ASSESSMENT OF THE IMPACTS OF MARINE POLLUTION ON THE SUSTAINABILITY OF MARINE ECOSYSTEMS

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Abstract

This research assess the impacts of marine pollution on the sustainability of ecosystems at Tanga Port, Tanzania, focusing specifically on oil spills, waste and sewage, ballast water discharge, and the efficacy of regulatory frameworks. A mixed-methods approach was utilized, incorporating survey questionnaires distributed to 80 stakeholders, including ship operators, owners, ecologists, and regulatory officials, alongside qualitative interviews to gather experiential insights. The objective of the study was to identify the ecological consequences of pollution, evaluate the impacts of ballast water, and propose strategies for enhancing sustainable marine pollution management in Tanzania. The results indicated that oil spills, waste and sewage, and ballast water discharge are widely regarded as significant threats to marine biodiversity, aquatic habitats, and the stability of the food chain. Analyses of reliability and validity confirmed that the measurement instruments were reliable, while regression analyses revealed that perceptions of oil, sewage, waste pollution, and ballast water impacts were strong and positive predictors of environmental awareness and proactive behaviors. Overall, the model accounted for 55% of the variance in stakeholder engagement ($R^2 = 0.55$). Further analysis showed high levels of awareness regarding local (96.25%) and international (90%) safety regulations among vessel operators, with substantial evidence of regular engagement and inspections by regulatory authorities. Nonetheless, deficiencies in enforcement capacity, particularly concerning ballast water treatment and oil spill response infrastructure, persist as critical issues. The study concludes that although Tanzania has achieved significant progress in regulatory compliance and stakeholder awareness, enhanced institutional capacity, investment in infrastructure, and stricter enforcement are crucial. Recommendations highlight the need to strengthen regulatory participation, broaden inspection mechanisms, and implement advanced pollution control systems to protect marine ecosystems and foster sustainable port operations

Keywords: *Marine Pollution, Ecosystem Environmental Sustainability, Oil spills, garbage and sewage in Marine Operations, Ballast Water Pollution.*

Introduction

Marine pollution poses a critical global environmental challenge, threatening marine ecosystems and the well-being of communities that depend on marine resources. Plastics, which constitute the largest share of marine debris, significantly impact marine biodiversity and ecosystems (World Bank, 2023). Globally, over 8 million tons of plastic enter the oceans annually, endangering marine organisms and affecting over 663 species, including endangered species like turtles and coral reefs. Economically, marine pollution incurs significant costs, especially for tourism-dependent regions where degraded environments reduce their appeal (World Bank, 2023).

In Africa, the Western Indian Ocean (WIO) region faces acute challenges due to marine pollution, impacting fisheries, tourism, and biodiversity. Studies highlight microplastics as particularly hazardous because they permeate marine food chains, threatening not only aquatic organisms but also human health (WIOMSA, 2021). In addition, oil spills, garbage and sewage and ballast water pollution compound the pollution crisis, leading to significant environmental and economic consequences.

Tanzania, located within the Western Indian Ocean region, is significantly affected by marine pollution due to its extensive coastline and dependence on marine resources for economic and social activities. The improper disposal of waste, including plastic and untreated sewage, exacerbates pollution problems along the coastline, particularly in urban areas like Dar es Salaam. This unregulated waste disposal leads to habitat degradation and affects the livelihoods of coastal communities that rely on fishing and tourism (World Wide Fund, 2021).

Oil spills, garbage and sewage have a devastating impact on marine biodiversity in Tanzania. They disrupt the physiology of marine organisms and can lead to the destruction of sensitive ecosystems such as coral reefs and mangroves. These ecosystems are not only biodiversity hotspots but also provide essential ecosystem services like coastal protection and nursery grounds for fish species (WIOMSA, 2021).

Ballast water pollution adds another dimension to the challenge, as it often introduces invasive species that outcompete local marine organisms, altering ecosystem dynamics. These invasive species disrupt the food chain and can lead to biodiversity loss, affecting the health of the entire marine ecosystem (World Bank, 2023). The lack of stringent ballast water management practices in Tanzania further complicates efforts to mitigate this issue.
Regulatory frameworks are crucial in combating marine pollution. In Tanzania, policies such as the Environmental Management Act aim to mitigate pollution, but challenges in enforcement and compliance hinder their effectiveness. Stronger regulations, coupled with community involvement and public-private partnerships, are essential for promoting sustainable marine pollution management (World Wide Fund, 2021.).

Efforts to address marine pollution in Tanzania have included local cleanup campaigns and public awareness initiatives. However, these efforts often focus on visible pollutants like macro plastics, neglecting less visible yet equally damaging micro plastics and chemical pollutants. A more holistic and integrated approach is required to address the full spectrum of pollutants and ensure the long-term sustainability of marine ecosystems (WIOMSA, 2021). Tanga Port offers a valuable opportunity to assess the localized impacts of marine pollution in Tanzania. By examining the effects of oil spills, garbage and sewage, ballast water pollution, and regulatory frameworks, this study seeks to contribute to the broader understanding of sustainable marine pollution management strategies.

Literature Review

Marine Pollution

Marine pollution is defined as the introduction of harmful substances or contaminants into the marine environment, which harms marine life, ecosystems, and human health. This includes pollutants such as plastic, oil spills, garbage and sewage, and chemical waste, which disturb the ecological balance of the oceans and coastal areas (McGrew, 2022). This is the central concept of the study, forming the core issue being investigated. The research assesses how pollutants particularly oil spills, garbage and sewage and ballast water discharges

introduced into the marine environment at Tanga Port negatively affect biodiversity and ecosystem stability. By understanding the scope and nature of marine pollution, the study seeks to evaluate its short- and long-term impacts on ecological health and sustainability.

