Assessing the Impact of Marine Traffic on Mangrove Ecosystems in Zanzibar

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Abstract:

This study assessed the impact of marine traffic on mangrove ecosystems in Zanzibar focusing on evaluating marine traffic management practices, identifying ecological challenges and proposing the sustainable strategies for mitigation. A mixed -methods design was employed collecting primary data from 80 respondents using questionnaires, interviews and focus group discussions and supplemented by secondary data from government reports and scientific literature. Data analysis combined descriptive and inferential statistics using SPSS Version 26 and thematic analysis for qualitative data. Findings revealed that 56.2% of respondents perceived current management practices as ineffective in safeguarding mangroves. Key ecological challenges included reduced mangrove coverage (61.3%), increased water pollution (56.3%) and declining marine biodiversity (42.5%). Thematic insights identified oil spills, dredging and anchor damage as primary drivers of degradation. A significant association was found between regulation awareness and reporting of ecological harm (χ^2 = 9.26, df = 3, p = 0.026). The study recommends stronger regulatory enforcement, environmental education and community based restoration initiatives. These measures are crucial to balance marine economic activities with mangrove conservation for sustainable coastal development

Keywords: Marine traffic, mangrove ecosystems, ecological challenges, environmental management, sustainability.

Introduction:

Coastal and marine ecosystems provide critical ecological services supporting biodiversity, protecting shorelines and sustaining livelihoods for millions of people globally (Alongi, 2018). Mangroves, in particular, are vital for coastal protection, serving as breeding grounds for fish and acting as natural barriers against erosion and storm surges. However, the rapid expansion of marine traffic driven by globalisation and increasing demand for maritime transport has placed immense pressure on these ecosystems (Lai et al., 2020).

Globally, studies report that maritime activities such as oil spills, ballast water discharge, and anchor dragging cause significant degradation of mangroves (GESAMP, 2019). In Southeast Asia, for example, mangrove loss of up to 30% has been

attributed to unregulated port expansions and shipping routes (Kurniawan et al., 2018). Similarly, in Sub-Saharan Africa, growing port activities have intensified pollution and deforestation in mangrove regions as observed in Kenya's Mombasa Port and Nigeria's Niger Delta (Njiru et al., 2020; Numbere & Camilo, 2017).

Zanzibar, situated along crucial Indian Ocean shipping lanes is experiencing increased marine traffic due to expanding trade and tourism. While this growth contributes to economic development it also exacerbates ecological threats to its mangrove ecosystems. Reports from the Zanzibar Maritime Authority (ZMA, 2023) indicate rising incidents of oil spills, waste dumping, and habitat destruction near coastal settlements. Despite existing marine traffic regulations, enforcement remains weak and community awareness is limited creating a significant gap between policy and practice.

This study addresses these issues by assessing the effectiveness of current marine traffic management practices, identifying ecological challenges linked to maritime activities and proposing sustainable strategies for mangrove conservation in Zanzibar. The findings aim to inform policymakers, conservationists and maritime stakeholders to promote environmentally sustainable development.

Materials and Methods:

Data Collection Method

A mixed-methods approach was adopted to gather comprehensive data. Primary data was collected through structured questionnaires distributed to key stakeholders, semi-structured interviews with policymakers and environmental experts and focus group discussions (FGDs) with local communities and marine operators. The questionnaire focused on demographic information, awareness of marine traffic regulations, perceived ecological impacts and recommendations for mitigation. Secondary data included environmental reports, policy documents and peer reviewed studies relevant to marine traffic and mangrove conservation.

Research Strategy

The study employed a descriptive cross-sectional design which is suitable for assessing perceptions and practices at a specific point in time (Creswell & Creswell, 2018). This approach allowed for the integration of quantitative and qualitative data to triangulate findings and enhance validity.

Study Population and Sampling Techniques:

The population comprised government officials, environmentalists, port authority employees, fishermen, businesspersons, and community members engaged in maritime activities. A sample size of 100 respondents was determined using Yamane's formula (1967):

A sample size of 100 employees was determined using Yamane's (1967) formula

$$n = \frac{N}{1 + N(e)^2}$$

Where, n=required sample size

N=the population size

e=level of precision, which is 0.05

A combination of purposive sampling (for experts and policymakers) and stratified random sampling (for community members and other stakeholders) ensured diverse representation.

