Environmental Data Integration

While the portal's primary focus is plastic pollution, its infrastructure will be designed for scalability to include additional environmental data. Future expansions could monitor other marine debris types (e.g., fishing nets), water pollutants (e.g., oil spills, heavy metals), and biodiversity indicators (e.g., species population trends). These features would enhance the platform's utility, positioning it as a comprehensive marine environmental management tool.

Financial and Resource Planning

Resource Allocation

Efficient resource planning will be essential for the OPWTRP to achieve its goals. Resource allocation would focus on:

- Technical Resources: Skilled software developers (a website developing company), Geographic Information System (GIS) experts, and environmental scientists.
- Hardware and Tools: Environmental sensors, GPS-enabled devices, and computer servers (web hosting).
- Human Resources: Community trainers, field coordinators, and platform administrators.
- Community Resources: Engaging local volunteers, NGOs, and stakeholders for data reporting and cleanups.

Cost Analysis and Timeline

Implementing the OPWTRP requires significant investment in technology, training, and community outreach. This includes:

- Development Costs: this is estimated at 52,000$ - 37,000$, and it includes web development (20,000$ - 15,000$), database infrastructure (5,000$ - 3,000$), geospatial mapping and sensors (8,000$ - 5,000$), predictive analytics integration (10,000$ - 8,000$), user interface and experience (4,000$ - 3,000$), testing and deployment (3,000$ - 2,000$), miscellaneous development costs (2,000$ - 1,000$).
- Annual Operational Cost: estimated at 36,000$ - 24,000$, it includes Server Hosting and Cloud Services (3,000$ - 2,000$), System Maintenance and Updates (- 3,000$ 5,000$), Sensor Maintenance and Replacement (3,000$ - 2,000$), Data Collection and Management (6,000$ - 4,000$), Community Engagement and Training (- 3,000$ 5,000$), Staffing Costs (10,000$ - 8,000$), Outreach and Marketing (4,000$ - 2,000$)

The timeline for completion is projected at 24–18 months, covering platform development, pilot testing, and full-scale rollout. Specific milestones will include six-month intervals for initial testing and stakeholder engagement.

Call for Support and Partnerships

The development of the OPWTRP is an ambitious proposal seeking to harness innovative technology to tackle one of the most pressing environmental challenges facing Ghana's coastlines as well as those of many African countries. Collaboration and support from various stakeholders: governmental agencies, international organizations, private sector entities, and NGOs are essential.

4. Conclusion and Future Work

The Ocean Plastic Waste Tracking and Reduction Portal for Ghana (OPWTRP) presents a transformative solution to marine plastic pollution, one of the most pressing environmental challenges facing coastal communities. By leveraging technology, community engagement, and data-driven insights, the portal offers a comprehensive approach to tracking, managing, and reducing plastic waste in Ghana's marine ecosystems. Its interactive mapping, real-time data collection, and predictive analytics empower stakeholders, from local residents and NGOs to researchers and policymakers, to take coordinated action against plastic pollution.

Beyond its immediate impact on reducing plastic waste, OPWTRP has the potential to foster a culture of environmental stewardship, promote sustainable waste management practices, and strengthen collaborations between government agencies, international organizations, and local communities. The portal's scalable design and integration with global initiatives such as the United Nations Clean Seas campaign position it as a model for tackling marine pollution across Africa and beyond.

With sustained support, ongoing community engagement, and strategic partnerships, OPWTRP could contribute significantly to preserving marine biodiversity, enhancing coastal resilience, and promoting a sustainable blue economy in Ghana and Africa at large. It embodies a hopeful vision for the future, one where technology and community action unite to restore and protect our oceans for generations to come.

While the initial focus of OPWTRP is on addressing plastic pollution, the portal›s framework can be expanded to tackle other forms of marine pollutants that threaten Ghana›s coastal and marine ecosystems. Future iterations of the platform could incorporate features to monitor and mitigate marine debris like abandoned fishing gear (ghost nets), shipwreck waste among others.

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LEVERAGING CONSTRUCTION AND MAINTENANCE OF SUBMARINE FIBER CABLES FOR MARINE BIG DATA ANALYTICS: A CASE STUDY OF TANZANIA AND THE GAMBIA

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Abstract

Submarine fiber cables are critical infrastructure enabling global connectivity and fostering digital economies. In East Africa, particularly Tanzania, and West Africa, particularly The Gambia, these cables face shared challenges. This research explores how the construction and maintenance of submarine fiber cables can be leveraged to advance marine big data analytics, providing a pathway to mitigate risks, enhance operational efficiency, and drive economic resilience. Employing a mixed-methods approach, the study examined stakeholder insights, technological readiness, and regulatory frameworks across both nations. Findings highlight the urgent need for clear liability frameworks, collaborative marine insurance policies, and enhanced capacity-building initiatives to address recurring cable damage and operational inefficiencies. The research emphasizes the transformative potential of marine big data analytics in optimizing cable routes, enabling real-time monitoring, and supporting eco-friendly deployment. Collaboration between East Africa and West Africa is proposed as a model for shared learning, resource pooling, and regional standard-setting. The study concludes that stable submarine fiber cables underpin a robust digital marine economy, enabling sustainable growth and improved connectivity. Future research should explore AI-driven predictive maintenance, renewable energy solutions for cable operations, and the socioeconomic impact of big data-enabled marine systems.

Keywords: *Marine Big data analytics, Submarine fiber cable, Digitalization, Marine technological innovation*

1.0 Introduction

Submarine fiber optic cables form the backbone of global telecommunications, transmitting over %99 of international data and providing essential connectivity for financial transactions, internet services, cloud computing, and government communications (International Telecommunication Union [ITU], 2024). Recognizing their importance, global initiatives like the International Cable Protection Committee (ICPC) and ITU have focused on enhancing cable resilience and security against diverse threats (ITU, 2024; ICPC, 2023). In Tanzania and The Gambia, submarine cables serve as critical infrastructure driving digital transformation and economic growth. Tanzania hosts four operational cables namely 2Africa, SEACOM, Eastern Africa Submarine System (EASSy), and Seychelles East Africa System (SEAS) whereas The Gambia currently operates the Africa Coast to Europe (ACE) cable and plans to inaugurate a second cable by 2026 to accommodate growing internet demands (ICPC, 2023; Submarine Telecoms Forum, 2023). Despite their pivotal role, these countries face unique challenges that hinder effective cable construction, maintenance, and resilience against disruptions.

Marine big data analytics, an emerging field leveraging advanced computational techniques to analyze vast datasets from oceanographic sensors, satellite imagery, and cable network performance metrics, offers significant potential to transform cable management. Yet, its integration into submarine cable operations in Tanzania and The Gambia remains limited (Carter & Burnett, 2015). The underutilization of such analytics restricts predictive maintenance, real-time fault detection, and environmental risk assessment, leaving these systems vulnerable to disruptions from fishing activities, anchoring, and geopolitical conflicts (ICPC, 2024; Workshop Report, 2024). Globally, submarine cable networks are susceptible to faults caused by fishing activities, ship anchors, and natural disasters, with fishing and anchoring accounting for approximately %70 of cable damage annually (ICPC, 2023). Recent incidents, such as the 2024 Red Sea cable severance caused by geopolitical conflicts, underscore the vulnerabilities and far-reaching economic impacts of cable disruptions (ICPC-UNEP Report, 2019). In response, industry best practices recommend spatial separation, armoring, and automated identification systems to mitigate risks (ICPC, 2024). However, implementing these measures in regions like Tanzania and The Gambia demands localized strategies that balance global recommendations with regional constraints.