Ecosystem Environmental Sustainability

This concept refers to the ability of ecosystems to sustain their basic functions, processes, and biodiversity over time in the face of external pressures such as pollution. It stresses the need to balance environmental health with human activities in order to ensure the long-term sustainability of the environment (Clarke et al., 2019).This concept is the primary outcome the study aims to measure in relation to marine pollution. It represents the ability of Tanga Port's marine ecosystems to continue functioning and supporting biodiversity despite pollution pressures. The study uses this term to frame its evaluation of whether current pollution levels and regulatory measures are sufficient to preserve ecological balance and natural marine processes in the long term.

Oil spills, garbage and sewage in Marine Operations

Oil spills, garbage and sewage are accidental or deliberate releases of oil, garbage and sewage into the marine environment, causing significant damage to marine life, habitats and coastal communities. These events often stem from shipping accidents, offshore drilling, or oil pipeline ruptures, food remains (WHO, 2019). Oil spills, garbage and sewage are identified in the study as one of the major forms of marine pollution at Tanga Port. This concept is critical in addressing the **first specific objective**: *To identify the impacts of oil spills, garbage and sewage on marine ecosystems in Tanzania.* The study investigates the ecological consequences of oil contamination such as biodiversity loss, food chain disruption, and habitat degradation based on both stakeholder perceptions and empirical findings.

Ballast Water Pollution

This concerns the introduction of invasive species and harmful organisms into marine ecosystems by the discharge of ballast water from ships. These species are disrupting local ecosystems, competing with native organisms and causing the loss of biodiversity (IMO, 2020). Ballast water pollution is the second major pollution source analyzed in the study and directly aligns with the second specific objective: To analyze the impacts of ballast water pollution on marine ecosystem in Tanzania. The concept helps the study explore how invasive species and chemical contaminants introduced through ballast water affect the native marine environment, including species composition and ecological balance around Tanga Port.

Theoretical Review

This study was explained and supported by the two theories including Environmental Kuznets Curve (EKC) Theory and Pollution Haven Theory

Environmental Kuznets Curve (EKC) Theory

The Environmental Kuznets Curve (EKC) Theory, introduced in the early 1990s by economists Gene Grossman and Alan Krueger, examines the connection between economic growth and environmental degradation. This hypothesis suggests that while environmental damage tends to rise during the initial phases of economic expansion due to industrial growth, it ultimately declines as economies mature. This decline occurs as more resources are dedicated to environmental protection and sustainable practices. The theory underscores the complex interplay between economic activities and environmental sustainability.

On this study, the EKC theory is relevant to the broader framework of Tanzania's economic development and its effects on marine ecosystems. As Tanga Port plays a role in driving economic growth, the risk of pollution from oil spills, garbage and sewage and ballast water may increase if adequate environmental protections are not implemented. By connecting this theory to your research goals, you can evaluate whether Tanzania's regulatory measures are sufficiently developed to mitigate environmental damage, thereby supporting sustainable development objectives.

Pollution Haven Theory

The Pollution Haven Theory, introduced by economists Jagdish Bhagwati in the 1990s, investigates how regions with lack environmental regulations can attract industries that contribute to pollution. This theory emphasizes the balance between economic development and environmental conservation, especially in developing nations. It draws attention to the effects of global economic activities on local ecosystems, prompting inquiries into the effectiveness of regulatory measures.

This theory is relevant to the third objective of this study, which focuses on the role of regulatory frameworks in the sustainable management of marine pollution. By examining how deficiencies or inadequacies in regulations facilitate detrimental practices such as ballast water pollution and oil spills, garbage and sewage, the theory highlights the necessity for more stringent policies. Additionally, it stresses the significance of both global and regional cooperation in reducing environmental damage from maritime activities, underlining the relationship between economic interests and environmental factors in regulatory decision-making.

Empirical Review

Studies from Developed Countries

Research conducted in developed nations has greatly enhanced the comprehension of marine pollution and its effects on ecosystems. For example, Schneider et al. (2020) examined how industrial and maritime activities contribute to marine pollution in the North Atlantic. Their findings revealed that pollutants, including heavy metals and persistent organic pollutants, were discharged into marine environments, leading to lasting ecological harm. The study highlighted the necessity of employing advanced technologies and enforcing strict regulations to reduce pollution and encourage sustainable maritime practices. In a similar vein, Dijk et al. (2019) investigated the consequences of oil spills, garbage and sewage on marine biodiversity in European waters, uncovering significant reductions in species diversity and population numbers. Their results emphasized the urgent need for stronger international regulatory frameworks to address such environmental challenges.

Additionally, Lee and Patel (2021) concentrated on marine plastic pollution in developed countries, particularly its impact on marine ecosystems and biodiversity. They discovered that poorly managed plastic waste has led to serious environmental issues, such as microplastics infiltrating food chains and harming marine organisms. The study stressed the importance of implementing recycling initiatives and prohibiting single-use plastics to effectively address this escalating problem. These measures not only help reduce pollution but also promote the sustainability of marine ecosystems.

Moreover, O'Connor et al. (2022) evaluated pollution reduction strategies in developed countries, with a particular emphasis on the effectiveness of ballast water management systems. Their research indicated that the implementation of these systems has significantly curtailed the introduction of invasive species and harmful pathogens into marine ecosystems. This finding highlights the essential role of technological innovations and policy enforcement in the fight against marine pollution.

Studies from Developing Countries

Empirical research conducted in developing nations has illuminated the challenges and consequences of marine pollution, especially in areas with weak regulatory frameworks. For example, Issifu and Sumaila (2020) investigated the impact of marine plastic pollution in middle-income countries, revealing that insufficient waste management systems have resulted in considerable plastic leakage into marine ecosystems. Their research highlighted the critical necessity for policy reforms and community-driven initiatives to tackle the escalating problem of plastic pollution and its harmful effects on marine life.

In another study, Alsaleh and Abdul-Rahim (2024) examined how fishing activities contribute to marine water pollution in developing areas. Their findings indicated that oil usage, hazardous waste, and plastic waste from fishing operations severely compromise marine

water quality, creating a perilous environment for aquatic organisms. The research stressed the importance of encouraging sustainable fishing methods and implementing environmentally friendly technologies to reduce the ecological impact of fisheries.