Table. 1 Sample Size Distribution Table

Category	Population (N)	Sample size (n)
Total population	500	100

Data Analysis Method:

Quantitative data was analysed using SPSS Version 26 applying descriptive statistics (frequencies, percentages) and inferential statistics (Chi-square tests) to examine associations between variables. Qualitative data from interviews and FGDs was analysed thematically

following Braun and Clarke (2006) six-step framework to identify key patterns and insights.

Ethical Considerations

Ethical clearance was obtained from the Zanzibar Research Ethics Committee. Participants were informed about the study objectives and assured of confidentiality and the anonymity. Written informed consent was obtained prior to participation and the respondents were reminded of their right to withdraw at any stage without repercussions

Results:

Introduction

This section presents the findings derived from questionnaires, interviews and FGDs addressing the study three objectives: evaluating marine traffic management practices, identifying ecological challenges and proposing sustainable mitigation strategies. The analysis integrates quantitative results with qualitative insights for a holistic understanding.

Demographic Characteristics of Respondents

Gender Distribution

The study determined the gender distribution of respondents and its implications to the study as shown in table 2 below

Table 2: Gender Distribution of Respondents

Gender	Frequency	Percentage (%)
Male	48	60.0
Female	32	40.0

Source: Field data, 2025

The gender distribution shows a higher proportion of male respondents (60%) compared to female respondents (40%). This could be attributed to the fact that male dominance is very common in sectors such as marine transport, port operations and fisheries in Zanzibar. According to the study by Kairo et al. (2018) similar gender patterns have been reported on coastal ecosystem governance in

East Africa where males made up over 65% of the respondents, especially in marine related occupations.

Age Group Distribution

The study determined the age group of the respondents and its implications to the study as shown in table 3 below

Table 3: Gender Distribution of Respondents

Age Group	Frequency	Percentage (%)
18–25 years	12	15.0
26–35 years	28	35.0
36–45 years	24	30.0
46–55 years	10	12.5
56 and above	6	7.5

Source: Field data, 2025

The largest age group which is represented in the study was 26–35 years (35%) followed by 36–45 years (30%). This suggests that a significant portion of respondents are in their productive years and likely to be engaged in marine operations, government work or environmental activities. The findings are consistent with Aboud and Said (2020) who found that the majority of stakeholders engaged in coastal conservation in Zanzibar were aged between 25 and 45 years citing their active role in the policy implementation and economic activities.

Occupational Composition

The study determined the occupational composition of the respondents and its implications to the study as shown in the table 4 below

Table 4: Occupational Composition of Respondents

Occupation	Frequency	Percentage (%)
Government Official	18	22.5
Environmentalist	15	18.75
Port Employee	16	20.0
Fisherman	11	13.75
Businessperson	20	25.0

Source: Field data, 2025

The occupations of respondents were diverse as follows: - Businesspersons (25%) and government officials (22.5%) formed the largest groups followed by port employees (20%) environmentalists (18.75%) and fishermen (13.75%). This diversity ensures a broad representation of views on marine traffic and mangrove conservation.

In the study by Mugo and Kimani (2019) a similar occupational profile was observed on the environmental impact of port activities in Mombasa Kenya where participants included local business owners, port authority staff and community leaders thereby enriching the ecological impact assessment with multidisciplinary perspectives.

The demographic profile of the respondents reflects the relevant stakeholders in Zanzibar's marine and environmental sectors. The gender, age, and occupational distribution align with regional studies, confirming the credibility and relevance of the sampled population in assessing marine traffic management and its ecological implications.

Educational Background of Respondents

Understanding the education level of respondents provides insight into their capacity to comprehend marine environmental issues, regulations and participate in ecological conservation efforts. Education levels are essential for evaluating community engagement and awareness about marine traffic impacts on mangrove ecosystems as illustrated in the table 5

Table 5: Educational Background of Respondents

Level of Education	Frequency	Percentage (%)
Primary	6	7.5
Secondary	14	17.5
Diploma	18	22.5
Bachelor's Degree	26	32.5
Master's Degree	12	15.0
PhD	2	2.5
Total	**80**	**100.0**

Source: Field data, 2025

Objective 1: Evaluating Marine Traffic Management Practices

Respondents were asked about their awareness of the marine traffic regulations and perceptions of the effectiveness of the existing management practices as shown in table 6.

Table 6: Awareness of Marine Traffic Regulations

Awareness Level	Frequency (n)	Percentage (%)
Yes	46	57.5
No	34	42.5

Source: Field data, 2025

Table 7: Effectiveness of Current Marine Traffic Management Practices

Effectiveness Level	Frequency (n)	Percentage (%)
Very Effective	5	6.3
Effective	12	15.0
Neutral	18	22.5
Ineffective	28	35.0
Very Ineffective	17	21.2

Source: Field data, 2025

A combined 56.2% of respondents rated management practices as ineffective or very ineffective, reflecting widespread dissatisfaction. Interviews with port authority officials revealed challenges such as understaffing, inadequate monitoring equipment, and lack of political will.