This research aims to explore how the construction and maintenance of submarine fiber cables can optimize the marine big data analytics in Tanzania and The Gambia, addressing the shared challenges of environmental risks, operational inefficiencies, and limited resources. Through adopting predictive analytics and integrating international best practices, the study seeks to enhance the sustainability and resilience of these critical infrastructures, ensuring uninterrupted digital connectivity and economic development in the region.

2.0 Methodology

This research was conducted within the contexts of Tanzania and The Gambia, two African nations reliant on submarine fiber cables as foundational infrastructure for digital connectivity and economic development (ITU, 2024). With Tanzania almost %99 connectivity depending on submarine fiber cables (TCRA, 2024) this is study is vital for development of all sectors within a country including Maritime industry. The study sought to investigate how leveraging the construction and maintenance processes of submarine fiber cables can advance the adoption and utility of marine big data analytics in these countries. This perspective emphasizes optimizing existing cable infrastructures to generate, process, and analyze large-scale marine data for enhanced technological, environmental, and economic outcomes. The research adopted a mixed-methods design, integrating both qualitative and quantitative approaches to achieve a comprehensive understanding of the intersection between submarine cable operations and marine big data analytics. This methodological triangulation facilitated the validation of findings and ensured the inclusion of diverse perspectives from key stakeholders in the submarine cable ecosystem.

The target population included stakeholders critical to submarine cable management: government policymakers, private sector leaders from telecommunications firms (Seacom, TTCL, and members of the Tanzania Internet Service Providers Association [TISPA]), regulatory bodies such as the Tanzania Communications Regulatory Authority (TCRA), environmental experts, and technical specialists involved in submarine cable construction, maintenance, and data analytics. A total of 50 participants were identified across Tanzania and The Gambia to provide regionally specific insights. A purposive sampling strategy was employed to ensure the inclusion of individuals with specialized expertise relevant to submarine cable management and big data integration. This approach maximized the depth and relevance of the data collected while ensuring representation across critical sectors.

The study focused on key variables, including the state of submarine cable infrastructure and construction practices, operational challenges, Stakeholder readiness to integrate marine big data analytics into cable management processes and the potential opportunities for data generation and analysis through enhanced cable operations. Data collection proceeded in two phases Quantitative Phase and Qualitative Phase. Structured questionnaires were distributed to stakeholders to capture metrics related to the current state of submarine cables, challenges in their construction and maintenance, and perceived opportunities for big data analytics integration. In-depth interviews and focus group discussions were conducted to elicit nuanced insights into stakeholder perspectives, organizational readiness, and potential barriers to the integration of big data solutions.

The Technology Acceptance Model (TAM) provided the theoretical lens to evaluate stakeholders' willingness to embrace innovations in marine big data analytics. This model helped assess perceived usefulness, ease of use, and readiness for adopting analytics tools within the submarine cable ecosystem. Quantitative data were analyzed using descriptive statistics to identify patterns, trends, and correlations, employing statistical software such as SPSS. Qualitative data from interviews and discussions were analyzed using thematic analysis, leveraging NVivo software to identify recurring themes and subthemes. This dual analytical approach ensured comprehensive insights and the triangulation of data. The methodology aimed to produce actionable insights on how construction and maintenance activities of submarine cables can be optimized to support and drive marine big data analytics in Tanzania and The Gambia. The findings are expected to inform policy frameworks, enhance operational practices, and enable sustainable management of submarine cable infrastructure while unlocking the potential of big data applications in marine ecosystems.

3.0 Results and findings

3.1 Participant Demographics

The participant pool reflected a diverse spectrum of stakeholders involved in submarine cable infrastructure and marine analytics. Government officials constituted %30 of respondents, representing policymakers and regulatory authorities. Private sector stakeholders, including telecommunications operators such as SEACOM and TTCL, and internet service providers, accounted for %40 of the sample. Researchers and academics from maritime and IT fields formed %20, while the remaining %10 comprised end-users, such as members of internet advocacy groups. Geographically, %60 of participants were from Tanzania, reflecting its broader submarine cable network, while %40 were from The Gambia. Participants were aged between 30 and 55, holding advanced degrees and professional experience ranging from 5 to over 20 years.

3.2 Key Findings from Technology Acceptance Model (TAM) Analysis

The Technology Acceptance Model (TAM) framework was instrumental in assessing stakeholder readiness to integrate marine big data analytics into submarine cable construction and maintenance processes. This section elaborates on stakeholders' perspectives concerning perceived usefulness, ease of use, and behavioral intention toward technology adoption.

3.2.1 Perceived Usefulness

Stakeholders unanimously acknowledged the value of leveraging construction and maintenance practices for marine big data analytics. The integration was widely regarded as a means to enhance predictive maintenance, improve fault detection, and optimize resource allocation. One government official stated,

"Big data can help us anticipate issues before they become crises, significantly reducing the costs and disruptions associated with cable repairs."

This view aligns with Bashir and Gill (2018), who identified predictive maintenance and real-time fault detection as transformative benefits of big data in telecommunications infrastructure.
Private sector representatives emphasized the role of real-time monitoring enabled by big data analytics. A telecommunications executive noted,

"Using data to monitor cable conditions and environmental impacts in real-time would revolutionize how we ensure the resilience of this infrastructure."

This observation is consistent with the findings of Kordahi et al. (2017), who underscored the importance of advanced analytics in minimizing outages caused by environmental and human activities.

3.2.2 Perceived Ease of Use

While stakeholders recognized the potential benefits, challenges in implementation were highlighted, particularly concerning technical expertise and infrastructure readiness. Academic respondents noted that

"the tools for big data analytics need to be intuitive and supported by robust training programs to ensure their widespread adoption."

Perera et al. (2020) similarly emphasized that ease of use significantly impacts the adoption rate of data-driven solutions in marine and telecommunications sectors.

3.2.3 Behavioral Intention

The findings revealed strong stakeholder intent to adopt big data analytics if supported by appropriate investments in capacity building and policy frameworks. A respondent from the Tanzania Internet Service Providers Association remarked,

"If stakeholders, particularly at the Tanzania Communications Regulatory Authority (TCRA), prioritize investments in analytics tools, we will see an industry-wide shift toward proactive management strategies."

3.2.4 Alignment with Broader Trends

The results resonate with industry-wide initiatives, such as those advocated by the International Cable Protection Committee (ICPC, 2023), which highlight the critical role of advanced analytics in enhancing the robustness of global submarine cable networks. Additionally, Drew et al. (2021) noted that integrating marine analytics into infrastructure projects provides operational insights that reduce risks and improve efficiency. These perspectives affirm the growing recognition of analytics as a cornerstone for resilient and sustainable cable systems.