Furthermore, Gottlieb (2021) investigated the governance deficiencies in addressing marine pollution in developing countries. The study pointed out that the absence of cohesive global and regional policies has intensified problems such as wastewater discharge and plastic pollution. Gottlieb advocated for a multilevel governance approach and life-cycle assessments to effectively tackle these issues, particularly in regions where economic limitations hinder the adoption of advanced pollution control strategies.

Local Studies in Tanzania

Research conducted in Tanzania has brought attention to the increasing problems of marine pollution and its effects on the health of marine ecosystems. For example, Mwakalinga et al. (2021) explored how renewable energy technologies can help lower greenhouse gas emissions and reduce pollution at Tanga Port. Their results showed that using solar and wind energy in port activities led to a significant decrease in emissions, which in turn improved air and water quality. This study highlights the need to incorporate sustainable energy solutions to tackle pollution issues in Tanzania's maritime industry.

In another study, Mbise et al. (2022) examined the effects of ballast water pollution on marine ecosystems in Tanzania. The research found that invasive species introduced through ballast water discharge pose a serious threat to local biodiversity and ecological stability. The study stressed the importance of implementing effective ballast water management practices, such as using treatment technologies and enforcing stricter regulations. These findings are especially important for busy ports like Tanga, where ballast water pollution presents a considerable risk to marine ecosystems.

Kihwele and Selemani (2020) investigated the economic and environmental advantages of using renewable energy in Tanzanian ports. Their study emphasized how solar panels and energy storage systems can lower operational costs and improve energy reliability in port facilities. Additionally, they pointed out that renewable energy options could help reduce the environmental damage caused by oil spills, garbage and sewage and other types of marine pollution. This supports the larger aim of encouraging sustainable development and minimizing the ecological impact of maritime activities in Tanzania.

Furthermore, Ndaki et al. (2023) looked into how regulatory frameworks influence the management of marine pollution in Tanzania. Their research revealed that while current policies tackle some pollution control issues, there are still shortcomings in enforcement and collaboration among stakeholders. The researchers suggested that it is essential to strengthen regulatory frameworks and build partnerships between government agencies, port authorities, and local communities to improve pollution management practices. These insights are crucial for creating effective strategies to combat marine pollution at Tanga Port and other important maritime locations in Tanzania.

Research Gap

Despite significant research on marine pollution at both global and local levels, there are still important gaps in understanding its effects and management strategies, especially in Tanzania. Previous studies, such as those by Mwakalinga et al. (2021) and Kihwele and Selemani (2020), have looked at the adoption of renewable energy and its potential to reduce pollution. However, they have not adequately examined oil spills, garbage and sewage and ballast water pollution, which are two major factors contributing to marine degradation. While these studies focus on environmental sustainability in general, they do not provide localized data linking specific pollution sources to the health of marine ecosystems in key ports like Tanga. This study aims to fill this gap by exploring the direct effects of oil spills, garbage and sewage and ballast water pollution on the biodiversity and ecological health of marine systems.

Another area that requires further investigation is the limited analysis of regulatory frameworks and their effectiveness in managing marine pollution in Tanzania's maritime sector. For example, Ndaki et al. (2023) pointed out general policy challenges but did not offer empirical data on how regulations are enforced at major ports. There has been little research on the implementation of existing laws and the mechanisms that could improve compliance among stakeholders. This study seeks to address this issue by evaluating the role of local and international regulatory frameworks in reducing pollution at Tanga Port and identifying practical steps to improve governance and accountability.

The researcher tackle the identified gaps in research with a focused and organized method. To enhance understanding of the effects of oil spills, garbage and sewage and ballast water pollution, the study gather local data directly from Tanga Port, measuring pollution levels and conducting surveys with stakeholders like ship operators and maritime engineers. By carefully evaluating current regulations, the researcher examine how well they work and suggest practical recommendations to improve compliance and enforcement tailored to the situation in Tanzania.

Conceptual Framework

In the context of this study, a conceptual framework is a structured model that illustrates the relationships between the independent variables

