UNIVERSITY OF NIGERIA MARITIME STUDIES AND RESEARCH JOURNAL

Published By
The Institute of Maritime Studies, University of Nigeria, Enugu Campus

University of Nigeria Maritime Studies and Research Journal

Vol.1 No. 1 (August 2025)

Published by
The Institute of Maritime Studies, University of Nigeria, Enugu Campus.

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Printed by:
Printed by: UNIVERSITY OF NIGERIA PRESS LIMITED
University of Nigeria, Nsukka
E-mail: *thepress@gmail.com* / *unnpress@yahoo.com*
Phone: 07038627778

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MARITIME SECURITY AND NIGER IA'S ECONOMIC DEVELOPMENT

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Abstract
The maritime industry is increasingly recognized as a vital driver of national development and economic prosperity. Globally, the sector facilitates about 80% of international trade and contributes over $6 trillion annually to the world economy. For Nigeria, a coastal and oil-exporting country, maritime activities are critical to sustaining international commerce. The high volume of shipping operations supporting oil exports and trade significantly benefits allied sectors such as finance, insurance, real estate, and legal services. These industries rely on efficient maritime infrastructure and logistics, which in turn stimulate broader economic growth. However, the productivity of Nigeria's maritime sector is closely tied to the effectiveness of maritime security. Insecurity in Nigerian waters and the wider Gulf of Guinea disrupts trade, discourages investment, and undermines the sector's economic potential. To address these issues, the Nigerian government, particularly through the Nigerian Maritime Administration and Safety Agency (NIMASA), has implemented several initiatives to enhance security and deter maritime threats. These efforts align with existing legal and institutional frameworks focused on fostering a safe and business-friendly maritime environment. With a coastline stretching approximately 853 kilometers, maritime security is a priority not only for economic development but also for national security. This paper examines the complex maritime security challenges facing Nigeria, their impact on economic growth, and the strategies deployed to enhance safety in Nigerian waters. It further evaluates the progress made in recent years to secure the maritime domain and create conditions conducive to sustained economic advancement.

Keywords: Maritime Sector, Maritime Security, Nigerian Maritime Administration and Safety Agency, Economic Development.

Introduction

In response to the shifting dynamics of the global economy, many of the world's leading nations are actively pursuing alternatives to fossil fuels. A notable example is the automotive industry's growing commitment to phasing out internal combustion engines in favor of electric vehicles within the next few decades. This global energy transition has prompted several oil-dependent nations to begin diversifying their economies in anticipation of a less oil-reliant future. Given that petroleum is a finite resource, the development of alternative sectors has become a strategic imperative to ensure continued economic growth and stability (IMF, 2024). Nigeria, despite its abundance of natural wealth, remains heavily reliant on crude oil exports and has yet to fully tap into other promising

sectors. Among these underutilized resources, the maritime industry emerges as a particularly valuable opportunity for diversification.

According to the National Bureau of Statistics (2016), Nigeria's economy has long been classified as mono-product, heavily centered on crude oil exports, which account for approximately 90% of the nation's foreign exchange earnings. The International Monetary Fund (2024) warns that while some countries still enjoy significant oil reserves, the depletion of hydrocarbon resources looms for many oil-producing nations. This reality underscores the urgent need for Nigeria to develop robust non-oil sectors capable of sustaining economic growth and employment in a post-oil era. The maritime sector represents a viable pathway toward this goal, yet it remains significantly underexploited. As a coastal nation with extensive access to inland and international waterways, Nigeria is well-positioned to generate substantial revenue from the movement of goods and people across its waters.

The maritime sector holds considerable promise for Nigeria's economic transformation (Lloyd et al., 2020). It encompasses a wide range of aquatic and marine resources—including oceans, seas, rivers, lakes, coastal zones, and even subterranean waters. Recognizing its strategic value, the Federal Government of Nigeria has begun repositioning the maritime sector as a key component of its broader economic diversification agenda (Salau & Falaju, 2018). However, just as the oil sector has benefitted from years of substantial investment and regulatory frameworks, realizing the full potential of maritime resources also requires sustained security, policy support, and infrastructural development. Abubakar (2019) highlights that the effective implementation of blue economy principles could not only diversify Nigeria's revenue streams but also offer solutions to several of its socio-economic challenges. Achieving these objectives, however, depends on the establishment of strong legal and institutional frameworks, along with critical enablers such as ecosystem-based management, marine spatial planning, and innovative financing strategies. Accordingly, institutions such as the Federal Ministry of Transport and NIMASA are at the forefront of efforts to coordinate and regulate the sector for maximum national benefit (Anozie et al., 2019).

The Nigerian Maritime Sector

Nigeria is strategically positioned in West Africa along the Gulf of Guinea, part of the Atlantic Ocean. Geographically, the country lies at approximately 9.0820° N latitude and 8.6753° E longitude, situated in the innermost part of the Gulf of Guinea along Africa's western coastline. Covering a total landmass of about 923,768 square kilometers (356,669 square miles), Nigeria stretches approximately 1,127 kilometers from east to west and 1,046 kilometers from north to south (Folami, 2017). It shares land borders with Benin to the west, Niger to the north, and Cameroon and Chad to the east. With an estimated population of over 216 million, Nigeria stands as the most populous country in Africa and ranks sixth globally (United Nations Department of Economic and Social Affairs in Olatunji & Adejoro, 2022).

Nigeria's maritime territory includes a sea area of approximately 46,500 square kilometers and an Exclusive Economic Zone (EEZ) of about 210,900 square kilometers (Folami, 2017). This expansive maritime endowment positions Nigeria to play a central role

in regional maritime commerce across the Gulf of Guinea and the broader West African coast (Lloyd et al., 2020; Ateme, 2020). The country's coastal region encompasses several key states, namely Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Lagos, Ogun, Ondo, and Rivers. Additionally, the Niger Delta region—an area critical to Nigeria's socio-economic landscape—comprises nine states: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers (Ringim, Muhammad & Lyakurwa, 2016). These geographical and demographic attributes highlight Nigeria's immense potential to leverage maritime assets for sustainable economic development.

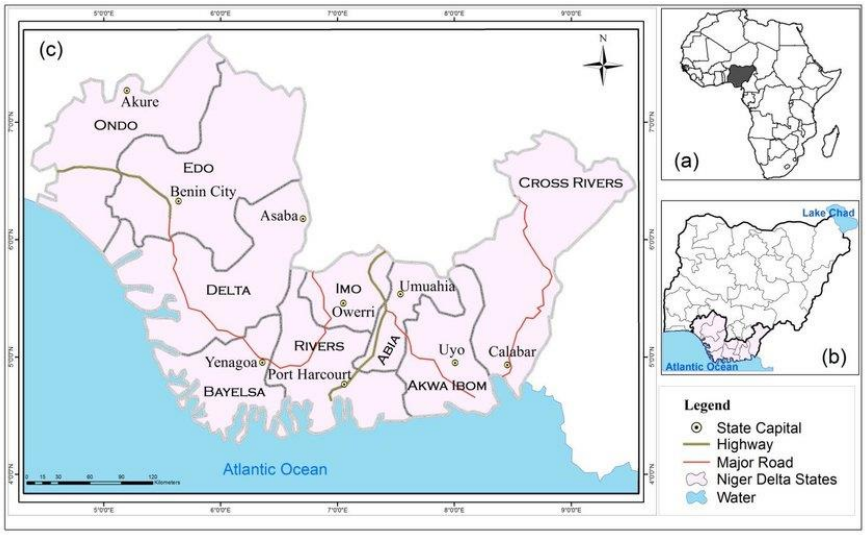

Fig. 1: (a) Position of Nigeria in Africa, (b) Map of Nigeria showing coastal area of the Niger Delta, (c) Niger Delta States (Ringim, Muhammad & Lyakurwa, 2016).

Such a geographically strategic position promises a myriad of economic benefit to the states and the country in particular, with the Niger Delta states being blessed with an abundance of natural resources.

The Nigerian maritime industry is a broad and multifaceted sector that encompasses all business and operational activities linked to the country's marine environment. It includes a wide array of both offshore and onshore economic engagements. Offshore operations involve fishing, salvage, towage, and the exploration and exploitation of underwater resources, while onshore activities cover port operations, maritime logistics, shipbuilding, ship repair, and maintenance services. These diverse enterprises collectively form the structural framework of Nigeria's maritime economy.

As noted by Nsan-Awaji (2019), maritime transportation in Nigeria serves as a vital and intricate component of the national transportation system. It integrates multiple interconnected functions such as harbor services—comprising pilotage, dredging, berth provision, and the maintenance of navigable waterways—and the interface between ships and ports, including cargo handling and freight operations. Additionally, the port-to-land interface ensures the efficient movement of goods to and from the inland regions, linking maritime trade to the wider economy.

According to the Department of Environmental Affairs (DEA, 2019), maritime transport involves the movement of people and goods through sea routes and encompasses elements such as national vessel registration, flagging, and cargo logistics. The maritime manufacturing sub-sector, on the other hand, focuses on the construction of ships and marine equipment, repair and maintenance services, and offshore oil and gas support operations. This entire system operates as an integrated chain involving the design, construction, operation, and management of various vessels serving both commercial and leisure purposes. It also covers offshore engineering, port infrastructure development, shipbuilding, and the overall transport of goods and individuals across sea and inland water networks. As emphasized by Walker (2018), this sector generates significant domestic demand and employment, playing a crucial role in driving national economic growth.