3.2.5 Capacity Building and Technical Expertise

The importance of tailored capacity-building initiatives was another recurring theme. Respondents highlighted the critical need for local technical expertise to manage data analytics systems effectively and ensure their long-term sustainability. Investments in technical training programs, particularly in developing regions, are essential to fostering a workforce skilled in managing data infrastructure and marine technologies. These efforts reduce dependency on external expertise and enhance regional autonomy.

A recurring theme was the lack of local technical expertise. Participants expressed concerns about over-reliance on external experts for cable repairs and advanced technology integration. This corroborates findings by Perera et al. (2020), who stress the importance of building a skilled local workforce capable of managing complex submarine cable systems and leveraging them for big data applications. Regulatory issues were also raised, with respondents citing outdated frameworks that fail to accommodate emerging technological advancements. The International Cable Protection Committee (ICPC, 2023) has similarly called for more streamlined and forward-looking policies to address these gaps.

3.3 Findings from Questionnaire Responses

3.3.1 Facilitating Conditions

The creation of a supportive ecosystem is essential for leveraging construction and maintenance activities of submarine fiber cables to drive marine big data analytics. Participants across Tanzania and The Gambia consistently emphasized enabling conditions, such as access to funding, capacity-building initiatives, and the establishment of robust policy frameworks. A respondent from Tanzania underscored this need, stating,

"Collaboration between government, academia, and the private sector is crucial to building the infrastructure and expertise needed to integrate big data analytics effectively."

This sentiment reflects the growing consensus in research that deploying big data analytics in the marine sector requires not only technological advancements but also coordinated multi-stakeholder efforts (Drew et al., 2021).

3.3.2 Collaboration across Stakeholders

Governments, academia, and private enterprises each have distinct but complementary roles in enabling big data analytics integration. Governments are pivotal in crafting supportive policies, allocating funding for innovation, and incentivizing private sector participation (ICPC, 2023). Academia can contribute through technical research and workforce training programs tailored to the complexities of submarine cable operations. Meanwhile, private companies offer practical insights and implementation expertise, bridging the gap between policy and practice. A marine expert from The Gambia remarked, "Academia must develop specialized programs to train a workforce skilled in both marine technology and analytics. This will reduce reliance on foreign expertise and create local technical capacity."

This aligns with Perera et al. (2020), who advocate for technical training programs that address challenges such as environmental variability, data integration, and maintenance complexities.

3.3.4 Need for Funding, External support and Capacity Building Gap

Access to funding emerged as a significant enabler of big data analytics deployment. Participants in The Gambia underscored the need for external support and capacity building to bridge the knowledge and skill gaps. According to Drew et al. (2021), such gaps are particularly pronounced in developing regions where access to training resources and technical expertise is limited. The researchers argue that the successful adoption of big data systems requires a robust framework for continuous education and technical training, tailored to the unique needs of the submarine cable industry. The ICPC (2023) recommends collaborative funding models that pool resources from governments, private operators, and global organizations to ensure sustainable implementation. A respondent working in Tanzania highlighted the importance of external partnerships, stating,

"Development agencies and international organizations must step in to bridge the funding gaps, ensuring that essential infrastructure for big data analytics becomes a reality in resource-constrained environments."

The need for external support, as emphasized by participants from The Gambia, is also supported by the findings of the International Cable Protection Committee (ICPC, 2023), which advocates for collaborative initiatives to share expertise and resources. Their report highlights the importance of regional partnerships and the role of international organizations in providing technical assistance to countries with limited in-house capacity. Respondents stressed the financial demands associated with advanced analytics systems, including investments in hardware, software, and skilled human resources. Bashir and Gill (2018) noted that international partnerships and development agency contributions are often crucial for regions like Tanzania and The Gambia.

3.3.5 Policy and Regulatory Frameworks

Robust policy frameworks are critical for ensuring the effective adoption of big data analytics in submarine cable management. Clear regulations that standardize data collection, processing, and sharing practices among stakeholders are essential. According to Kordahi et al. (2017), such policies also address critical concerns related to data privacy, cybersecurity, and cross-border data sharing, which are particularly relevant given the global scope of submarine cable systems.

A participant from The Gambia emphasized the importance of regulatory clarity, noting, "Without well-defined policies, there is a risk of fragmented approaches to data management, which could undermine the benefits of analytics integration."

Facilitating conditions such as funding, capacity building, and supportive policies are indispensable for leveraging the construction and maintenance of submarine fiber cables to enable marine big data analytics. These efforts not only address immediate operational challenges but also lay the foundation for long-term technological and economic advancements in Tanzania and The Gambia.

3.4 Findings from Interview

3.4.1 Challenges in Submarine Cable Management

The findings revealed several persistent challenges affecting the construction and maintenance of submarine fiber cables, which have implications for their potential to support marine big data analytics. Respondents frequently highlighted the physical risks posed by human activities, such as fishing and ship anchoring, which remain primary causes of cable damage. These observations align with Drew et al. (2021), who identified shallow water zones as particularly vulnerable despite advancements in cable armoring and burial technologies. A stakeholder in Tanzania remarked,

"Shallow areas are especially risky, and damage here disrupts not just connectivity but also analytics potential tied to real-time monitoring systems."

Both Tanzania and The Gambia struggle to secure adequate funding for consistent maintenance, upgrades, and timely repairs of submarine cables. According to Bashir and Gill (2018), the high costs of cable infrastructure maintenance place a disproportionate burden on developing economies, often leading to operational inefficiencies. Respondents emphasized the need for international partnerships and development agency support to bridge funding gaps.

3.4.2 Perceptions of Technology Integration

The level of technology integration into the construction and maintenance of submarine cables varied significantly across respondents. While some noted progress in adopting digital tools, many highlighted an ongoing reliance on manual processes. A telecommunications manager in The Gambia noted,

"We have made progress, but we still rely heavily on manual processes and external support."

This finding is consistent with Drew et al. (2021), who observed that operators in developing countries face barriers to implementing advanced technologies, including cost and technical constraints. Despite challenges, there was a consensus on the value of adopting modern maintenance and monitoring technologies. Perera et al. (2020)

argue that remote monitoring systems and predictive analytics are particularly valuable for improving operational efficiency and reducing response times during emergencies. However, respondents emphasized that realizing these benefits in Tanzania and The Gambia will require targeted investments in infrastructure and training.

3.4.3 Role of Marine Big Data Analytics

There was broad recognition among respondents of the transformative potential of marine big data analytics in enhancing the construction and maintenance of submarine cables. Common themes included route optimization, where big data can analyze environmental and maritime activity patterns to identify the safest and most efficient cable paths. This application mirrors findings by Bashir and Gill (2018), who highlighted big data›s utility in reducing risks during cable planning and installation. A Gambian participant remarked, "With big data, we could identify better routes that minimize risks and reduce future maintenance costs."

Another key theme was the value of real-time monitoring, where big data analytics combined with sensor technology enables operators to detect faults early and proactively mitigate risks. Drew et al. (2021) argue that such capabilities significantly lower repair costs and minimize disruptions. Respondents also emphasized the role of big data in environmental assessments. By mapping sensitive marine ecosystems, analytics can guide eco-friendly cable deployment and maintenance strategies. Kordahi et al. (2017) support this perspective, noting that integrating environmental data reduces ecological impacts while ensuring operational efficiency.