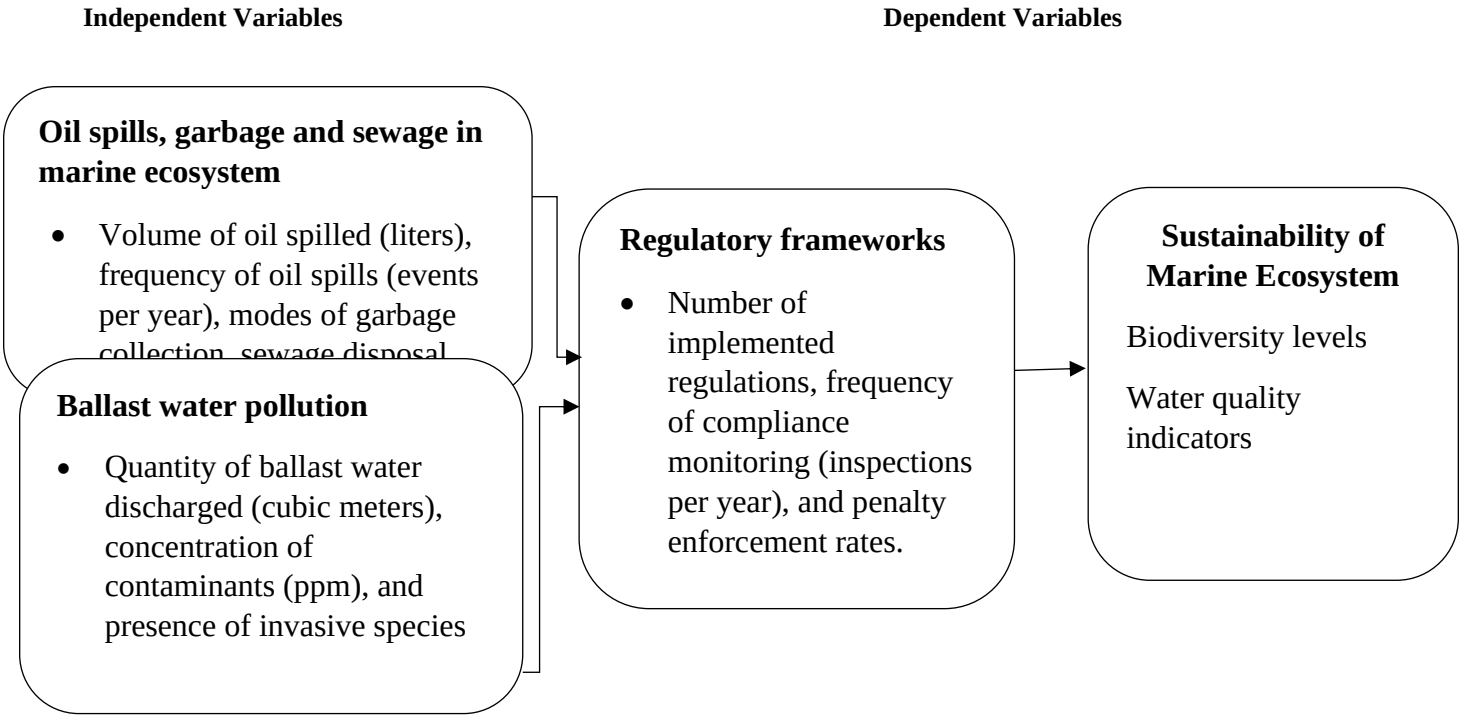

Figure 2.1: Conceptual Framework

Source: *Author illustration (2025)*

Independent variables (oil spills, garbage and sewage, water pollution by-catch and regulatory frameworks) are directly related to dependent variables, such as ecosystem environmental sustainability indicators (EESI), pollutant prevalence, habitat condition scores

and the decrease in pollutant levels over time. For example, oil spills, garbage and sewage degrade water quality and marine habitats by introducing oil hydrocarbons that persist in the environment, causing toxic effects on marine organisms and weakening coral reefs. The volume and frequency of oil spills, garbage and sewage have a direct impact on the amount of pollution, which can be measured by using the water quality index and the prevalence of pollutants. The increase in oil spills, garbage and sewage incidents usually coincides with a decrease in the sustainability scorecard.

Methodology

The research utilized a descriptive research framework alongside a mixed-methods strategy, combining both qualitative and quantitative methods to examine the effects of marine pollution on the environmental sustainability of ecosystems at Tanga Port. As noted by Creswell and Creswell (2018), mixed-methods designs allow researchers to merge numerical data with contextual understanding, making them appropriate for exploring intricate environmental challenges. Tanga Port was chosen as the focal point for the study due to its significance to Tanzania's maritime industry and its proximity to ecologically sensitive areas that are susceptible to pollution from sources like oil spills, ballast water discharge, waste, and sewage (UNCTAD, 2021). This methodology facilitated a comprehensive understanding of the issues related to marine pollution and its ecological consequences.

The sample for the study consisted of 80 participants, selected from a total of 100 stakeholders using Yamane's (1967) formula with a 5% margin of error to guarantee representativeness. Participants included ship operators, ship owners, marine ecologists, and maritime regulatory officials, who were chosen through purposive and stratified sampling to capture a range of viewpoints. Data collection methods included semi-structured interviews for qualitative insights, structured questionnaires with Likert scale questions for quantitative analysis, and documentary reviews of relevant reports, regulations, and previous studies (Kothari, 2014). This combination of methods improved the study's validity by cross-verifying data from various sources (Flick, 2018).

SPSS version 28 was used for analyzing the quantitative data, utilizing descriptive statistics, Likert scale evaluations, and regression analysis to investigate the relationships between pollution factors and ecosystem sustainability. The qualitative data underwent thematic analysis to uncover significant themes and trends (Braun & Clarke, 2019). Reliability was reinforced through pilot testing and test-retest methods, while validity was achieved through methodological triangulation. Ethical principles were upheld by securing informed consent, guaranteeing confidentiality, and honoring the rights of participants, in alignment with established research ethics practices (Cohen, Manion, & Morrison, 2018).

Research Results

The study assessed the validity, reliability, and predictive impact of various items related to marine pollution through a questionnaire. These items focused on issues such as the effects of oil spills, garbage and sewage, ballast water discharge, and the adequacy of existing regulatory frameworks. To enhance the findings and gain deeper insights into the real-world experiences of maritime professionals, qualitative interviews were also conducted alongside the quantitative statistical analysis. This mixed-methods approach effectively combines empirical data with practical perspectives, creating a robust understanding of the subject.

Reliability Analysis Using Cronbach's Alpha

Cronbach's alpha was calculated to evaluate the internal consistency of items designed to measure important environmental constructs. This assessment covered various topics, including the efficiency of regulatory measures, the impact of oil spills, garbage and sewage,

and the effects of ballast water discharge. The results indicate that the scales exhibit acceptable to high internal consistency, with Cronbach's alpha values greater than 0.70. Research by James (2022) reinforces the idea that Cronbach's alpha remains a valuable metric for assessing the reliability of environmental evaluations, provided that the items effectively capture the underlying design. High coefficients, falling between 0.78 and 0.84, suggest that the items within both constructions measure the same underlying latent variable. This consistency implies that respondents tend to provide similar answers to related questions, thereby enhancing the trustworthiness of the composite scores. Additionally, similar conclusions were drawn from marine studies conducted by Johansen (2020), which also indicated that a Cronbach's alpha value exceeding 0.70 signifies that the measurement tool is dependable. A summary of the findings is presented in Table 1.