A Historical View of the Nigerian Maritime Sector

Modern maritime transport in Nigeria traces its roots back to 1892 with the arrival of Elder Dempster's pioneering vessel, The Fore Runner (Igberi & Ogunniyi, 2013). This marked the beginning of structured maritime operations in the region. Building on this foundation, the Nigerian National Shipping Line (NNSL) was established in 1958 as part of efforts to assert national control over shipping activities (Ekpo, 2012). Since gaining independence, the growth of Nigeria's maritime industry has been marked by notable achievements. From the modest inheritance of two first-generation ports—Lagos and Port Harcourt—the country has expanded its port infrastructure significantly. Today, Nigeria boasts multiple modern seaports, including deep-sea and river port projects developed through public-private partnership (PPP) initiatives across various coastal states.

The post-independence period has seen several transformative developments in the maritime sector. One of the most impactful was the liberalization and concessioning of port operations in the early 2000s, aligning Nigeria's maritime governance with global best practices. This shift attracted considerable investment in container terminals and boosted the efficiency and competitiveness of port operations. Nigerian stakeholders have played a prominent role in this evolving port landscape. Another key area of progress is human capital development. Over the past six decades, there has been substantial growth in maritime personnel, particularly in seafaring professions, supported by both government-owned and private maritime training institutions. The now-defunct NNSL was instrumental in providing sea-time experience to several generations of Nigerian seafarers until its decline in the early 2000s.

Further advancements have emerged in the offshore supply vessel (OSV) sub-sector, driven by enabling policies such as the Coastal and Inland Shipping (Cabotage) Act of 2003 and the Nigerian Oil and Gas Industry Content Development Act of 2010. These legislative instruments have fostered greater indigenous participation, encouraging more Nigerians to invest in ship ownership, shipbuilding, and maritime services. For example, local capacity has grown so significantly that institutions like the Maritime Academy of Nigeria (MAN), Oron—which once relied on foreign leadership—are now managed by highly qualified Nigerians.

Despite these considerable gains, challenges persist. Omoju (2020) observes that, alongside its accomplishments, the Nigerian maritime industry has also faced criticism,

particularly concerning insecurity along its waterways. This remains a critical issue for both domestic stakeholders and the international maritime community. Given that over 95% of Nigeria's trade by volume and more than 70% by value is conducted via maritime routes (NIMASA, 2019), securing the industry is imperative. Addressing these vulnerabilities is essential for protecting national interests and sustaining the progress made so far.

Contribution of the Maritime Sector to the Nigerian Economy

Over time, Nigeria's maritime sector has evolved into a vital engine for economic growth and development. From its modest beginnings under colonial rule, the industry has matured into a powerful source of national revenue, industrial advancement, human capital development, and a gateway to international trade and diplomatic engagement (Jamoh, 2022). In the early post-independence period, when Nigeria operated a regional system of governance, agriculture was the country's primary foreign exchange earner. Products like cocoa, palm oil, and groundnuts were exported through maritime channels, demonstrating that both agriculture and, later, the oil sector have always relied on maritime transportation to thrive. Thus, maritime logistics form a critical bridge between key economic sectors and national development (Lloyd et al., 2020). With an estimated annual freight bill ranging between $5 billion and $6 billion, shipping remains central to Nigeria's trade infrastructure and broader economic strategy (Atoyebi, 2022).

According to the United Nations Conference on Trade and Development (UNCTAD, 2024), global maritime trade saw a 2.4% increase in 2023, reaching 12.3 billion tons, with further growth of 2% projected for 2024. The average annual growth rate is expected to hover around 2.4% between 2025 and 2029, led predominantly by increases in containerized and dry bulk cargo, projected to grow at compound annual rates of 4.5% and 3.9% respectively. The economic value of seaports is significant, extending beyond cargo handling to encompass storage, shipping agency operations, and various ancillary services. Charges such as port rent, especially for ships in transit, further contribute to national income. The maritime domain continues to dominate global trade and offers expansive opportunities in sectors like fisheries, renewable energy, marine tourism, environmental management, and biodiversity conservation (Amechi in NIMASA, 2019). It is also a major employer, supporting thousands of Nigerians through both formal and informal employment. Industry analysts estimate that if properly harnessed, Nigeria's maritime sector could generate up to ₦7 trillion annually (Agbakoba, 2025).

The sector's contributions to Nigeria's economy are evident in its impact on Gross Domestic Product (GDP), both directly and through multiplier effects. Direct contributions include the sector's revenue, profits, and value-added activities. Indirectly, the maritime industry stimulates other sectors by demanding goods and services needed for its operations. Induced impacts emerge when maritime-generated income fuels spending across the economy, enhancing consumer purchasing power and stimulating growth in ancillary industries (Lloyd, 2020). The maritime sector is therefore indispensable, serving as a foundational input into nearly every aspect of the national economy. Few industries can function effectively without the maritime transport system, which facilitates the importation of critical raw materials and equipment (Onyeabor et al., 2020).

As maritime trade volume increases, so does national economic output. This surge in activity has far-reaching implications, positively influencing sectors such as finance, insurance, law, and real estate. These industries benefit from the increased connectivity and efficiency provided by maritime logistics, enabling them to operate at optimal capacity and contribute to broader economic development.

There have long been projections that the maritime sector could eventually surpass the oil industry in revenue contribution. Recent data suggests this shift may be underway. In 2024, four key regulatory bodies in Nigeria's maritime domain—the Nigerian Ports Authority (NPA), the Nigerian Maritime Administration and Safety Agency (NIMASA), the Nigerian Shippers' Council (NSC), and the National Inland Waterways Authority (NIWA)—collectively generated ₦850.32 billion in revenue. Specifically, the NPA contributed ₦758.26 billion, NIMASA ₦67.02 billion, NSC ₦19.15 billion, and NIWA ₦5.89 billion (Adenubi, 2025). Additionally, the NPA has projected a revenue target of ₦1.75 trillion for 2025 (Ships and Ports, 2025). These figures underscore the immense and growing potential of the maritime industry as a cornerstone of Nigeria's economy.

However, persistent security threats continue to undermine this potential. Oyeduntan (2022) emphasizes that maritime insecurity has remained a serious challenge for years. Prof. Alfred Oniye, an international anti-piracy expert, revealed that the absence of adequate security along 98% of Nigeria's 853-kilometre coastline results in estimated annual losses of over $100 billion (Onyenucheya, 2024). This insecurity imposes steep economic costs on Nigeria relative to other coastal nations. President Muhammadu Buhari once noted that the country loses approximately $26.3 billion annually due to maritime insecurity, a situation he described as harmful to both economic development and public safety (Okodidi, 2021). In alignment with the former Director General of NIMASA (Agwaibor, 2021), it is clear that strengthening stakeholder collaboration—both domestically and across the Gulf of Guinea—is vital to mitigating these threats and realizing the sector's full potential.

The Concept of Maritime Security

Security has consistently ranked among the most significant factors influencing the performance of Nigeria's maritime sector (Anozie et al., 2019; Lloyd et al., 2020; Omoju, 2020; Edih, Igemohia & Faghawari, 2022). Other notable challenges include inadequate infrastructure, bureaucratic bottlenecks, inconsistent legal frameworks, corruption, limited investment capital, poor incentives for investors, scarcity of indigenous carrier vessels, and concerns about the seaworthiness of locally owned ships (Lloyd et al., 2020).

Broadly speaking, security refers objectively to the absence of threats to established values, and subjectively to a state free from fear that these values may be compromised (Paul, 2023). While there is no globally standardized definition of maritime security, it generally encompasses both longstanding and emerging regional and international threats affecting the maritime domain. It is a multidimensional concept that intersects with national security, environmental protection, economic stability, and human safety (Bueger & Edmunds, 2017; Siebels, 2020). Operationally, maritime security covers a wide range of challenges such as piracy, armed robbery at sea, illegal trafficking (of persons and goods), unregulated fishing, and marine pollution (McNicholas, 2016). Additionally,

state-level conflicts, maritime terrorism, and disputes over territorial waters, such as those seen in the South China Sea and the Strait of Hormuz, further complicate the maritime security landscape.

The scope of maritime security also spans several sectors, including search and rescue operations, coastal policing, offshore oil and gas safety, marine environmental surveillance, and naval operations (Maluki, 2012). At its core, maritime security involves safeguarding all elements within the maritime environment—whether natural or man-made—through the implementation of protective measures by vessel operators, port authorities, offshore facility managers, and maritime institutions. These efforts aim to deter acts of piracy, sabotage, theft, terrorism, and any interference with legitimate marine operations (McNicholas, 2018).

Limo (2012) conceptualizes maritime security as the condition in which navigable waterways are free from activities that undermine environmental integrity and endanger lawful maritime operations. Similarly, Payi (2015) views it as a mix of preventive and reactive actions designed to shield maritime infrastructure and commerce from unlawful threats, emphasizing proactive steps to enable safe and efficient maritime trade.