3.5 Finding from Various National and International Reports

3.5.1 Subgroup Analysis

The subgroup analysis highlighted critical differences between Tanzania and The Gambia regarding their capacity to leverage submarine cable construction and maintenance for advancing marine big data analytics. Tanzania demonstrated a comparatively higher readiness due to its larger submarine cable network, which includes systems such as SEACOM, 2Africa, and EASSy, and a more developed information and communication technology (ICT) sector due to implementation of The Electronic and Postal Communications (EPOCA) national regulations. This reflects the nation's greater capacity for integrating marine big data analytics into cable operations, supported by a relatively robust technological ecosystem and skilled workforce (Perera et al., 2020).

Conversely, The Gambia faced more pronounced challenges due to its smaller cable network, which is currently limited to the Africa Coast to Europe (ACE) cable, and a higher dependency on external expertise for maintenance and technological integration. These challenges underscore the need for targeted investments in infrastructure and capacity-building programs to enhance The Gambia's operational resilience and analytic capabilities (Bashir & Gill, 2018). Both countries have ratified and implement various national regulations including Submarine Cable Regulation (UN,2014) and the International Ship and Port Facility Security Code (ISPS Code).

3.5.2 Connectivity between Submarine Fiber Cables and the Shipping Industry

The cable cut incidents analysis also revealed the interdependence between submarine fiber cables and the shipping industry, particularly regarding maintenance, risk management, and the potential for data integration. Shipping routes are often proximate to submarine cable corridors, raising risks of damage from anchoring and maritime traffic. Reports showing various incidents of cable cuts emphasized the need for enhanced coordination between the cable and shipping industries. Improved collaboration with the shipping sector will help mitigate risks and support shared data systems for monitoring maritime activities. This aligns with findings by Kordahi et al. (2017), who highlight the role of marine spatial planning in reducing operational conflicts.

Marine big data analytics could serve as a bridge between these sectors by providing real-time data on ship movements and environmental conditions. For instance, analytics could optimize cable routes to avoid high-risk shipping zones while also informing maritime operations about cable locations to prevent accidental damage. Drew et al. (2021) suggest that integrating sensor networks with marine big data platforms could enable predictive maintenance and enhance risk mitigation for both industries.

3.5.3 Prolonged Legal Battles, Liability and Blame in Cable-Cutting Incidents

One of the recurring issues identified in the management of submarine fiber cables is the ambiguity surrounding liability when cable cuts occur due to ship anchorage. This lack of clarity often leads to protracted legal disputes between telecommunications companies, shipping operators, and their respective insurance providers. The C-Lion1 incident in the Baltic Sea provides a prime example of this challenge, where the liability for a submarine cable cut due to vessel anchoring remains unresolved, creating operational and financial setbacks for all parties involved (Lieber Institute West Point, 2023).

Submarine cable cuts are caused by accidental anchoring or negligence on the part of vessels traversing routes near cable systems. In these scenarios, telecommunications companies typically hold the shipowners responsible for damages, while shipping companies argue that the cables were not properly charted or that the incident occurred in an unregulated zone. This blame-shifting is exacerbated by gaps in marine insurance policies, which rarely specify coverage for such incidents. Also a respondent from Tanzania commented,

"When a cable cut occurs, we often face delays because no party wants to assume responsibility everyone shifts the blame."

Protracted legal disputes following cable-cut incidents impose significant economic costs. These include operational downtime, repair expenses, and reputational damage for telecommunications providers, as well as higher insurance premiums for shipping companies. The C-Lion1 case demonstrated how such disputes could create geopolitical and economic tensions, with shipping companies and telecommunication providers locked in protracted legal battles due to unclear jurisdictional and liability frameworks (Lieber Institute West Point, 2023).

Current insurance structures also fail to provide clarity. Third-party insurers for both the vessel and the cable often dispute the extent of their liability. According to ICPC reports, the lack of explicit marine insurance coverage for cable damage caused by ship anchorage leaves both sectors in a precarious position, requiring expensive legal recourse to settle disputes (ICPC, 2023).

3.5.4 The Need for a New Insurance Framework

There is a growing consensus on the necessity for a specialized marine insurance policy tailored to address cable damage caused by ship anchorage. Such a policy would define clear liability parameters for cable operators, ship owners, and third-party insurers, reducing the likelihood of protracted disputes. A standardized marine insurance policy that covers anchor-related cable damage could streamline resolution processes and improve accountability. Industry stakeholders, such as the International Cable Protection Committee (ICPC), have advocated for regulatory reforms to bridge this gap. Recommendations include mandating vessel owners to obtain specialized insurance that explicitly covers damage to submarine cables, as well as requiring telecommunications companies to collaborate with maritime agencies to ensure cable routes are clearly mapped and well-communicated (ICPC, 2023).

The recurring blame game in cable-cut incidents underscores the urgent need for regulatory clarity and new insurance frameworks. The legal ambiguity surrounding liability between telecommunications companies, shipping operators, and insurers not only escalates disputes but also delays repairs, causing significant economic and operational disruptions. Drawing lessons from incidents such as C-Lion1, stakeholders must collaborate to establish clear liability standards and implement specialized marine insurance to cover cable damage caused by anchoring. This approach would foster accountability, expedite resolution processes, and ensure the resilience of submarine cable systems globally.

3.5.5 Submarine cable cuts and Environmental Impacts

Submarine cable cuts often require repair operations that disturb the seabed, potentially affecting benthic organisms and habitats. During cable recovery or reburial, sediment is displaced, which can alter the local seabed structure and turbidity, impacting marine life such as corals, sponges, and other bottom-dwelling organisms (UNEP-WCMC & ICPC, 2019). These disturbances are generally temporary but can have long-term effects in sensitive ecosystems. Repair operations, involving cable ships and remotely operated vehicles (ROVs), may interfere with marine mammals by creating underwater noise pollution. This noise can disrupt the communication and navigation of species such as whales and dolphins (Kordahi et al., 2017).

During cable repairs and construction, the resusspension of sediments can increase water turbidity, potentially affecting photosynthetic organisms and filter feeders in the vicinity (Halpern et al., 2018). Interestingly, cables themselves can act as artificial habitats for marine life, providing surfaces for colonization by species such as barnacles and corals (Drew et al., 2021). However, when cables are cut and exposed, the disruption to this habitat could displace these organisms. While the overall environmental footprint of submarine cables is generally considered small compared to other marine activities, repair operations and cable cuts can have localized effects on marine ecosystems. Effective marine spatial planning and the adoption of eco-friendly repair technologies can help mitigate these impacts (UNEP-WCMC & ICPC, 2019).

4.0 Recommendations

4.1 Establish Clear Liability Frameworks for Cable-Cutting Incidents: The ambiguity surrounding liability for submarine cable cuts caused by ship anchorage demands immediate regulatory action. Governments and international organizations must develop and enforce clear liability frameworks that outline the responsibilities of telecommunications companies, shipping operators, and third-party insurers. These frameworks should define specific scenarios of liability, ensuring accountability and reducing the occurrence of protracted legal battles. Standardized agreements, such as those recommended by the International Cable Protection Committee (ICPC), can streamline dispute resolution processes and provide a baseline for cross-border collaborations.