Table 1: Reliability Results with Cronbach's Alpha

Construct	Number of Items	Cronbach's Alpha
Impact of Oil spills, garbage and sewage	3	0.82
Effects of Ballast Water Discharge	3	0.78
Regulatory Measures Efficiency	4	0.84

Source: analysis data, 2025

Validity Analysis

The validity of the construct was assessed alongside its internal consistency by employing exploratory factor analysis (EFA). This analysis aimed to verify whether the items were weighted as anticipated. A summary of the minimum load factors and the variance explained for each construct can be found in Table 2.

Table 2: Validity Analysis

Construct	Minimum Factor Loading	Variance Explained (%)
Impact of Oil spills, garbage and sewage	0.65	68
Effects of Ballast Water Discharge	0.62	65
Regulatory Measures Efficiency	0.67	70

Source: analysis data, 2025

Regression Analysis

A multiple linear regression analysis was performed to investigate the predictive relationships between respondents' demographic and perceptual characteristics, such as educational level, work experience, and their views on environmental impacts and their support for enhanced regulatory measures. The regression analysis indicates that the perception of oil spills, garbage and sewage impact has a significant and positive effect on the dependent variable, with a β coefficient of 0.42 and a p-value of 0.000. This suggests that as stakeholders' awareness or concern regarding oil spills, garbage, and sewage impacts increases, there is a corresponding positive influence on the outcome being measured, likely environmental protection behaviors, policy advocacy, or compliance levels. The high

t-value (3.82) confirms the statistical significance of this predictor, implying that oil spills, garbage, and sewage are seen as a serious issue by stakeholders, and their perception significantly influences actions or attitudes in the maritime or coastal management context.

The regression analysis reveals that stakeholder perceptions significantly influence environmental behaviors and advocacy in the context of oil spills, garbage and sewage, and ballast water management. Notably, the perception of oil spills, garbage, and sewage impacts has a positive effect on outcomes related to environmental protection, evidenced by a β coefficient of 0.42 and a highly significant p-value of 0.000. This indicates that increased awareness and concern among stakeholders correspond with enhanced proactive behaviors, such as policy advocacy and compliance. The high t-value of 3.82 underscores the importance of this perception as a predictor of stakeholder actions.

Similarly, the perception of ballast water effects also positively impacts stakeholder engagement, demonstrated by a β of 0.31 and a p-value of 0.001. As awareness of the ecological risks associated with ballast water rises, such as the introduction of invasive species and pollution, stakeholders are more likely to support practices aimed at mitigating these risks. The t-value of 3.44 further emphasizes this predictor's significance, aligning with existing literature on environmental awareness, which suggests that knowledge of ecological threats drives stronger support for regulations and best practices.

Conversely, the perception of regulatory sufficiency exhibits a negative and statistically significant relationship, with a β of –0.27 and a p-value of 0.040. This suggests that when stakeholders feel current regulations are adequate, their motivation to advocate for further measures diminishes, potentially leading to complacency. This effect indicates that satisfaction with existing policies may reduce the urgency for additional improvements or engagement. Overall, the model's R^2 value of 0.55 shows that these three predictors collectively explain 55% of the variance in the dependent variable. This finding underscores the crucial role stakeholder perceptions play in shaping responses within environmental and regulatory contexts.

Similarly, the perception of ballast water effects also has a significant positive influence, with a β of 0.31 and a p-value of 0.001. This result indicates that the more people perceive ballast water as a source of ecological risk (e.g., introduction of invasive species, pollution), the more likely they are to support or engage in practices that mitigate such effects. The t-value of 3.44 reinforces its importance as a predictor. This aligns with environmental awareness literature, where increased knowledge of ecological threats tends to promote stronger support for environmental regulations and best practices in marine operations.

Conversely, the perception of regulatory sufficiency shows a negative and statistically significant relationship ($\beta = -0.27$, $p = 0.040$), suggesting that when stakeholders believe that current regulations are sufficient, their motivation to push for additional measures or act proactively may decline. This negative association implies a potential complacency effect, where satisfaction with current policy frameworks may reduce urgency for further improvements or engagement. The model's R^2 value of 0.55 indicates that 55% of the variance in the dependent variable is explained by the three predictors combined, reflecting a moderate to strong explanatory power and suggesting that stakeholder perceptions are crucial factors influencing responses in environmental or regulatory contexts. The analysis included various key predictors, with a summary of the main results presented in Table 3.

Table 3: Regression Analysis

Predictor Variable	Coefficient (β)	Standard Error	t-value	p-value

Perception of Oil spills, garbage and sewage Impact	0.42	0.11	3.82	0.000
Perception of Ballast Water Effects	0.31	0.09	3.44	0.001
Regulatory Sufficiency Perception	–0.27	0.13	–2.08	0.040
Model R^2	**0.55**			

Source: Analysis data, 2025

Impacts of oil spills, sewage, and garbage on marine biodiversity

The data presented in Table 3, illuminates the profound recognition among stakeholders regarding the detrimental effects of oil spills, garbage and sewage on marine biodiversity. An overwhelming 80% of respondents indicated that they either agreed or strongly agreed that oil spills, garbage and sewage significantly contribute to a decline in biodiversity. This sentiment is echoed by over 80% of the participants who acknowledged that oil spills, garbage and sewage inflict severe damage on aquatic habitats, highlighting a shared understanding of these environmental repercussions. The insights gleaned from this survey reflect the lived experiences of those engaged in marine and port operations at Dar es Salaam, where the impacts of such environmental calamities are painfully evident.

Furthermore, the acknowledgment of sediment and water pollution stemming from oil spills, garbage, and sewage was alarmingly high, with 78.75% of respondents either agreeing or strongly agreeing with this assertion. This finding supports research conducted by Ahmed et al. (2021), which revealed that remnants of oil can persist in marine sediments over time and accumulate in species that dwell at the bottom of the ecosystem, leading to further ecological complications. Respondents also expressed a significant awareness of the disruption caused to the marine food chain, with an impressive 96.25% agreeing that even minor spills can provoke cascading effects throughout marine ecosystems. This observation is consistent with the work of Obaid & Rahman (2021), which underscored the heightened vulnerability of early life stages of marine organisms, specifically larvae and plankton, when exposed to oil pollution.