In the Nigerian context, several maritime crimes have emerged as major threats to the nation's economic and strategic interests. Rear Admiral Obinwanne Egbuchulam, Flag Officer Commanding the Central Naval Command, identified sea robbery, piracy, oil theft, sabotage, and militancy as critical security issues confronting Nigeria's waters (Igoni, 2021). Given the sector's importance as a core economic engine, safeguarding maritime resources is of paramount importance. Nigeria's maritime potential arguably surpasses that of its oil, gas, and agricultural sectors. In fact, oil production and transportation increasingly occur offshore—within the maritime domain—making maritime security indispensable to the functioning of the broader economy (Payi, 2015).

Moreover, the significance of the maritime industry extends beyond oil to include key export sectors like fishing and shipping. Professor Donna Nincic, as cited in Payi (2015), highlights that fishing is Nigeria's second-largest non-oil export sector. However, due to frequent pirate attacks on fishing vessels, many captains have opted to stay docked, causing considerable economic losses. Nigerian maritime exports also represent over 60% of seaborne trade for 16 countries in West Africa. Consequently, piracy-related disruptions could cost Nigeria up to $600 million in lost export revenue. In addition, maritime insecurity has raised shipping costs, as insurers impose higher premiums to offset risk—ultimately translating into increased prices for goods and contributing to inflation across the region.

The International Maritime Bureau (IMB, 2022) identifies several piracy hotspots in Nigeria, including Lagos/Apapa, Bayelsa, Brass, Bonny Island, and Port Harcourt. IMB reports that attackers are frequently armed and aggressive, often hijacking vessels, looting cargo, and kidnapping crew members. Attacks have been recorded as far as 212 nautical miles from shore, and many incidents likely go unreported. Kidnapping for ransom remains a predominant threat, and vessels are strongly advised to implement additional safety measures when operating in these high-risk zones. In the past, there were also reports of tankers being hijacked and partially emptied of cargo, particularly petroleum products.

Beyond piracy and armed robbery—the oldest and most pervasive maritime crimes—Nigeria's waters are plagued by a wide array of transnational organized crimes.

According to Odanwu (2016) and the Yaoundé Code of Conduct (2013), these include money laundering, arms and drug smuggling, illegal oil bunkering, human trafficking, marine pollution, illegal fishing (IUU), dumping of toxic waste, maritime terrorism, hostage-taking, and destruction of offshore infrastructure. These illicit activities have stained Nigeria's image in the global maritime community and stifled economic development.

In relation to IUU fishing, Odanwu (2016) noted that illegal practices in this sector result in considerable losses to the Nigerian economy. Fisheries contribute over $30 million annually in foreign exchange, and the Federal Department of Fisheries has reportedly lost an average of ₦44 million yearly due to reduced licensing revenues. Nigeria's coastal waters, like those of other West African nations, are rich in biodiversity, supporting small-scale fisheries that produce 80% of the nation's fish and provide livelihoods to an estimated 24 million Nigerians. Notably, around 73% of these individuals are women. The fishing sector contributed 0.84% to national GDP in 2019 and 1.09% in 2020. Industry leaders, under the Fisheries Cooperative Federation of Nigeria Limited, estimate that the country loses $70 million annually to illegal fishing, primarily due to the activities of foreign vessels exploiting Nigeria's poorly monitored maritime territory (Laminu, 2021). The economic ramifications of these illicit operations are immense and demand urgent, concrete interventions beyond policy statements.

Impact of Maritime Security on Economic Development

Maritime transport remains the dominant mode for global trade, handling the vast majority of imports and exports worldwide. As such, maritime security is of strategic importance to all nations, serving as a fundamental component of national security, particularly for littoral states. In Nigeria, the significance of maritime transportation is underscored by its vital role in economic development, functioning as a key link in the supply and value chains associated with the extraction, distribution, importation, and exportation of goods (Ogoun, 2022). Insecurity within this domain can lead to substantial economic losses, including direct reductions in hydrocarbon revenue and fisheries output, and indirect impacts such as heightened transportation and logistics costs, reduced tourism inflows, and diminished foreign direct investment. Moreover, insecurity in offshore zones presents economic and environmental risks that could undermine the nation's maritime potential. It is therefore imperative to recognize the growth potential of the sector, particularly as the uninterrupted inflow of imports relies heavily on effective maritime governance and security infrastructure (Ikpechukwu, Olowolagba & Yomi, 2020).

In support of this position, the National President of the Association of Nigeria Licensed Customs Agents (ANLCA), Iju Tony Nwabunike, emphasized in his presentation titled "Blue Economy: Pathway for Nigeria's Economic Diversification" that as many as 300,000 jobs could be immediately created if Nigeria's maritime and inland waterways were made safe for legitimate commercial activity (Onyenucheya, 2021). The protection of vessels, cargoes, and crew members is thus not merely a security imperative, but a foundational requirement for sustained economic growth, particularly in sectors related to trade, investment, employment generation, and maritime recreation. Failure to secure this vital space threatens to erode the vast economic benefits it can offer.

Several studies have documented the maritime sector's contributions to Nigeria's GDP and broader economic growth (Lloyd et al., 2020; Ikpechukwu, Olowolagba & Yomi, 2020; Oyeduntan, 2022). Nevertheless, these contributions cannot be realized without security. Development is inextricably tied to the existence of a safe and secure environment, and without this foundation, maritime trade and enterprise cannot thrive. It is this realization that has driven Nigeria and its international partners to initiate various strategies—nationally, regionally, and globally—to ensure effective maritime security and surveillance.

A reflection of the sector's performance can be seen in Nigeria's vessel traffic trend over a 17-year period as reported by the Nigerian Ports Authority (NPA, 2023). Between 2013 and 2018, vessel arrivals at Nigerian ports showed a steady decline, possibly linked to worsening insecurity and operational inefficiencies. However, an upward shift was recorded in 2019. A subsequent dip in 2020 may be attributed to disruptions caused by the COVID-19 pandemic. Notably, a sharp rebound occurred in 2021, which coincided with the launch of the Deep Blue Project—a major maritime security initiative. During this period, vessel traffic rose from 3,972 in 2020 to 4,640 in 2021, indicating that improved security infrastructure may have had a positive impact on maritime activity.

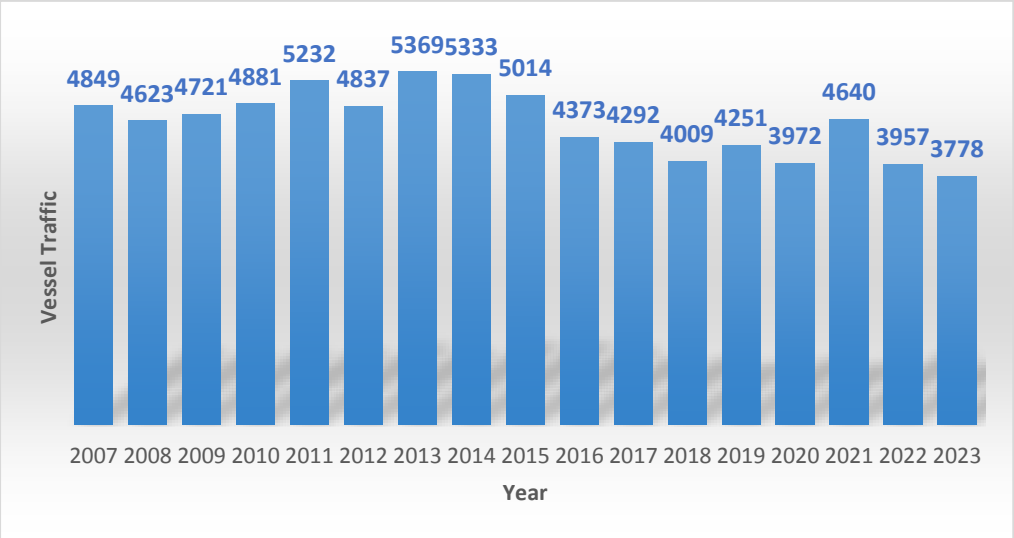

Fig. 2: Vessel Traffic in Nigeria 2007-2023 (NPA, 2023)

A renewed downward trend in vessel traffic was recorded between 2022 and 2024, with 3,957 and 3,778 vessels arriving at Nigerian ports in 2022 and 2023 respectively (Punch, 2024). Maritime analysts have attributed this decline not to security concerns but to macroeconomic instability, particularly the persistent scarcity of foreign exchange, which triggered a sharp depreciation of the naira. This economic challenge significantly reduced import activity, thereby impacting port operations. According to Mr. Lucky Amiwero, President of the National Council of Managing Directors of Licensed Customs Agents, the downturn was primarily driven by the floating of the naira's exchange rate. He noted that, "People were no longer importing. If you go to the ports, they are dry. The hardship in the

country is too much. Many people cannot even access funds" (Punch, 2024). This observation underscores the fact that while improvements in maritime security have enhanced operational safety, broader economic factors—particularly currency volatility and financial accessibility—continue to exert significant pressure on Nigeria's maritime sector.