4.2 Develop Specialized Marine Insurance Policies: To mitigate the financial and operational risks associated with cable-cut incidents, the development of specialized marine insurance policies is crucial. These policies should explicitly cover damage to submarine cables caused by ship anchorage, providing clarity on the extent of coverage for all stakeholders. Governments and marine insurance providers should collaborate to design and mandate such policies, ensuring that both vessel owners and telecommunications operators are adequately protected. Implementing this recommendation would reduce the economic burden on individual stakeholders and expedite the repair process after incidents.

4.3 Enhance Marine Spatial Planning and Awareness Programs: To prevent cable damage caused by anchoring, governments and industry stakeholders should invest in marine spatial planning tools and awareness campaigns targeting the shipping industry. Submarine cable routes must be clearly charted and communicated to vessel operators, with mandatory inclusion in nautical charts and real-time geospatial systems such as Automatic Identification Systems (AIS). Awareness programs, coupled with robust monitoring, will enable ships to navigate safely and avoid areas with high cable density.

4.4 Strengthen Collaboration Among Stakeholders: Effective collaboration between the telecommunications and shipping industries is essential for reducing cable-cut incidents. Stakeholders must establish formal communication channels and joint task forces to coordinate activities. For instance, telecommunications companies can partner with shipping operators to share data on cable locations, maintenance schedules, and potential risk zones. Maritime authorities can serve as mediators, fostering cooperation and ensuring that both sectors work towards shared goals of safety and operational efficiency. With expected increase in submarine fiber cables from four to six in Tanzania between 20230 -2024, it is crucial for TCRA and TASAC to form a collaborative platform to work together on associated challenges.

4.5 Build Technical Capacity in Developing Regions: Developing countries such as Tanzania and The Gambia must prioritize building local technical expertise to manage cable maintenance and the integration of marine big data analytics. Capacity-building initiatives, supported by international development agencies, should focus on training programs that equip local professionals with the skills needed for cable repair, monitoring, and analytics integration. This investment would reduce reliance on external experts and strengthen the operational resilience of submarine cable systems.

4.6 Promote the Integration of Marine Big Data Analytics: Marine big data analytics must be fully integrated into cable construction and maintenance processes to enhance risk management and operational efficiency. Telecommunications operators should adopt advanced tools, such as predictive analytics and real-time monitoring systems, to identify potential risks proactively. These tools can optimize cable routes, reduce repair costs, and minimize disruptions caused by anchoring or environmental factors. Governments and private stakeholders should co-invest in infrastructure that supports data collection and analysis to enable these capabilities.

4.7 Advocate for International Regulatory Standards: Given the global nature of submarine cable networks, international regulatory bodies must prioritize the establishment of standardized policies for cable protection. A unified legal framework under organizations such as the United Nations or the International Maritime Organization (IMO) would ensure consistency across jurisdictions, addressing gaps in liability and insurance coverage. Such standards would facilitate seamless collaboration between countries and safeguard critical global connectivity infrastructure.

5.0 Conclusion

The findings of this research underscore the critical need for clarity in liability frameworks, enhanced collaboration, and innovative solutions to address the challenges associated with submarine cable construction and maintenance. Tanzania and The Gambia, as representatives of East and West Africa, face shared obstacles, including limited resources, technical expertise, and regulatory gaps. However, these challenges present an opportunity for both nations to collaborate strategically and set a benchmark for addressing global issues surrounding submarine cable stability and marine big data analytics.

Through working together, Tanzania and The Gambia can share resources, technical knowledge, and best practices, creating a model for other developing regions. Joint initiatives could include harmonizing regulatory frameworks to establish clear accountability in cable-cut incidents, co-developing specialized insurance policies tailored to their shared needs, and building regional capacity through targeted training programs. The stability of submarine fiber cables is integral to building a robust digital marine economy in both regions. Reliable cable infrastructure underpins uninterrupted connectivity, supports maritime operations, and enhances economic resilience through data-driven decision-making. Marine big data management, enabled by stable submarine cables, can revolutionize industries such as shipping, environmental monitoring, and resource management, driving sustainable growth across Africa.

Future research should focus on creating predictive models for cable risk management, exploring the potential of artificial intelligence in cable monitoring, and assessing the economic impact of stable submarine cable systems on regional development. Additionally, studies on the integration of renewable energy solutions into cable maintenance operations could offer sustainable and cost-effective approaches. Through championing innovative solutions, Tanzania and The Gambia can position themselves as leaders in submarine cable management, providing a roadmap for global best practices. This collaboration has the potential to set a new standard, ensuring the resilience of critical infrastructure, driving the digital marine economy, and safeguarding the future of global connectivity.

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7.0 Acknowledgement

Our sincere appreciation goes to the Ministry of Communications and Digital Economy, The Gambia, the Ministry of Information Technology and Communication, Tanzania, and the Department of Science and Management, Dar es Salaam Maritime Institute, Tanzania, for their invaluable guidance and access to critical data on regional submarine cable infrastructure. Their contributions greatly enriched this study.

We are thankful to the International Cable Protection Committee (ICPC), the International Telecommunication Union (ITU), and SubTel Forum for their comprehensive resources and reports, which provided essential background and context for our work. Special thanks to telecommunications stakeholders, including SEACOM, TCRA, TTCL, Airtel Tanzania, Vodacom Tanzania, and Yas, as well as other licensed operators in Tanzania and The Gambia, for their active participation in stakeholder discussions and for sharing their operational insights.

We are deeply grateful to the participants of the questionnaires and interviews including government policymakers, private sector leaders, academic researchers, and technical experts whose perspectives shaped the study's findings.

Finally, we extend heartfelt thanks to our colleagues at the Dar es Salaam Maritime Institute and the academic community for their constructive feedback and encouragement throughout this project. While their support was invaluable, the interpretations and conclusions of this study remain solely the responsibility of the authors.

ASSESSING THE INTEGRATION OF SUSTAINABLE DEVELOPMENT IN THE MARITIME EDUCATION AND TRAINING: A CASE STUDY OF DMI

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ABSTRACT

The marine industry is paying more and more attention to sustainable development (SD). It was discovered that the growing corpus of research on sustainable development in the marine industry is mostly focused on the sustainability of the maritime environment and, more precisely, on maritime decarbonization, which is mainly concerned with global maritime transport and carbon dioxide emissions. As a result, there is still a gap in the body of knowledge about maritime education and sustainable development, suggesting that insufficient attention has been paid to the SD notion and its implications for Maritime Education and Training. The aim of this research work was to assess how sustainable development is currently integrated into maritime education and training in the institution. This involved using an SD model with the variables: curriculum, research, industrial engagement, and SD policy and governance to evaluate how well SD was integrated into Maritime education and training. The study is qualitative and will use face-to-face interviews and personally administered survey questionnaires with open ended responses. The paper ends with giving conclusion and recommendations that DMI should introduce SD policy strategically and structuring procedures to promote it, their curriculum should per se incorporate and equate SD into their courses and having a priority in researches considering SD together with expanding cooperation with others in the maritime field as advised by UN to foster the SDGs ultimately promoting a more sustainable future for the maritime industry in Tanzania.