Thematic Insights from Interviews and FGDs:

Themes emerging included the following:

"*Weak enforcement of marine regulations allows vessels to discharge waste near mangroves*" (Port Official).

"*There are rules but few people follow them because penalties are not strict*" (Community FGD).

These findings aligns with Wang et al. (2019) who noted that enforcement gaps in developing regions hinder effective marine traffic regulation. Likewise, McKenna et al. (2021) observed that without community participation policies often fail.

Objective 2: Identifying Ecological Challenges Posed by Marine Traffic

Respondents were asked about ecological changes observed in mangrove areas over the past five years as indicated below

Table 8: Observed Ecological Changes

Ecological Challenge	Frequency (n)	Percentage (%)
Reduced mangrove coverage	49	61.3
Increased water pollution	45	56.3
Decline in biodiversity	34	42.5
Soil erosion	22	27.5

Source: Field data, 2025

Chi-Square Test Result

An association was tested between awareness of regulations and reported ecological degradation.

Test Statistic	Value	df	Sig. (p-value)
Chi-Square	9.26	3	0.026*

(P < 0.05 indicates statistical significance)

A significant relationship exists between the regulation awareness and the reported degradation suggesting informed citizens are more observant of ecological changes.

Thematic Insights from FGDs and Interviews:

Key themes included the following:

"*Anchor damage is a major issue. Boats destroy roots when they park in shallow areas*" (Fisherman).

"*Oil spills kill fish and blacken mangrove roots*" (Environmentalist).

Similar findings were reported by Alongi (2018) in Southeast Asia and Numbere & Camilo (2017) in the Niger Delta where maritime activities contributed significantly to mangrove degradation.

Objective 3: Sustainable Strategies for Mitigating the Negative Effects of Marine Traffic on Mangrove Ecosystems.

This presents findings on stakeholders' perspectives regarding potential sustainable strategies to address the environmental challenges posed by marine traffic. Data was gathered using questionnaires, interviews and FGDs and analysed quantitatively using SPSS and qualitatively through thematic analysis.

Quantitative Analysis: Perceptions of Sustainable Strategies

Respondents were asked to select from a list of suggested strategies or propose additional measures they believe could mitigate environmental degradation. The table below summarises their responses.

Table 9: Suggested Sustainable Strategies for Marine Traffic Management

Suggested Strategy	Frequency (n)	Percentage (%)
Strengthening enforcement of regulations	58	72.5
Providing environmental education and awareness	52	65.0
Establishing designated marine traffic routes	43	53.8
Introducing eco-friendly marine technologies	39	48.8
Supporting mangrove restoration programs	35	43.8
Enhancing community participation in monitoring	33	41.3
Installing waste management facilities at ports	30	37.5

The data shows a clear prioritisation of enforcement and education initiatives. Over 72% of respondents believe that stricter implementation of marine traffic and an environmental law is essential for safeguarding mangroves. Similarly, 65% emphasized the need for widespread education and awareness campaigns targeting marine operators and local communities.

Inferential Analysis (Chi-Square Test)

To assess whether awareness of marine traffic regulations influences support for sustainable strategies, a chi-square test was conducted.

Variable	Chi-Square	df	Sig. (2-tailed)
Regulation Awareness vs Support for Strategies	8.72	3	0.034*

(*p < 0.05)

This significant relationship suggests that respondents who are aware of existing regulations are more likely to advocate for sustainable management measures.

Qualitative Insights from Interviews and FGDs

Thematic analysis of qualitative data identified three recurring themes regarding sustainable management as follows:

Theme 1: Participatory Governance

Respondents emphasised the importance of involving local communities in mangrove

protection efforts. As one conservation officer noted:

"*The communities who depend on mangroves for their livelihoods must be involved in their protection. Without local ownership even the best policies will fail.*"

Theme 2: Eco-friendly Technologies and Infrastructure

Marine operators and environmentalists stressed the need for cleaner technologies:

"*Subsidizing low-emission engines and installing port waste treatment facilities could significantly reduce pollution,*" said a port authority manager.

Theme 3: Restoration and Education

Many participants advocated for large-scale mangrove reforestation programs and continuous environmental education:

"*We need to restore what is lost and educate the young generation so that they value mangroves as a life-saving resource,*" expressed a local fisherman during an FGD.