The impact of these economic challenges on the maritime industry becomes clearer when viewed alongside Nigeria's historical GDP data. Figure X below presents the country's Gross Domestic Product (GDP) in billions of U.S. dollars from 2007 to 2023, based on data from the World Bank (2025). This chart provides a broader macroeconomic context for understanding the fluctuations in maritime trade volumes and highlights the interdependence between national economic performance and maritime industry activity.

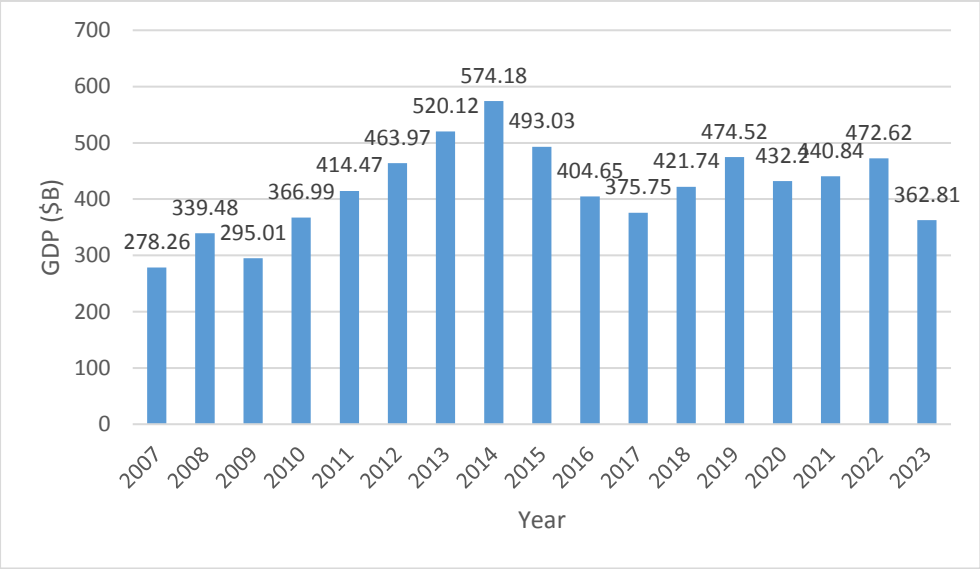

Fig 3: Nigeria GDP from 2007 to 2023 (World Bank, 2025)

When compared with Fig. 2, a similar trend could be deduced. GDP grew with increase in port vessel traffic, and vice versa. The years 2016, 2017, 2018 and 2020 in Fig. 2 were marked with relatively low vessel traffic, which coincided with same periods in Fig. 3 where lower GDP growths were recorded. This is, therefore, a clear pointer to the fact that maritime trade contributes to economic growth.

Maritime insecurity has a profound and adverse effect on the cost of international trade. In regions where piracy and related threats are prevalent, trade routes are often rerouted, maritime insurance premiums rise, and cargo shippers opt for alternative, often more expensive, ports to ensure the safety of their goods (Anyanwu, Melvin, Obasi, Ogola & Ogwo, 2022). In 2020 alone, the financial burden of piracy in affected areas was estimated to exceed $1.1 billion, a sum that could have been directed toward infrastructure, social services, or other developmental priorities (Sackey et al., 2022).

The economic implications of maritime insecurity for Nigeria are particularly severe due to the country's reliance on maritime trade. Olugbenga Oyewole, former Senior Special

Assistant to President Goodluck Jonathan on Maritime Services, warned in a February 2013 Daily Independent interview that if Nigeria continued to be rated among the most insecure maritime nations globally, it would trigger a resurgence in insurance surcharges, with the costs being passed down to consumers through higher prices (Oyewole, as cited in Daily Independent, 2013). At the time, Nigerians were reportedly paying an estimated $15 million daily on imports—a cost exacerbated by the imposition of high-risk insurance premiums due to the unsafe reputation of Nigerian waters (Obi, 2013).

Although the Nigerian Bureau of Statistics has not published exact figures on War Risk Insurance expenditures, estimates suggest that the country has spent over $1.5 billion in just the past three years on premiums paid to major international insurance firms such as Lloyd's of London, Protection and Indemnity (P&I) Clubs, and other insurers (Egole, 2025). This financial drain represents a major economic consequence of maritime insecurity and underscores the urgent need for comprehensive and effective measures to safeguard Nigeria's maritime domain and reduce the cost of doing business.

Recent Trends of Maritime Insecurity in Nigeria and the Gulf of Guinea

Maritime security challenges are inherently transnational and cannot be effectively addressed by a single nation, regardless of its capacity or strategic resources. The nature of maritime threats—spanning piracy, smuggling, illegal fishing, and transnational organized crime—demands collaborative international efforts for meaningful containment. Jamoh (2021) emphasizes that collective action among affected and neighboring states is indispensable for combating such threats. A fitting parallel can be drawn from Nigeria's counter-insurgency operations in the North-East, where initial unilateral efforts yielded limited results. It was not until the formation of a multinational joint task force involving Chad and Cameroon that the security situation began to stabilize. This experience underscores the necessity of regional alliances in tackling border-transcending threats.

In response to maritime security challenges, various multilevel initiatives have been launched involving local, regional, and global actors. These interventions range from legislative enforcement under frameworks such as the Yaoundé Code of Conduct to strategic cooperation in capacity building, financial assistance, and technological enhancement (Sackey et al., 2022). In addition, attention is increasingly being drawn to lesser-publicized maritime crimes such as illegal, unreported, and unregulated (IUU) fishing, which has significantly contributed to the depletion of fish stocks in the Gulf of Guinea region (Sackey et al., 2022). Policy responses have thus expanded beyond traditional piracy and armed robbery to include broader ecological and economic threats in the maritime domain.

One of the most significant national efforts in recent years is Nigeria's establishment of the Deep Blue Project (DBP) through the Nigerian Maritime Administration and Safety Agency (NIMASA). The DBP was designed to enhance maritime security, with a specific focus on deterring piracy, sea robbery, and other illegal maritime activities within Nigeria's territorial waters and the broader Gulf of Guinea. Central to the DBP is the coordination of inter-agency operations and intelligence-sharing frameworks among Gulf of Guinea nations to address maritime threats collectively. Since its launch, the project has recorded notable successes. For instance, data from the International Maritime Bureau

(IMB) in its 2021 trend analysis (see Fig. 4) revealed a significant decline in reported piracy and armed robbery incidents in Nigerian waters, suggesting that criminal activities may be shifting away from areas secured by the DBP.

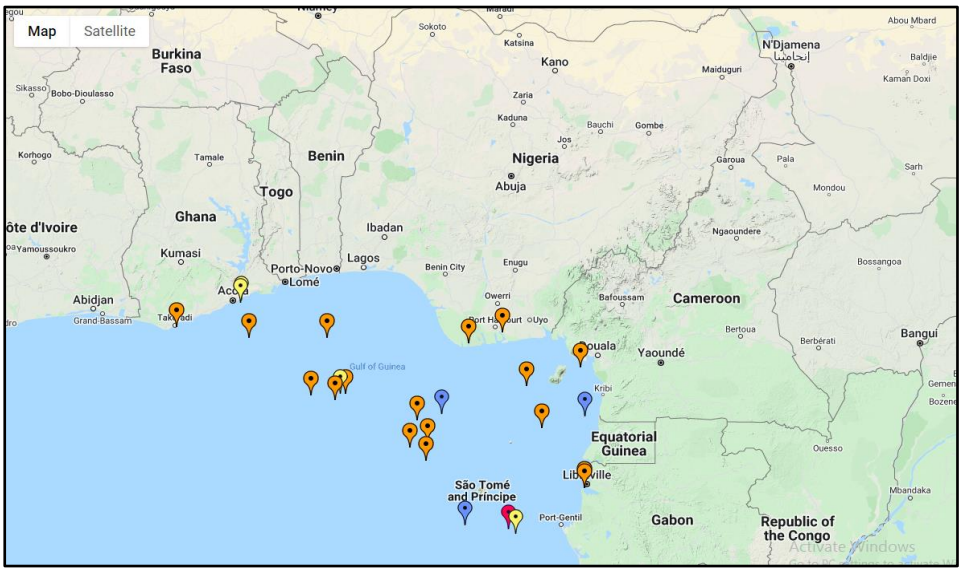

Fig. 4: IMB Piracy & Armed Robbery Map, 2021 (IMB, 2022)

= Attempted Attack = Boarded = Fired upon = Hijacked = Suspicious vessel

According to the International Maritime Bureau's (IMB) 2021 global piracy report, there were 68 recorded cases of piracy and armed robbery against ships—a significant decline from the 98 incidents reported during the same period in 2020, marking the lowest figure since 1994. During the first half of 2021, the IMB's Piracy Reporting Centre (PRC) documented 61 cases of vessels being boarded, along with four attempted attacks, two incidents involving gunfire, and one hijacking.