Keywords: *Sustainability, Maritime Education and Training, Curriculum Assessment, SD model*

12. INTRODUCTION

BACKGROUND AND STATEMENT OF THE PROBLEM

Manuel & Prylipko (2019) urged that the United Nations (UN) has long concentrated its efforts on sustainable development through the UN Sustainable Development Goals (SDGs), and the concept of sustainable development (SD) has grown in popularity throughout time, as seen by plenty of literature on sustainability.

This study is therefore in line with Goal 4 of the SDGs, which is to provide high-quality education. In the marine industry, sustainability is gaining more and more attention. According to some literature, sustainability in this industry has evolved from a trendy term to a problem that requires immediate response.

Again, Koustoumpardis (2019) stated that it is important to note that within the maritime sector, the growing body of research on sustainable development is based on maritime decarbonization, which is mainly focused on international maritime transport and CO2 emissions .The author also makes the case that more study is being done on environmental sustainability measures and how to evaluate them, as well as how required laws and regulations affect business operations and performance. The fact that the primary focus is on reducing maritime emissions indicates that there is still insufficient information in the literature on education and capacity building to guarantee that sustainable development is accomplished with a workforce that is well qualified.

It is indisputable that proper education and training play a crucial role in knowledge transfer, maintaining competence, enacting necessary change, tackling new issues, and lessening the negative effects of past choices and actions (Manuel,2013, p. 475)

Žalėnienė and Pereira (2021) feel the same way, contending that universities have a unique duty to develop future professionals and operationalize ideas and information. The authors add that colleges have considered sustainability as part of their responsibilities since 1970.

Building capacity and developing abilities are inherent components of education and training. As a result, certain curriculum will be reviewed or improved in order to keep them current with the demands of society today. The concept of sustainable development in higher education can be included into courses, curriculum, and other specific activities for a comprehensive educational reform, or it can be expressed simply as policy declarations (Sammalisto & Lindhqvist ,2008). Similarly, it was determined that one of the pillars around which the sustainable marine development goals ought to be established is marine Education and Training (MET) (Prylipko, 2013; Rowihill & Farag, 2021).

The existing literature on sustainable development and maritime education is still lacking.

World Maritime University (2020), contends that this idea and its consequences for MET have not received enough attention which is also relevant to the Tanzanian context as well

One of the goals of Vision 2025 of the Tanzanian National Development Plan (NDP) is ' to be a country with excellent education at all levels; a country that generates enough educated individuals

with the necessary skills to address societal issues, meet development challenges, and become competitive on a regional and international scale' and links to the blue print SDG 4, quality education with one of the main instruments to assist in achieving these objectives is higher education

Nevertheless, despite these steps, there appears to be little progress in fully incorporating sustainability into higher education, with even less clarity regarding Maritime Education and training Institutions.

Therefore, the disparity between the skills that are needed and those that are provided is a worldwide issue, and it will persist if individuals receive training for the abilities required for Sustainable Development without taking into account the demands to accomplish within Dar es salaam maritime institute (DMI). In light of this context, this study aims to determine how sustainable development is currently integrated into dar es salaam maritime institute (DMI) courses so as to ascertain the appropriate curricula that will achieve the capacity building and education demands.

13. LITERATURE REVIEW

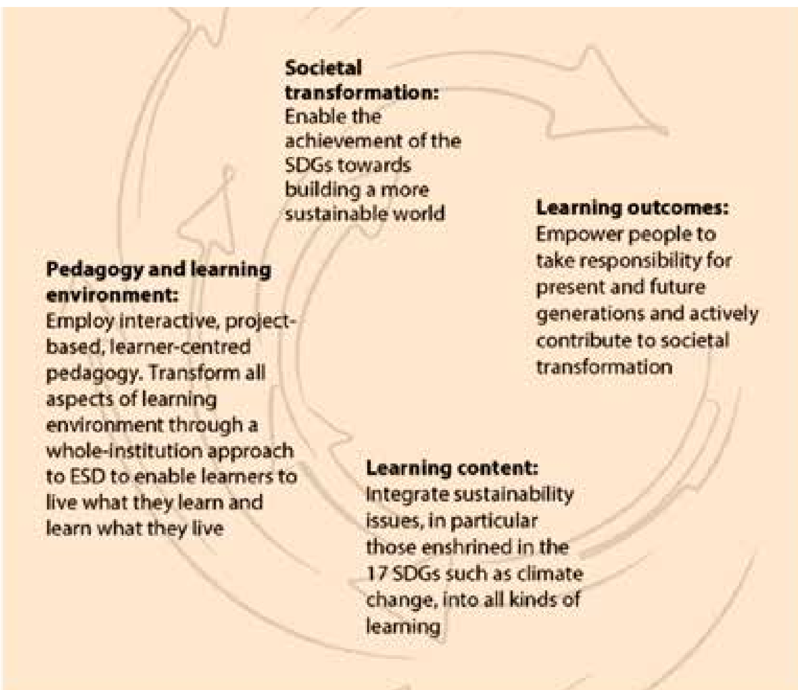
Education for Sustainable Development (ESD) aims to equip individuals with the knowledge, skills, attitudes, and values necessary for building a sustainable future. It focuses on global challenges like climate change, poverty, and sustainable consumption, promoting active, participatory learning that empowers students to take action (Prylipko, 2013; Pauw et al., 2015; Tiese & Le Roux, 2016). Since UNESCO (2019) launched the Decade of Education for Sustainable Development (2014-2005), the organization has continued to drive ESD, now focusing on the ESD for 2030 Framework to align education with the Sustainable Development Goals (SDGs). ESD is a lifelong learning process that emphasizes cultural diversity, social transformation, and inclusivity, making it a key enabler of all SDGs, particularly SDG 4 (Quality Education).

A national framework is essential for guiding decision-making and achieving policy goals that enhance societal welfare, with coordination among government policies being critical for effective implementation (UNCTAD, 2011). In Tanzania, the National Strategy for Growth and Reduction of Poverty (MKUKUTA) and the Tanzania Development Vision 2025 focus on addressing challenges like poverty, unemployment, and inequality, with education and innovation playing central roles in the country's long-term development

(National Planning Commission, 2011). These national policies align closely with the SDGs, particularly SDG 4 on quality education, and are consistent with the African Union›s Agenda 2063, which envisions an integrated, prosperous, and peaceful Africa (VNR, 2019). Tanzania›s commitment to these goals is evident in its participation in global discussions on the SDGs and the development of SDG indicators, with Statistics Tanzania playing a key role (Sidiropoulos, 2019). These frameworks work in synergy, with Tanzanian policies reflecting a strong connection to both the SDGs and the AU›s Agenda 2063, as well as an ongoing commitment to achieving sustainable development through coordinated efforts across government and society.

Education for Sustainable Development (ESD) in Tanzania is a key strategy for addressing the nation›s developmental challenges and promoting long-term sustainability, aligned with global frameworks like the UN›s SDGs and the African Union›s Agenda 2063. The Tanzanian government integrates ESD into both formal and non-formal education, focusing on environmental conservation, social equity, and economic development, as outlined in national policies like Tanzania Development Vision 2025 and MKUKUTA. Efforts to localize SDG 4 (Quality Education) include incorporating sustainability principles into the curriculum, with programs promoting eco- friendly practices, sustainable agriculture, and community-based conservation. Despite progress in improving access to education, challenges remain, such as insufficient teacher training, limited resources, and disparities between rural and urban areas.