These findings align with Ofori et al. (2019) in Ghana where strengthening enforcement and community-based conservation models were found effective in managing coastal ecosystems. Similarly, Njiru et al. (2020) in Kenya highlighted the role of eco-sensitive shipping corridors and technological upgrades in mitigating marine-related environmental challenges.

Discussion:

Interpretation of Results

This study assessed the impact of marine traffic on mangrove ecosystems in Zanzibar highlighting critical gaps in current management practices and proposing sustainable mitigation strategies. The findings revealed that over 56% of respondents perceived existing marine traffic management efforts as ineffective or very ineffective. This perception reflects inadequate regulatory enforcement, limited stakeholder engagement and poor awareness campaigns identified through interviews and FGDs. Observable ecological impacts such as reduced mangrove coverage

(61.3%) and increased water pollution (56.3%) underscore the severity of unregulated maritime activities like oil spills, waste dumping and dredging.

Furthermore, 72.5% of respondents advocated for stronger enforcement of marine traffic regulations while 65% emphasised the need for enhanced environmental education. These results suggest widespread public support for proactive, participatory management approaches to balancing maritime economic activities with ecological conservation.

Comparison with Previous Research

The study findings align with global patterns identified in earlier studies. According to Alongi (2018) observed similar ecological pressures on mangroves in Southeast Asia where unregulated marine traffic led to habitat destruction and biodiversity loss. Similarly, according to Njiru et al. (2020) reported a 15% increase in mangrove deforestation linked to port expansion in Mombasa, Kenya illustrating comparable challenges in East Africa. More so, according to Numbere and Camilo (2017) documented the destruction of over 40% of mangrove forests in the Niger Delta in Nigeria due to oil spills from maritime traffic.

Conversely, successful examples like Australia's "no-anchor zones" in the Great Barrier Reef demonstrate that strict regulatory frameworks and technological innovations can significantly mitigate such environmental impacts (Great Barrier Reef Marine Park Authority, 2021). This contrast highlights the potential benefits of adopting stronger governance models in Zanzibar.

Theoretical and Practical Implications

This study draws on Urie Bronfenbrenner's Ecological Systems Theory which conceptualises human environment interactions within nested systems of influence (Bronfenbrenner, 1979). In the context of Zanzibar, the microsystem (local communities), mesosystem (government institutions and port authorities) and macrosystem (international maritime regulations) interact to shape environmental outcomes. The findings

underscore the theory's relevance to the study particularly the need for cross system collaboration to address ecological degradation.

By extending this theoretical framework, the study suggests that effective marine traffic management requires not only policy interventions but also active participation from all ecological levels including local knowledge systems and community stewardship.

Practically, the study highlights the necessity for strengthened enforcement, eco-friendly maritime technologies and educational programs to bridge the identified knowledge practice gap. Policymakers, port authorities and conservation organisations can use these insights to design more comprehensive marine traffic management strategies.

Research Limitations

Despite its contributions, the study has limitations. The sample size of 80 respondents while sufficient for exploratory research may not fully capture the diversity of perspectives across Zanzibar's coastal communities. Self-reported data introduces potential biases and the cross sectional design restricts causal inferences. Future studies employing larger sample sizes and longitudinal designs would provide more robust insights.

Conclusion:

The study concludes that marine traffic significantly threatens Zanzibar's mangrove ecosystems through unregulated practices and weak governance structures. Key findings include widespread perceptions of ineffective management, evidence of ecological degradation, and strong stakeholder support for sustainable solutions. Protecting mangroves—vital ecological buffers against coastal erosion and climate change—requires urgent, coordinated interventions.

Implications:

Theoretical Implications

The study validates Bronfenbrenner's Ecological Systems Theory in an environmental management context, showing the interdependence of ecological, social and institutional systems in addressing marine traffic impacts.

Practical Implications

Recommendations include the following

Strengthening regulatory enforcement and patrol systems.

Promoting eco-friendly technologies and waste management facilities.

Empowering communities in mangrove conservation through training and resources.

Future Research Directions

Future studies should therefore explore the following areas:

i. The role of indigenous knowledge in mangrove conservation and marine traffic management.
ii. Comparative analyses of regulated versus unregulated marine zones across East Africa.
iii. Longitudinal studies assessing the socioeconomic and ecological impacts of marine traffic.
iv. Economic valuation of mangrove ecosystem services to inform cost-benefit analyses for conservation initiatives.

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