Although the overall number of incidents decreased, threats to crew safety remained a serious concern. In the first six months of the year, 50 crew members were kidnapped, while three were taken hostage, three threatened, two assaulted, one injured, and one killed. Despite the encouraging drop in overall figures, the IMB PRC warned that the maritime industry must remain vigilant, noting that boarding occurred in 91% of reported cases (IMB, 2022).

Meanwhile, in 2021, the Deep Blue Project's marine assets began to secure the Lagos mooring area through operational patrols. Data from the beginning of the year to date suggests significant changes in piracy trends in comparison to previous years. Since the beginning of 2021, 6 piracy events have taken place in Nigerian waters. This represents an over 60% decrease in piracy events in Nigerian waters. It has been reported that between the years 2019-2020, piracy attacks occurred near the coast and there were a lot of piracy incidents in Lagos Port Waiting Area, compared to 2021 when there was no record of such incidents. In addition, it has been also reported that during the years 2019-2020 there were

a lot of piracy incidents near the coast of the "Niger Delta" area, gas and crude oil terminals. That means the attacks seem to come from this area.

It is important to note that the piracy attacks that occurred in Nigerian waters in 2021 occurred in blue water areas far from the Nigeria Coast, except for only one incident that occurred within a port or port waiting area. The remainder of the events took place on maritime borders within Nigeria and internal waters and the joint regime area where enforcement and prevention present more challenges (Sanni, 2022).

In the past three years (Q1 2022 to Q1 2025), Nigeria has consistently maintained a zero piracy record, a significant achievement that underscores the effectiveness of enhanced maritime security measures and strategic policy interventions (Ubanna, 2025). This milestone has positioned Nigeria's waters as one of the safest for maritime trade and investment, fostering increased confidence among local and international stakeholders. The sustained efforts of agencies such as the Nigerian Maritime Administration and Safety Agency (NIMASA), alongside collaborations with regional and global partners, have played a crucial role in ensuring the security of the country's maritime domain. As a result, Nigeria's shipping and offshore activities continue to thrive, driving economic growth and reinforcing the nation's status as a key player in the global maritime industry.

Contemporary Efforts towards Sustaining Maritime Security in Nigeria

Recent global and national initiatives to combat maritime insecurity have begun to show promising outcomes. The Nigerian Maritime Administration and Safety Agency (NIMASA, 2022) highlighted that the International Maritime Bureau (IMB), in its mid-year 2022 report, commended the worldwide decline in piracy and described it as a hopeful turning point for the international shipping industry. This recognition followed the Bureau's recording of the lowest number of piracy incidents since 1994, attributing the progress to sustained awareness campaigns aimed at enhancing maritime safety.

Jamoh (2022) emphasized that this positive trend is largely the result of collaborative efforts among local, regional, and international stakeholders. Notably, the Gulf of Guinea Declaration on the Suppression of Piracy reported zero cases of seafarer abduction one year after its adoption in May 2021—a remarkable improvement compared to 2020, when 130 seafarers were kidnapped. The declaration's status update further noted that no incidents of kidnap-for-ransom were reported in 2022, down from 20 in 2020 and 12 in 2021 (Tribune Online, 2022). The overarching objective remains to maintain this progress, with expectations that Nigeria will eventually benefit through reduced insurance costs on cargo bound for its ports and potential adjustments to the current War Risk premium (Jamoh, 2022).

Below is a live map showing all piracy and armed robbery incidents reported to IMB Piracy Reporting Centre during 2025.

Fig. 5: IMB Piracy Map 2025 (IMB, 2025)

A highlight of recent maritime attacks in the Gulf of Guinea indicates a shift away from Nigerian Waters. Between Q1 2022 and Q1 2025, no incidence of piracy has been recorded in the Nigerian waters. However, some neighboring countries do not share similar testimony. Most of the recently recorded attacks took place in Equatorial Guinea, Ivory Coast and Ghana.

It is important to note that there has been a resurgence in the incidents of piracy and armed robbery in some Gulf of Guinea countries in 2024. On January 1, 2024, pirates attacked the Hana 1, a small chemical tanker sailing through the waters of Equatorial Guinea and kidnapped nine (9) crew members. Also, the IMB third quarter (Q3) 2024 Piracy Report highlighted that twelve (12) incidents were reported in the Gulf of Guinea region from January to September 2024, with eleven (11) crew members kidnapped and twenty-one (21) taken hostage (Williams, 2024). Most recently, on March 27th, 2025, a Ghana-flagged fishing vessel Mengxin 1 was attacked off the coast of Accra, and three Chinese crew members kidnapped. This shift from Nigerian waters may be attributed to measures which have been put in place to prevent such attacks.

Current efforts to combat maritime insecurity in Nigeria are multifaceted, involving both national and international strategies. Notably, the Nigerian Navy has taken proactive steps by dismantling pirate camps, while the Deep Blue Project's C4i coastal surveillance system and partnerships with foreign naval forces have bolstered law enforcement capabilities beyond Nigerian territorial waters. Key regional initiatives such as the Gulf of Guinea Maritime Coordination Forum/Shared Awareness and Deconfliction (GoG/SHADE) have also played a crucial role in improving maritime safety in the region.

Olufowobi (2022) highlighted Nigeria's pioneering role in addressing maritime threats in the Gulf of Guinea. He noted that Nigeria's regional engagement led to the formation of frameworks such as the ECOWAS Integrated Maritime Security Strategy (EIMS), the Inter-Regional Coordination Centre (ICC) in Yaoundé, and the African Integrated Maritime Strategy (AIMS) (Osamgbi, 2019). At the national level, the enactment of the Suppression of Piracy and Other Maritime Offences (SPOMO) Act on 24 June 2019, signed

into law by President Buhari, marked a significant milestone. This legislation provides a legal basis for prosecuting maritime crimes and aligns with the International Maritime Organization's call for distinct anti-piracy laws.

NIMASA (2021) further outlined several initiatives aimed at strengthening maritime security. These include the implementation of the Deep Blue Project, active community engagement, the empowerment of regional navies, and cooperation with various security agencies and maritime industry stakeholders through bodies like the Joint Maritime Industry Working Group (JMIWG) and GoG-MCF/SHADE. NIMASA is also working in concert with international institutions such as the IMO, INTERPOL, private security firms, submarine cable operators, and seafarer organizations.

Olufowobi (2022) also emphasized the leadership of the Nigerian Navy in fostering interagency and international cooperation. Bilateral and multilateral engagements have led to the development of the Harmonized Standard Operating Procedure (HSOP), which aims to address coordination gaps among Maritime Law Enforcement Agencies (MLEAs). Additionally, a memorandum of understanding signed among the Naval Chiefs of Nigeria, Benin, Togo, and Niger under the Multi-National Maritime Coordination Centre (MMCC) for Zone E has facilitated joint maritime and aerial patrols, as well as the real-time sharing of intelligence. These efforts have contributed to a reported 50% reduction in piracy incidents between the first quarters of 2018 and 2019.

Despite these achievements, several challenges persist. Olufowobi (2022) pointed out that many of the commitments under the Yaoundé Declaration remain largely symbolic, hindered by insufficient funding, personnel shortages, equipment gaps, and uncoordinated communication systems. Moreover, several member states have yet to implement core aspects of the Code of Conduct, including the establishment of national maritime security strategies, dedicated security committees, and the designation of national focal points. To address these gaps, it is recommended that steps be taken to make the Code legally binding and operationally enforceable.

Conclusion

The fact that Nigeria is blessed with abundant natural resources calls for a robust transport sector which supports export, as the country stands to benefit hugely from international trade if it gets it right in the maritime sector. There is no doubt that the national security issues which recently abound in the country affects economic activities across land and water. While efforts are on ground by contemporary government to address security issues across various parts of the country, investments are also obviously on ground to make the coastal space safe for navigation. Coming at a time when Nigeria needs economic revival and diversification, investments in maritime security deserves to stand out as a priority. It is only when this is achieved and sustained that there will be a free flow of local and international trade within and around the Nigerian maritime domain. The multiplier effect from investments in maritime security covers a wide range of economic growth and development indicators such as increase in employment, improvement in revenue generation by government agencies such as NPA, NIMASA which also culminates to increase in remittance of operating surplus to the Consolidated Revenue Fund (CRF), and so on. As such, contemporary maritime security initiatives of the Nigerian government such

as the Deep Blue project and the SPOMO Act, are steps in the right direction, especially considering the recent successes recorded in addressing the spate of piracy and other maritime crimes within the Nigerian EEZ and the Gulf of Guinea. The sustenance of such local and a number of other regional and international initiatives will, no doubt, culminate in a notable economic prosperity for coastal nations like Nigeria.