Nonetheless, Tanzania continues to advance ESD initiatives, recognizing the importance of education in achieving sustainable development and working towards a more sustainable future, though further efforts are needed to ensure quality and inclusivity across all education levels as seen in Figure 1.



Tanzania encounters challenges in aligning its maritime education with sustainable development (SD). Tanzania has its own maritime training institution that is Dar es Salaam Maritime Institute (DMI). This institution play a vital role in training, but integrating SD comprehensively into their curricula is still a challenge.

The Tanzania Shipping Agencies Corporation (TASAC) is responsible for overseeing maritime training and safety standards, aligning with international conventions such as the STCW. However, Tanzania›s maritime education system is often more focused on vocational training rather than academic and policy-oriented education that incorporates SD principles.

For effective integration of SD into maritime education, factors highlighted by Prylipko (2013) should be considered, such as the educational level, future professional responsibilities, and alignment with national and international policies. This could involve revising curricula to include sustainability-focused courses and incorporating fields like maritime economics and environmental management (Rahman et al., 2022). Following Björneloo et al. (2008), SD should be embedded throughout the curriculum rather than treated as a standal one subject.

Training instructors to deliver SD concepts is essential, as Bataeineh and Aga (2022) emphasize that educators must possess the skills to promote transformational education. Tanzania should adopt multidisciplinary, interdisciplinary, and transdisciplinary approaches (University of Gothenburg, 2008) to ensure SD principles are deeply embedded in maritime education. This approach will align the sector with sustainable practices, contributing to the country's long-term maritime development.

Following the explanation of the SD idea and a summary of its key characteristics, specifically with regard to Education for Sustainable Development in higher education, this study suggests an evaluation model that will be used as a means of gauging an institution›s SD integration. (Tumbas et al., 2015) stated that Previous empirical and theoretical studies show various methods that maritime education and training institutions can participate in or integrate SD, such as through operations, education, research, planning, management. (Yamkela Nhleko,2022) suggested the following measurable variables from the literature review towards the integration of SD in an institution as follows:

Governance and SD policy	The way mission and vision of the institution is embedded in the functions and operations
Curriculum:	The application of SD practices and concepts to academic programs, teaching and learning objectives, subject matter, and module delivery.
Research	The focus of the research on SD aspects
Industry collaboration	The involvement of stakeholders on performing different sustainability work

The above variables can be shown through Figure 2, below that focuses on how the issues areinterconnected

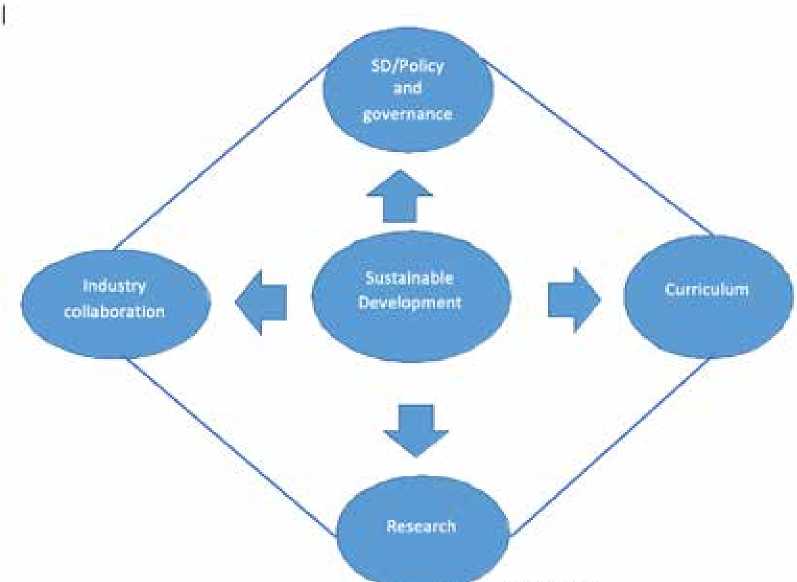


FIGURE 2:SD MODEL

(Tumbas et al., 2015). It can be further argued that by implementing a consistent sustainability evaluation methodology, the use of a model for these identified variables could help higher education institutions benefit from clear indications that allow comparison with other institutions and encourage the discovery of best practices.

14. RESEARCH METHODOLOGY

The research methodology utilized a case study approach within a qualitative research framework. Data was collected through semi-structured interviews with open-ended questions, supplemented by document analysis and personally administered questionnaires. The sample size of 30 respondents was adopted in this study to represent the whole population including 15 students and 15 staff respondents from DMI, with unrestricted or simple random sampling applied to students and purposive/judgmental sampling used for staff, which consisted of lecturers, research coordinators, and departmental management. Data was analyzed using NVivo 12 software to gain insights into the integration of Sustainable Development (SD) in Maritime Education and Training.

15. FINDINGS OF THE STUDY

The research question of this study sought to identify how the DMI is currently integrating SD in different aspects which are embedded in the identified themes in the SD model. The themes are also indicated in the below. The responses were then grouped according to the befitting theme. The participants are identified as G for the staff respondents and P for the student respondents

Table 4.1 A summary of the responses from the personally administered semi-structured interviews with open-ended questions