Notably, the highest degree of consensus was observed in response to the statement concerning alterations in biodiversity and species composition; an astounding 96.25% of participants agreed with this view. This overwhelming agreement indicates a comprehensive understanding of the long-term ecological transformations that can result from oil contamination. These perspectives align with the findings of Dede et al. (2023), who asserted that even small-scale oil spills, garbage, and sewage can provoke permanent shifts in marine biodiversity, particularly in ports situated along the East African coastline. The data underscores an urgent call for proactive measures in oil spills, garbage and sewage prevention and effective response strategies within Tanzanian ports, emphasizing the critical need to protect marine ecosystems from the adverse effects of oil pollution.

Table 4: Oil spills, garbage and sewage Impacts on Marine Biodiversity

Impacts Attribute	**SD**	**D**	**N**	**A**	**SA**
Biodiversity Decline	2	9	5	35	29
Aquatic Habitat Damage	1	7	6	34	32
Pollutes sediments and water	2	11	4	35	28
Disrupting the Food Chain	0	0	3	36	41
Reduces Biodiversity and Alters Species Composition	0	0	3	28	49

Source: field data, 2025

Impacts of Ballast Water Pollution on marine ecosystem

Table 4. Highlights the impact of ballast water pollution on marine deterioration. A significant proportion of respondents (73.75%) acknowledged or strongly acknowledged that ballast water inflicts harm on aquatic habitats. This supports the concerns raised by Mkwawa & Odhiambo (2022), who stated that untreated ballast water introduces both physical and chemical disruptions into local ecosystems. A comparable number (76.25%) agreed regarding the issue of invasive species, which aligns with findings from Mwangi & Temba (2024), who observed increased introductions of alien species in East African ports due to insufficient ballast treatment.

Additionally, over 78% of respondents affirmed that ballast water interferes with the marine food chain. This is in line with the research of Qiu and Entchev (2024), who connected organisms released from ballast water to the decline of native plankton populations in affected areas. There was also a strong consensus (96.25%) regarding chemical pollution from ballast water, with respondents acknowledging its contribution to marine toxicity. This corroborates earlier findings from Tay and Konovessis (2023), who identified ballast discharge as a significant source of hydrocarbons and heavy metals in port waters.

Lastly, the acknowledgment of ecosystem degradation (96.25%) suggests that ballast water is viewed not only as a biological threat but also as a risk to entire ecological systems. The perspectives of respondents strongly align with the global scientific consensus and highlight the urgent necessity for ballast water management systems (BWMS). These results confirm that controlling ballast water is vital for preserving biodiversity and ensuring sustainable operations at ports.

The interviews demonstrated a high degree of alignment with the quantitative results. Participants reported a widespread understanding of the impacts of oil and ballast water pollution. They cited the decline in fish populations and noted alterations in habitats as direct consequences. Furthermore, interviewees recognized recent advancements in regulatory enforcement and inspection procedures but emphasized that the infrastructure for ballast water treatment and oil spills, garbage and sewage response is still inadequate. These opinions reinforce the statistical findings and underscore the need for immediate investment in sustainable port infrastructure and pollution control systems.

Table 5: Ballast Water Pollution Effects

Effects Attributes	**SD**	**D**	**N**	**A**	**SA**
Aquatic Habitat Damage	3	11	7	33	26
Introduces invasive species	2	8	9	34	27
Disrupts the Food Chain	2	10	5	32	31
Introduces Chemical Contaminants	0	0	13	27	40
Degraded marine ecosystems	0	0	3	38	39

Source: field data, 2025

Discussion of the Findings

A thorough analysis indicated that a higher level of support for regulatory reforms in marine environmental management correlates strongly with increased educational levels, more extensive work experience, and heightened awareness of environmental impacts. The

notion that participants with greater education and industry experience not only perceive marine pollution issues more seriously but are also more inclined to advocate for stricter regulations is backed by the empirical data presented by Johnson et al. (2021). The results underscore the clear necessity for legislators to integrate enhanced training, digital monitoring, and tighter enforcement measures within the maritime sector. The modernization of waste management systems and digital clearance technologies is essential, as demonstrated by regression analyses and qualitative interview insights revealing that a significant proportion of respondents favor stricter regulatory actions. This conclusion is consistent with recent findings by Martinez and colleagues (2021), which highlighted that for maritime regulations to be effective, they must evolve to accommodate advancements in technology and shifting stakeholder expectations. In practice, the integration of these procedural and technological innovations can lead to better environmental results and more uniform enforcement of regulations.