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HARNESSING SOLAR POWER WITHIN NIGERIA'S BLUE ECONOMY

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Abstract
The blue economy is a critical pillar of Nigeria's economic development, comprising marine-based activities such as fisheries, maritime transport, tourism, aquaculture, and renewable energy. With an 850-kilometre coastline and a vast exclusive economic zone, Nigeria has strong potential to harness solar power within its blue economy. This study employed a qualitative case study approach using secondary data from 23 sources to explore successful global applications of solar energy. Four case studies were examined: floating solar farms in Singapore, solar-powered desalination in the UAE, solar marine transport in India, and solar-powered aquaculture in China. Each case offered valuable insights into solar integration within marine economies. Singapore's Tengeh Reservoir demonstrates scalable floating solar technology; the UAE's solar desalination addresses water scarcity; India's solar ferries highlight clean transport solutions; and China's "aquavoltaics" model combines energy and food production. Despite these global successes, Nigeria faces barriers such as infrastructure gaps, policy limitations, and financing challenges. The study concludes that solar power can significantly advance Nigeria's blue economy by enhancing energy security, food production, water access, and sustainable transport. Key recommendations include formulating a dedicated blue economy/solar policy, integration of solar-powered solutions within existing and planned infrastructure development, investment in solar-powered desalination plants, deployment of solar floating farms and solar-powered transportation, and investment in capacity building for long-term success.

Keywords: *Solar Power, Blue Economy, Renewable Energy, Coastal and Marine.*

1.0 Introduction

The blue economy represents a vital component of Nigeria's economic development, encompassing diverse marine-based activities such as fisheries, aquaculture, maritime transport, tourism, and renewable energy exploration (Dike, 2025). Nigeria, with its vast coastline stretching over 850 kilometres, and an exclusive economic zone covering approximately 200 nautical miles, possesses significant untapped potential for harnessing renewable energy within its blue economy (Eyo et al, 2024). As the demand for sustainable energy alternatives increases in response to climate change and environmental degradation, integrating solar power into Nigeria's marine and coastal sectors presents a viable pathway to achieving both economic growth and environmental preservation. However, despite its potential, Nigeria has yet to fully capitalise on solar energy within its blue economy, with infrastructural deficits, policy gaps, and economic constraints limiting progress (Nweke & Ali, 2025).

The increasing global emphasis on sustainability and the need to transition from fossil fuel dependency has made solar power a crucial alternative for marine-based industries. Solar energy has been successfully integrated into blue economies in countries such as the Netherlands, India, and China, where offshore floating solar farms, solar-powered desalination plants, and solar-driven marine transportation have demonstrated their efficiency in reducing carbon emissions and reliance on traditional energy sources (Li et al, 2022). These applications align with global climate action frameworks, particularly the Paris Agreement, which urges nations to reduce greenhouse gas emissions by at least 45% by 2030 to prevent catastrophic climate impacts (IPCC, 2022). Nigeria, as a signatory to this agreement, must explore innovative renewable energy solutions within its blue economy to meet its commitments to carbon reduction and sustainable economic expansion.

Economic activities within Nigeria's coastal and marine sectors currently depend largely on fossil fuels, which pose significant risks to marine biodiversity and environmental stability. Marine transportation, for instance, contributes to nearly 4% of the country's total carbon emissions, exacerbating pollution levels in coastal cities such as Lagos, Port Harcourt, and Calabar (Isidore & Julius, 2023). Additionally, the reliance on diesel-powered generators for offshore oil and gas operations has been linked to oil spills, habitat destruction, and declining fish populations, which have reduced Nigeria's fisheries yield by approximately 15% between 2015 and 2023 (Olalekan & Gbenga, 2018). These environmental challenges necessitate the adoption of cleaner energy solutions such as solar power to ensure that economic activities within Nigeria's blue economy do not further degrade marine ecosystems.

Harnessing solar power in Nigeria's blue economy presents multiple options, each with its peculiar potential to mitigate environmental harm while driving economic growth. For instance, floating solar farms, have gained traction globally as an effective means of generating renewable energy without occupying valuable land space. Countries such as India have deployed large-scale floating solar projects that contribute over 5 gigawatts of electricity annually to national grids (Uma & AMP, 2022). In Nigeria, where land-use conflicts often hinder large-scale renewable energy deployment, offshore solar farms could provide an efficient alternative while reducing transmission losses associated with inland power generation (John & Eliaser, 2023). Moreover, solar-powered desalination plants could address Nigeria's coastal water scarcity issues by providing clean, drinkable water for communities suffering from saline intrusion and industrial pollution.

Another promising application of solar power within Nigeria's blue economy is in marine transportation. Solar-powered ferries and boats have been successfully implemented in Scandinavian countries, reducing fuel costs and emissions by up to 90% compared to conventional diesel-powered vessels (Felix & Dennis, 2022). Nigeria, with its extensive network of waterways, could benefit from similar initiatives, particularly in high-traffic areas such as Lagos Lagoon and the Niger Delta, where ferry services are crucial for daily transportation. The cost-effectiveness and environmental benefits of solar-powered marine vessels could significantly contribute to Nigeria's emission reduction targets while enhancing connectivity in coastal and riverine communities (ForSea Ferries, 2018).

Despite these potential benefits, several challenges hinder the widespread adoption of solar power within Nigeria's blue economy. Financial constraints remain a

major impediment, as the initial capital investment for solar infrastructure is often high, deterring both public and private sector investments. Nigeria's renewable energy sector has struggled with inadequate financing, with less than 2% of the country's energy budget allocated to solar projects between 2020 and 2023 (Abdulrasheed & Michael, 2023). Additionally, policy and regulatory frameworks governing Nigeria's blue economy does not explicitly prioritise solar energy integration, creating uncertainties for investors and limiting large-scale deployment (Agunbanjo, 2023).

The integration of solar power into Nigeria's blue economy is not only a matter of environmental sustainability but also an economic imperative. The global market for marine renewable energy is projected to reach $53 billion by 2030, with solar energy playing a pivotal role in driving investment and innovation (Ramazan & Hafize, 2024). By strategically investing in solar-powered infrastructure within its blue economy, Nigeria could unlock new revenue streams, create job opportunities, and enhance energy security in coastal and marine-dependent communities. Moreover, embracing solar energy aligns with Nigeria's Vision 2050 development agenda, which prioritises sustainable industrialisation and climate resilience.

2.0 Methodology

This study adopted a qualitative research methodology, relying entirely on secondary data. The primary approach employed was a case study research design, which facilitated an in-depth analysis of successful global solar energy applications within blue economies. Data were sourced through a systematic review of relevant literature, including published research papers, institutional reports, policy documents, and articles focusing on floating solar farms, solar-powered desalination, solar marine transportation, and solar-powered aquaculture.

The research specifically examined global precedents to draw valuable lessons for Nigeria's unique coastal and marine environments. This involved a detailed analysis of successful solar energy applications in countries such as Singapore (for floating solar farms), the United Arab Emirates (for solar-powered desalination), India (for solar-driven marine transportation), and China (for solar-powered aquaculture).

A thematic content analysis was applied to identify patterns, best practices, and transferable insights from these diverse global experiences. The use of secondary data provided a broad and comprehensive perspective on established methodologies and successful outcomes in integrating solar power into blue economy sectors worldwide. This approach enabled the study to critically assess the potential, opportunities, and barriers for harnessing solar energy within Nigeria's blue economy.

3.0 Global Case Studies: Successful Solar Energy Applications within Blue Economies

The integration of renewable energy sources, especially solar power, into Nigeria's Blue Economy presents an exciting opportunity to reconcile the needs of economic growth with marine preservation. As the global demand for marine resources grows, so does the need to balance development with the health of marine ecosystems. In the context of Nigeria, solar power offers promising solutions to bridge the gap between economic growth and environmental sustainability. This section explores the results of research into various

options for harnessing solar power within Nigeria's Blue Economy, examining global case studies, Nigeria's potential, barriers, and opportunities.

3.1 Floating Solar Farms in Singapore: A Case Study

Singapore's deployment of floating solar farms represents a pioneering model in harnessing renewable energy in water-based environments. The Tengeh Reservoir Floating Solar Farm, launched in 2021, is one of the world's largest inland floating solar systems, featuring over 122,000 solar panels spanning 45 hectares. With a capacity of 60 megawatt-peak (MWp), the installation provides sufficient electricity to power Singapore's five water treatment plants, thereby reducing carbon emissions by about 32 kilotonnes annually (Lee, 2021). This initiative emerged as a strategic response to land constraints and rising energy demands, utilizing underused water surfaces to generate clean energy without competing for urban land. Moreover, the Tengeh project integrates environmental safeguards, including biodiversity assessments and the use of corrosion-resistant panels, to minimize ecological disruption (Scully, 2021). Singapore's success illustrates how countries with abundant water bodies and sunlight can leverage floating photovoltaic (FPV) technology to meet energy needs sustainably. The model showcases key innovations such as dual-use of space, grid integration, and climate resilience, making it a viable blueprint for other coastal or riverine nations. For countries like Nigeria with extensive inland and coastal waters, the Singaporean case study demonstrates a scalable, sustainable, and space-efficient solar power option.

3.2 Solar-Powered Desalination in the United Arab Emirates: A Case Study

The United Arab Emirates (UAE) stands as a leading example of integrating solar power into its blue economy, particularly through advanced solar‑powered desalination technologies. Faced with acute water scarcity and abundant solar resources, the UAE has heavily invested in innovative solutions to secure potable water supplies. A notable instance is the Ghantoot pilot programme, which demonstrated that solar‑powered reverse osmosis desalination achieved up to 75 % energy savings compared to conventional methods (Masdar, 2018). Moreover, hybrid solar desalination systems have been widely reviewed for their structure and performance, showcasing low noise, cost-effectiveness, and zero emissions ideal for arid regions (Alghassab, 2024). This approach not only provides a sustainable source of fresh water but also aligns with blue economy principles by minimizing environmental impact, showcasing a scalable model for regions confronting dual challenges of energy and water scarcity.