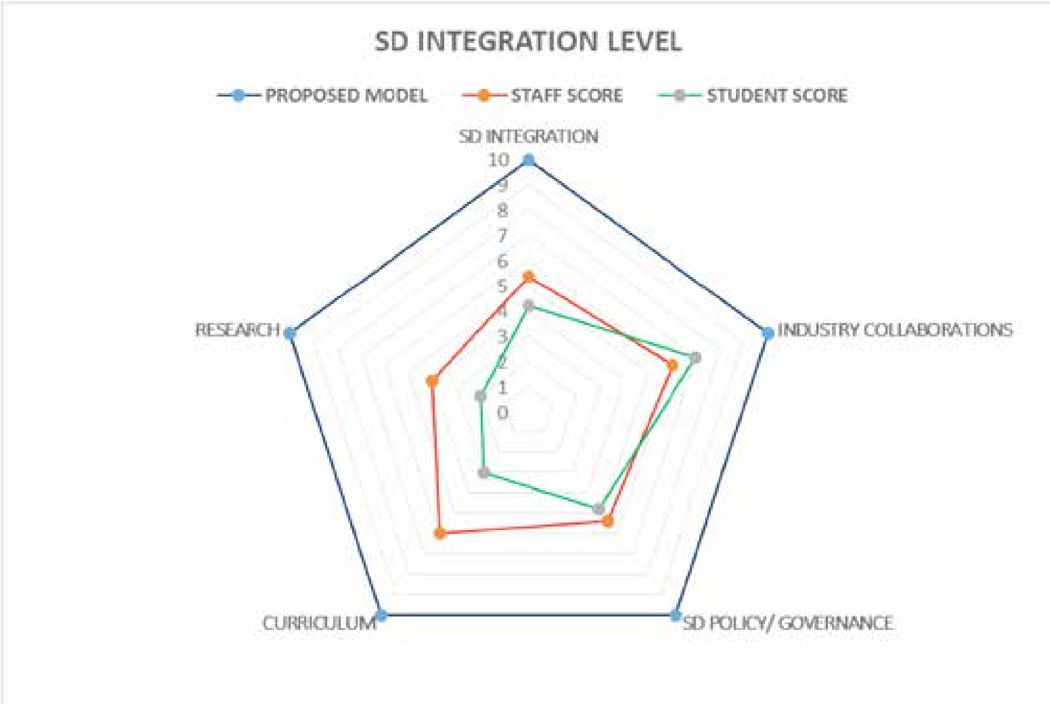
THEMES	EXPLANATIONS	QUOTES
Curriculum	The results demonstrated that SD concepts and principles are incorporated into the curriculum at the institution. According to every staff member who responded, "adding SD knowledge elements to existing modules" is the most effective way to incorporate SD into the curriculum. The majority of students who responded also concurred that the institution should "effectively promote SD principles and operations in curricula as they are not much aware of it." According to 14 out of 15 students agreed that, SD should be given top priority when it comes to the "curriculum and student learning outcomes	Respondent G12 stated that, "The curriculum should incorporate SD" Respondent P6 stated that, "To my current understanding, the course that I am currently enrolled, I think it has small elements of SD issues incorporated within our curriculum"
Research	The majority of respondents stated that institution funds sustainability research and that the studies it does concentrate on numerous aspects of SD. While 15 out of 15 students who responded said that the university is dedicated to SD through its research projects on SD, all staff respondents gave this element a good reaction. The findings also revealed that the Research Consultancy and Publications Unit provides the majority of the research funding that is primarily accessible to researchers and students.	Respondent G7 on whether the institution supports research in sustainability with funding stated that, "DMI award prizes to deserving students whose research focus in centered on SD. It also sponsors students attending different workshops for research and innovation on Mechatronics and Robotics focusing on SD. The respondent further indicated that, the institution currently has begun Masters degrees programmes to increase number of dissertations focusing on SD for more emphasis and improvement"

SD Policy /Governance	While 14 out of 15 students responded that SD-related concepts and principles are present in the way the college functions, all of the staff respondents stated that the institution does have requirements to include SD in various aspects. The results also showed a lack of clarity regarding the institution's SD policy, suggesting that SD is still a vague idea that is not well explained or comprehended by staff and students at all levels	Respondent G5 responded that,"DMI does not have a sustainable development policy per se but rather integrates programs that endorse and promote sustainable development" Respondents P3 said that "The requirement of SD policy is not well communicated during subject delivery and institutions operations"
Industry Collaboration	Based to the findings, the majority of staff respondents—14 out of 15— believe that the institution is working with the industry on sustainability projects and consultancy, and this is clear from the various interactions the institution has with industry stakeholders	Respondents G5 stated that , "The institution provides consultancy to the field related to maritime on considering Sustainable development" Respondents G7 stated that "The institution hosts the blue economy conference that invite different partners which carry out activities and implementing SD".

16. DISCUSSIONS

The results are discussed in this section in light of the literature that was consulted for this research. The data›s findings mostly showed answers that fit the themes that were found and displayed using a model. Figure 3 aims to illustrate the general evaluation of the organization using the suggested assessment approach in light of the outcomes. The discussion that follows goes into further detail about this. Figure 3 numerical values are hypothetical, non-empirical values that are just intended to serve as indicators of the overall findings.

Figure 3: SD integration level



The following are the interpretations of the above findings; SD Policy/Governance
Based on the data, it can be concluded that the institution has made an effort to include sustainable development (SD) into its operations, including SD components in student courses, and doing research initiatives that support SD. Nevertheless, the results additionally showed that the institution lacks a clear policy devoted to SD from a governance and policy standpoint. The respondents have shown that

No specific policy Per se dedicated to SD but there are policies which considering SD eg Staff development policy.

Curriculum

The findings indicated that there an importance of the institute to drop some issues from the curriculum and adding important issues on SD. It has shown that the integration of SD concepts in the maritime studies should be implemented practically in their modules due to that the some respondents indicated that the nature of some courses permit for a more practical and comprehensible integration of SD concepts

Respondent X2 said the institution to "have a fully support on considering SD modern infrastructure for learning and incorporating SD curriculum is of paramount importance".

Research

The institution is committed to conducting research with particular projects and bursaries dedicated to SD in an effort to address SD difficulties, according to the results of the document analyses. However, most students and staffs seem not to be aware of the SD issues despite the effort made by the institution and government at large in funding the research and projects related to SD issues

The respondent G4 said that "the institution does support research which consider SD however, financial insufficiency drops down the efforts".

Industry collaboration

Based on the findings, the majority of staff believe that the institution is actively engaging with the industry on sustainability projects and consultancy, as evidenced by the various interactions the institution has with industry stakeholders. The institution provides consultancy in the maritime field with a focus on sustainable development. Additionally, it hosts the Blue Economy Conference, inviting different partners who are involved in activities and the implementation of sustainable development initiatives

17. RECOMMENDATIONS AND CONCLUSION

- **Recommendations**

Finding out if SD is currently included in maritime education and how it has been included was the aim of this project. This was accomplished by including inquiries in the research tools that would help accomplish this goal. Although SD is not present at the strategic level, the institution emphasizes integration by incorporating SD concepts and principles into some of its courses, operations, and research output with SD-inspired solutions, according to the data gathered and the institution›s supporting documentation. The institution›s desire to teach SD concepts and principles to its academic staff is another indication of this. Consequently, this goal was accomplished however, there is still scope for improvement

SD Policy and governance	The implementation of an SD policy is not strategically performed even the findings had shown that the institution's approach to SD is unstructured thus it is recommended to introduce the SD policy , structuring the procedures which will promote and encourage accountability and put a sense of responsibility on the institution concerning the integration of SD. This further forces the institution to continuously assess its plans and strategies and pinpoint areas in need of modification.
Curriculum	It is recommended that DMI should per se incorporate SD principles and concepts in their curriculum, giving awareness to students and staffs, equating SD in every level and course as their courses are SD oriented courses
Research	Similar to the curriculum component, it is advised that the institution start research given the discussion in earlier chapters and the findings, initiatives and programs that promote faculty cooperation for SD. This will also make it possible for the institute to consider its priorities that cut across academic areas.
Industry collaboration	The UN encourages collaboration in order to achieve the SDG targets, and MET that want to contribute to SD issues should do the same. In the instance of this institution It is advised that this institution expand its research cooperation in the field of maritime research.

Conclusion

The study›s overall conclusions indicate that, with the necessary adjustments, the institution satisfies the requirements for incorporating sustainability into the curriculum. The model created as a measuring instrument states that the variables are included in the results, however certain variables have a higher priority than others. For example, participants responded more favorably to the curriculum and industry collaboration variables than to the research and SD policy and governance variables. More respondents pointed to the need for improvement for the latter variable. The results demonstrated that there is still a gap in implementation when it comes to integrating a sustainability curriculum in MET, particularly at DMI

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DESIGN & PRINTING: 024 445 0018