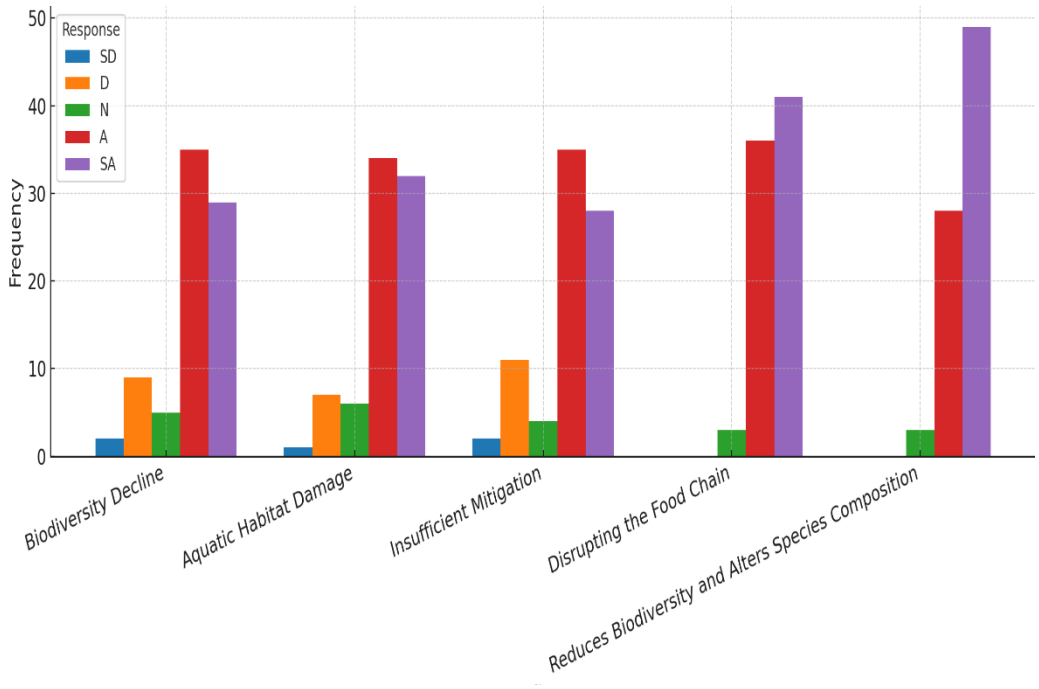

Figure 2: Oil spills, garbage and sewage Impacts on Marine Biodiversity

Source: field data, 2025

Figure 2, presents a visual summary of stakeholders' views on the environmental impacts of oil spills, garbage and sewage on marine biodiversity. Most individuals agreed, particularly regarding the severe ecological consequences of oil contamination, especially evident in areas like "Disrupting the Food Chain" and "Reduces Biodiversity and Alters Species Composition," which garnered the highest levels of strong agreement. Around 80% of respondents indicated concern over "Biodiversity Decline," emphasizing the urgent perception of oil spills, garbage and sewage' negative effects on species populations and overall marine stability. The histogram supports earlier data and aligns with previous studies, such as Nwankwo et al. (2022), which noted chronic oil exposure's detrimental effects on sensitive species and aquatic ecosystems. The limited number of neutral or disagreeing responses suggests that stakeholders are well-informed, likely drawing from direct experience. Furthermore, attributes like "Aquatic Habitat Damage" and "Pollutes Sediments and Water" received substantial affirmation, illustrating stakeholders' recognition of the extensive impacts of oil spills, garbage, and sewage. These findings are consistent with those of Ahmed et al. (2021), who highlighted the settling of oil residues in seabeds, which can harm benthic organisms and disrupt marine habitat regeneration.

Figure 4.6 demonstrates a strong awareness among maritime stakeholders regarding the complex effects of oil spills, garbage, and sewage on marine biodiversity. The overall agreement on these issues points to an informed understanding of the consequences of oil pollution and underscores the urgent need for effective mitigation strategies. This calls for strengthened environmental monitoring, improved spill response infrastructure, and stringent enforcement of marine pollution controls at Tanga Port.

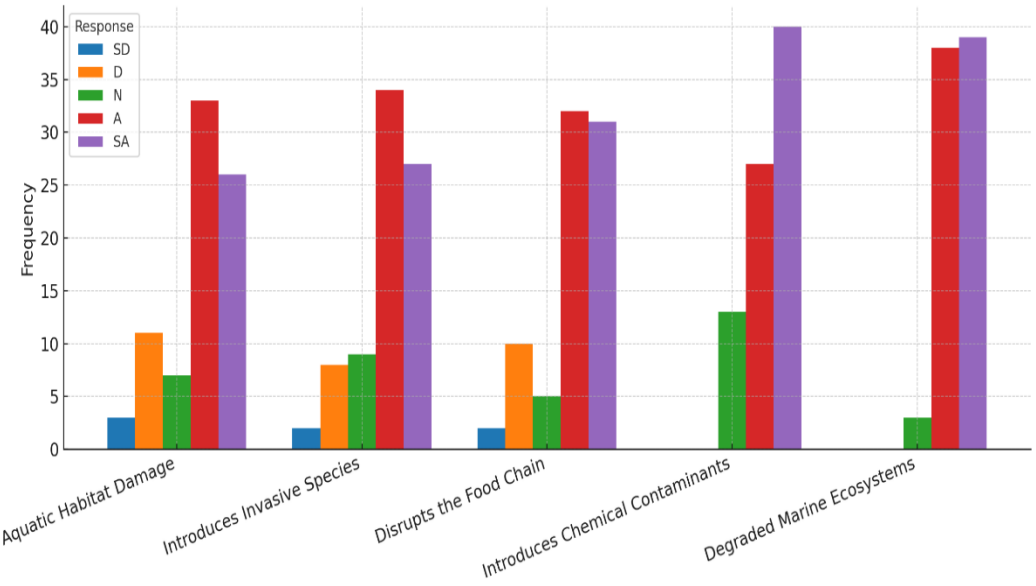

Figure 3: Ballast Water Pollution Effects on Marine Biodiversity

Source: field data, 2025

Figure 3, presents a comprehensive graphical illustration of stakeholder perceptions related to the ecological impacts of ballast water discharge on marine biodiversity. The data indicate a significant concentration of responses within the “Agree” and “Strongly Agree” categories for all identified impacts, demonstrating a broad consensus among maritime stakeholders that ballast water represents serious and multifaceted environmental threats at Tanga Port. A particularly noteworthy finding is the substantial level of agreement regarding the role of ballast water in “Degraded Marine Ecosystems” and the “Introduction of Chemical Contaminants.” These two factors registered the highest frequencies in the “Strongly Agree” category, suggesting that stakeholders not only acknowledge biological risks such as species invasion but also recognize the chemical hazards associated with untreated ballast discharge. This observation aligns with the research of Tay and Konovessis (2023), which identified ballast water as a conduit for persistent pollutants such as heavy metals and hydrocarbons that compromise water quality and adversely affect benthic habitats over time.