3.3 Solar-Powered Marine Transportation in India: A Case Study

India's pioneering work with solar-powered marine transportation, exemplified by the "Aditya" ferry in Kerala, offers a compelling blueprint for how a nation with extensive waterways can embrace sustainable maritime practices. Launched in January 2017, the "Aditya" stands out as India's first commercially successful solar-electric ferry, demonstrating the practical application of solar energy in the blue economy (Paul, 2020). This 75-passenger vessel operates predominantly on solar energy captured by roof-mounted photovoltaic panels charging its onboard battery system. Its consistent daily

operation has proven the reliability and efficiency of solar propulsion for public transport, significantly curbing reliance on fossil fuels. The "Aditya" has achieved remarkable operational cost reductions from roughly ₹8,000 per day for diesel ferries to just ₹180 per day alongside a significant decrease in carbon emissions, saving over 100,000 L of diesel and cutting approximately 280 t of CO_2 over three years (Onmanorama, 2020). Its success in India's tropical climate and functional deployment across inland waterways, mirroring those in many developing nations, underscores its relevance as a direct learning case. This model illustrates that with innovative engineering and strategic planning, solar-powered vessels can offer a commercially viable and ecologically sound solution for domestic marine transport.

3.4 Solar-Powered Aquaculture in China: A Case Study

China stands as a global leader in integrating solar power into aquaculture, offering a model for sustainable food production within the blue economy. In response to increasing seafood demand and the need for clean energy, China developed "aquavoltaics" a dual-use model where photovoltaic (PV) panels are mounted over fish ponds. This innovative approach generates clean electricity while supporting fish farming. A case study in Jiangsu Province demonstrated the economic viability of this system, with a payback period of 10.44 years, a net present value of USD 18.5 million, and an internal rate of return of 8.06% (Wang & Chen, 2022). These systems also enhance land-use efficiency and promote rural economic development. Additionally, environmental co-benefits are evident. A 2025 study by Kahana found that installing solar panels over sea cucumber ponds in the Yellow River Delta reduced water temperatures by 1.2°C and shortened the summer dormancy period of sea cucumbers by 12 days, boosting yields by 20% (Kahana, 2025). Importantly, no adverse ecological effects were reported. China's aquavoltaics model reduces energy costs, curbs emissions, and supports food security, providing a strong reference point for Nigeria. With vast water surfaces and solar potential, Nigeria can adopt this model to sustainably grow its blue economy.

4.0 Discussion of Findings

The integration of renewable energy sources, particularly solar power, into Nigeria's Blue Economy presents a critical pathway to sustainable development, reconciling the demands of economic growth with the imperative of marine ecosystem preservation. This research has examined diverse global applications of solar energy within blue economies, identifying key options and drawing direct lessons for Nigeria, while also highlighting the inherent opportunities and formidable barriers.

4.1 Applicability of Floating Solar Farms in Nigeria's Blue Economy

The findings from the case study of Singapore's floating solar farms clearly demonstrate a pioneering and highly relevant model for Nigeria. Singapore, a nation grappling with severe land scarcity and high energy demands, has successfully leveraged its vast water surfaces for clean energy generation, exemplified by the Tengeh Reservoir Floating Solar Farm. This 60 MWp installation, covering 45 hectares, powers all of Singapore's water treatment plants, significantly reducing carbon emissions (Lee, 2021). For

Nigeria, with its extensive network of inland water bodies including major reservoirs like Kainji, Shiroro, and Jebba, numerous natural lakes, and vast lagoons along its coastline, this strategy offers an innovative solution to energy deficits, particularly in densely populated coastal cities where land for conventional solar farms is at a premium. The inherent dual-use benefit of such systems, coupled with proven climate resilience and environmental safeguards demonstrated in Singapore (Scully, 2021), underscores the potential for Nigeria to exploit its unutilized water surfaces for sustainable power generation without competing for valuable terrestrial space, fostering both energy security and environmental protection.

4.2 Potential for Solar-Powered Desalination in Addressing Water Scarcity

The United Arab Emirates (UAE) stands as a global leader in utilizing solar power to address acute water scarcity, providing a potent case study for Nigeria. The UAE's commitment to integrating solar energy, particularly photovoltaic (PV) and thermal technologies, with reverse osmosis (RO) desalination processes, has led to sustainable potable water production (Al-Juaidi et al., 2021; Ghaffour et al., 2023). This approach drastically reduces the carbon footprint associated with conventional, energy-intensive desalination. Nigeria faces pressing challenges related to access to clean, potable water, especially in its sprawling coastal communities, riverine areas, and islands where freshwater sources are often contaminated or scarce, and grid electricity is unreliable or absent (Olabode & Comte, 2024). The deployment of decentralized, solar-powered desalination plants in these regions could provide a reliable and sustainable supply of fresh water, directly improving public health, sanitation, and supporting local livelihoods like fishing and agriculture. This application aligns perfectly with blue economy principles by leveraging renewable resources to meet fundamental human needs while minimizing environmental impact and promoting resilience against climate change.

4.3 Prospects for Solar-Powered Marine Transportation in Nigeria

India's pioneering development of solar-powered marine transportation, notably the 'Aditya' ferry in Kerala, offers a compelling blueprint for Nigeria's extensive maritime and inland waterways sector. Launched in 2017, the 'Aditya' represents India's first commercially successful solar-electric ferry, demonstrating reliable operation, significant reductions in fossil fuel consumption, and near-zero emissions (Paul, 2020). Nigeria, with its vast network of inland waterways spanning thousands of kilometres and a coastline extending over 850 km, possesses immense potential for a similar transition. Implementing solar-powered ferries for urban and rural passenger transport, fishing boats for artisanal fishermen, and even smaller cargo vessels could drastically reduce the environmental impact of fossil fuel-based vessels, including air and noise pollution in sensitive aquatic ecosystems (Tamunodukobipi et al, 2018). Beyond environmental benefits, such a transition promises substantial operational cost savings for operators, freeing them from the volatility of fuel prices, thereby fostering economic sustainability and enhancing the viability of maritime transport in Nigeria's blue economy.

4.4 Integration of Solar-Powered Aquaculture for Food Security and Sustainability

China's extensive integration of solar power into its aquaculture sector, popularly known as "aquavoltaics," provides an innovative and sustainable model directly applicable to Nigeria. Faced with immense demands for seafood, China has strategically installed solar panels over fish farms, creating a unique dual-use system that generates clean electricity while simultaneously supporting fish cultivation (Wang & Chen, 2022). These solar installations provide the necessary power for critical aquaculture equipment such as water aerators, pumps, and environmental monitoring systems, all vital for maintaining optimal water quality and fish health. A key synergistic benefit is that the shade provided by the solar panels can help regulate water temperature and reduce evaporation, creating a more stable and favorable environment for aquatic life, potentially leading to increased yields (Kahana, 2025). For Nigeria, where aquaculture plays a vital and growing role in national food security and economic development, adopting solar-powered aquaculture systems offers a path to significantly reduce operational costs, mitigate the environmental impact of conventional energy sources, and enhance the overall sustainability and productivity of fish farming operations (Anyanwu & Adeleke, 2023).

4.5 Overarching Opportunities and Barriers to Solar Integration in Nigeria's Blue Economy

Nigeria has substantial solar energy potential, with daily average solar radiation estimated at approximately 5.5 kWh/m² across much of the country and slightly lower but still significant levels in its coastal regions. This natural endowment positions solar power as a viable energy alternative capable of supporting diverse sectors within the nation's blue economy (Omotayo et al, 2024). By adopting solar technologies in maritime transport, aquaculture, desalination, and waterfront industries, Nigeria can promote economic diversification and reduce overreliance on fossil fuels. The shift to solar also promises environmental benefits lowering carbon emissions, reducing air and water pollution, and enhancing the resilience of vulnerable coastal communities. Beyond environmental sustainability, solar energy integration offers socio-economic advantages such as job creation in solar panel production, system installation, and maintenance. However, challenges persist, including high initial capital requirements, weak regulatory incentives, and limited technical expertise. Encouragingly, Nigeria's new 10-year National Policy on Marine and Blue Economy (2025 - 2034) highlights renewable energy as a priority area, indicating growing governmental support for sustainable marine resource development (Onyenucheya, 2025). With coordinated public-private investment and policy reforms, solar energy could become a cornerstone of Nigeria's sustainable blue economy.