Furthermore, the attributes “Introduces Invasive Species” and “Disrupts the Food Chain” also garnered strong support, highlighting stakeholder awareness of the biological instability instigated by foreign organisms. Invasive species have the potential to outcompete native populations, disrupt predator-prey dynamics, and precipitate the collapse of localized ecosystems. This finding corresponds with the study conducted by Mwangi and Temba (2024), which noted a rising incidence of invasive species in East African ports due to inadequate ballast water management. The chart’s visual emphasis on these factors illustrates a sophisticated understanding among respondents of how such disruptions permeate marine ecological networks.

Implications for Future Empirical Investigations

Future research should prioritize longitudinal studies to gain a comprehensive understanding of how stakeholder perceptions and regulatory effectiveness change over time. While current analyses provide valuable insights, they only offer a limited snapshot of a dynamic landscape. Continuous data collection allow researchers to identify trends and evaluate the effects of new technologies and policies on environmental outcomes.

Patel and colleagues (2022) highlight that dynamic research designs that leverage real-time data can provide deeper insights, particularly in fast-evolving technological and environmental settings. By incorporating regular feedback from stakeholders into these longitudinal studies, researchers can enhance their understanding and ensure that their work aligns with practical applications and the needs of the real world.

Policy and Operational Recommendations

Maritime regulatory bodies are urged to invest in advanced digital inspection and waste management systems to effectively address marine pollution. Emphasizing the implementation of eco-friendly procedures onboard ships, the importance of enhanced collaboration between agencies and public-private partnerships is also highlighted. Policy recommendations should focus not only on technological advancements but also on training initiatives that enhance operational competencies and stakeholder awareness. Research conducted by Brown and colleagues in 2023 underscores the benefits of comprehensive policy packages that integrate rigorous regulatory oversight, technology, and training to standardize environmental practices across various industries.

Conclusion

This study assesses the impacts of marine pollution on the sustainability of the marine ecosystem, with a specific focus on Tanga Port in Tanzania. The research addressed key pollution concerns, including oil spills, garbage and sewage, ballast water discharge, and the effectiveness of regulatory frameworks in mitigating these challenges. The findings, derived from both quantitative and qualitative data, provide compelling evidence that marine pollution continues to pose a significant threat to ecological sustainability along Tanzania's coastline.

The reliability and validity analyses confirmed the robustness of the study instruments, with Cronbach's alpha scores above 0.70 and factor loadings exceeding 0.60, indicating that the tools effectively captured the constructs of interest. This statistical soundness provided a solid foundation for further interpretation of the data, particularly in exploring how stakeholder perceptions align with actual pollution management practices and policy enforcement at Tanga Port.

Regression analysis demonstrated that stakeholder perceptions particularly regarding the impacts of oil spills, garbage and sewage, and ballast water discharge positively and significantly influence pro-environmental behaviors and support for regulatory reforms. A key insight was that when stakeholders perceive greater harm from oil and ballast discharge, they are more likely to engage in advocacy or compliance behaviors. The perception of oil spills, garbage and sewage impact emerged as the strongest predictor, emphasizing the need for continued awareness-building in this area.

Conversely, perceptions of regulatory sufficiency were negatively associated with stakeholder motivation to support further interventions. This suggests a potential complacency effect, whereby stakeholders who believe that current regulations are adequate may disengage from active participation in environmental initiatives. This finding highlights the importance of striking a balance between assuring stakeholders of progress while also communicating ongoing environmental risks that demand further attention.

The analysis of frequency tables and descriptive statistics revealed strong levels of awareness and compliance among marine vessel operators regarding both local and international safety regulations. Over 90% of respondents acknowledged their familiarity with safety protocols, which reflects positively on the work of regulatory bodies such as the Tanzania Ports Authority (TPA) and Tanzania Shipping Agencies Corporation (TASAC). These findings are consistent with Tanzania's recent advancements in harmonizing its maritime regulatory practices with international standards.

However, some limitations were identified in enforcement consistency and inspection coverage, particularly in remote or under-resourced areas. While 92.5% of respondents agreed that inspections are frequent and effective, interviews revealed logistical and budgetary constraints that sometimes impede inspection efficacy. This gap underscores the need for increased funding, staff training, and the adoption of digital inspection systems to strengthen the reach and reliability of enforcement.

The ecological impacts of oil spills, garbage and sewage were universally acknowledged by respondents. Notable concerns included biodiversity decline, aquatic habitat degradation, and the disruption of food chains, insights that are strongly supported by empirical literature. Likewise, the effects of ballast water pollution, including the introduction of invasive species and chemical contaminants, were recognized as significant environmental threats. These consistent findings across data sets reaffirm the urgent need for investment in pollution control technologies at Tanzanian ports.

Stakeholders highlighted the inadequacy of current port infrastructure for ballast water treatment and oil spills, garbage and sewage response, despite recognizing improvements in regulatory enforcement. This observation supports the study's recommendation for the adoption of modern ballast water management systems (BWMS) and emergency oil spills, garbage and sewage containment equipment to minimize long-term ecological damage and uphold Tanzania's environmental commitments.

Importantly, the research illuminated the value of regulatory engagement with stakeholders. A remarkable 97.5% of respondents acknowledged that authorities actively promote safety awareness. This high level of engagement fosters mutual accountability and strengthens the culture of compliance. However, ongoing efforts are needed to maintain these relationships and ensure that all operators, especially those in smaller or locally owned vessels, are fully integrated into the regulatory framework.

The study confirms that marine pollution, particularly from oil spills, garbage and sewage and ballast water discharge, poses significant risks to marine biodiversity and ecological resilience at Tanga Port. While regulatory frameworks have advanced and awareness is high, there remain critical gaps in enforcement consistency, treatment infrastructure, and stakeholder engagement. Addressing these challenges requires a multi-stakeholder approach, investment in technology, and continuous education. The sustainability of Tanzania's marine ecosystem depends on proactive, coordinated, and evidence-based interventions guided by insights such as those generated in this study.

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