However, realizing this potential is not without significant barriers. Policy and Regulatory Frameworks are often inadequate, lacking specific incentives, clear licensing procedures, and comprehensive guidelines tailored for solar projects within marine and aquatic environments, which deters private sector investment (Okhirebhu & Agboola, 2025)

Financial Investment poses a substantial hurdle, characterized by high upfront capital costs for specialized marine-grade solar infrastructure and limited access to affordable long-term financing, especially for local entrepreneurs and small-to-medium enterprises. Technological and Human Capacity Gaps are pronounced, with insufficient local manufacturing capabilities for specialized components and a scarcity of skilled personnel

for design, installation, operation, and maintenance of advanced solar systems in marine contexts (Akinola, 2023). Furthermore, Inadequate Infrastructure in terms of grid integration challenges for large-scale floating solar, and specialized charging or maintenance facilities for solar-powered vessels, can hinder widespread adoption. Lastly, Environmental and Social Considerations require careful navigation, demanding thorough environmental impact assessments to ensure ecological protection and robust community engagement to prevent conflicts over resource use and foster local ownership (Payton, 2024). Overcoming these multi-faceted barriers necessitates a coherent and concerted effort from all stakeholders.

5.0 Summary of Key Findings

The following are the summary of key findings emerging from the study:

5.1 Applicability of Floating Solar Farms in Nigeria's Blue Economy

a. Singapore's model of floating solar farms offers a viable solution for Nigeria to leverage its vast inland water bodies and mitigate land constraints in coastal urban areas.
b. This technology promises substantial clean energy generation and reduced carbon emissions, demonstrating dual-use space efficiency.

5.2 Potential for Solar-Powered Desalination in Addressing Water Scarcity

a. The UAE's experience with solar-powered desalination showcases a sustainable method to provide potable water.
b. This approach can address critical water scarcity in Nigeria's remote coastal and riverine communities, improving public health and livelihoods.

5.3 Prospects for Solar-Powered Marine Transportation in Nigeria

a. India's solar-powered ferries prove the commercial viability and environmental benefits of solar-electric vessels for public transport.
b. Nigeria's extensive waterways provide a significant opportunity to decarbonize its maritime sector, reducing operational costs and pollution.

5.4 Integration of Solar-Powered Aquaculture for Food Security and Sustainability

a. China's "aquavoltaics" demonstrate a synergistic model for generating clean energy while enhancing aquaculture productivity.
b. Adopting solar-powered aquaculture can significantly lower operational costs and improve the environmental sustainability of fish farming in Nigeria.

5.5 Overarching Opportunities and Barriers to Solar Integration in Nigeria's Blue Economy

a. Nigeria possesses abundant solar resources and vast marine/inland water bodies, creating immense opportunities for economic diversification, job creation, and climate change mitigation.

b. Significant barriers include inadequate policy frameworks, high financial investment requirements, limited technological and human capacity, and insufficient supporting infrastructure.

6.0 Conclusion

This study confirms that solar power presents a crucial and multifaceted opportunity for transforming Nigeria's blue economy. Global case studies from Singapore, UAE, India, and China demonstrate the efficacy and economic viability of floating solar farms, solar-powered desalination, solar marine transport, and solar aquaculture, respectively. These applications directly address critical Nigerian needs in energy security, potable water provision, sustainable transportation, and enhanced food security. While the potential for harnessing Nigeria's abundant solar resource within its blue economy is immense, unlocking it requires navigating substantial challenges, particularly in developing robust policy and regulatory frameworks, securing significant and affordable financial investment, enhancing technological and human capacity, and building essential supporting infrastructure. A strategic, multi-pronged approach integrating these diverse solar solutions is essential to propel Nigeria towards a sustainable, resilient, and prosperous blue economy.

7.0 Recommendations

The following recommendations aim to enhance the efficacy of harnessing solar power within Nigeria's Blue Economy:

Recommendation One: Comprehensive Blue Economy Solar Policy

The Federal Ministry of Marine and Blue Economy, in collaboration with the Federal Ministry of Power and other relevant government agencies, should develop and implement a clear, robust, and incentivized national policy framework specifically for solar energy integration across all blue economy sectors.

Recommendation Two: Dedicated Funding Mechanisms for Blue Solar Projects

The Federal Government in partnership with local and international financial institutions, should create specialised green financing mechanisms, credit facilities, loan schemes, and targeted grants to reduce high upfront capital costs tied to solar projects.

Recommendation Three: Local Capacity Building and Technology Transfer

Federal Government should direct Universities, polytechnics, and vocational training centres to introduce specialised curricula and training programs focused on marine-grade solar technologies, installation techniques, operation, and maintenance, fostering local expertise and facilitating technology transfer.

Recommendation Four: Investment in Solar-Powered Desalination Plants

Federal Government should direct its key agencies to partner the private sector in investing in pilot projects for solar-powered desalination plants to enhance and boost the provision of reliable and sustainable fresh water supply of fresh water within the coastal communities.

Recommendation Five: Public-Private Partnerships (PPPs) and International Collaborations

The Federal Government should actively promote and create enabling socio-economic environment for strategic collaborations between relevant MDAs, the private sector (both local and international), and research institutions, to pool resources, share knowledge, and accelerate the deployment of innovative solar solutions in the blue economy.

Recommendation Six: Integrate Solar Solutions with Existing and Planned Infrastructure Development

The Federal Government should ensure that all ongoing and future infrastructure development projects within Nigeria's maritime and inland waterway sectors, such as port expansions, jetties, and coastal communities, incorporate provisions for renewable energy infrastructure, including solar power generation and charging facilities.

Recommendation Seven: Deployment of Solar Floating Farms

Federal Ministry of Marine and Blue Economy in collaboration with the Federal Ministry of Innovation, Science and Technology, Nigerian Navy and Nigerian Inland Waterways Authority (NIWA), should facilitate the deployment floating solar farms across its inland and coastal waters leveraging floating photovoltaic technology (FPV) to harness renewable energy in these water-based environments.

Recommendation Eight: Solar Powered Transportation

Federal Ministry of Marine and Blue Economy in collaboration with the Federal Ministry of Transport; Federal Ministry of Innovation, Science and Technology; and Nigerian Inland Waterways Authority (NIWA), should facilitate the transition to and deployment of solar-powered ferries, fishing boats and smaller cargo vessel across Nigeria’s vast inland waterways network.

Recommendation Nine: Sustainable Food Production and Security

Federal Ministry of Marine and Blue Economy in collaboration with the Federal Ministry of Agriculture and Food Security; and Federal Ministry of Innovation, Science and Technology, should facilitate investment and integration of solar-power technology into the aquaculture sector leveraging ‘aquavoltaics technology’ to secure dual-use systems that generate clean electricity while simultaneously and significantly boosting fish cultivation.

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ECO-FRIENDLY MARINE RECREATION: A NEW TREND IN TOURISM AND HOSPITALITY MANAGEMENT IN BONNY ISLAND, RIVERS STATE, NIGERIA

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Abstract
Eco-friendly marine recreation is gaining popularity in tourism due to environmental awareness and demand for sustainable travel experiences. This paper's primary goal was to quantitatively and qualitatively examine the emerging trend of eco-friendly marine tourism in Bonny Island, highlighting its potential benefits, challenges, and opportunities for sustainable development, and to suggest necessary recommendations. Destination areas in Bonny Island to study are Finima Nature Park, Bonny Island Beaches, Finima Beach, Bonny Beach, and Lighthouse Beach. One hundred and thirty (130) questionnaires were distributed randomly to tourists, local community members, and management staff in order to collect information to suit the subject matter. One hundred and twenty (120) questionnaires were retrieved. Five people were interviewed, which included tourists, management staff, and members of the host communities. The gathered data was analyzed using descriptive statistics, employing frequency, percentages, and tables for representation. Existing literature and documents from secondary sources were reviewed. The study also explores ecotourism activities like sustainable boating, eco-friendly beach tourism, snorkeling, mangrove conservation, and wildlife observation, evaluating their environmental and economic impacts. Eco-friendly marine recreation can boost economic growth, employment, and biodiversity conservation, but challenges like oil pollution, weak regulations, inadequate infrastructure, and limited awareness hinder sustainable tourism development. The study suggests policy changes, eco-tourism infrastructure investment, public-private partnerships, and community engagement to promote responsible marine tourism in Bonny Island. This study contributes to the discussion of sustainable tourism in Nigeria by emphasizing the need to combine economic development with environmental preservation.

Keywords: Eco-Friendly Marine Recreation, Sustainable Tourism, Bonny Island, Hospitality Management, Marine Conservation.

1.0 Introduction

Nigeria has a sizable economy that depends on maritime resources, but its marine tourist sector is not yet completely developed. Numerous resources that sustain livelihoods and economic growth may be found in Nigeria's maritime area. Marine activities encompass established sectors like fisheries, shipping, offshore oil and gas, maritime tourism, manufacturing, dredging, and emerging ones like marine aquaculture, offshore wind energy, and marine mining. Nigeria's tourism surge has led to a lack of awareness about

sustainable river use as natural tourism destinations, despite its health benefits, including physical wellness, stress reduction, emotional, social, and mental well-being. Marine recreation, including boating, snorkeling, scuba diving, fishing, and beach tourism, attracts millions of tourists, contributes to coastal communities' economic growth, promotes cultural exchange, and enhances tourist experiences. Nigeria's Atlantic Ocean coastline offers potential for marine tourism, boosting economic development in coastal cities like Lagos. However, this also poses environmental challenges like habitat destruction and pollution, necessitating a shift towards sustainable practices. Increased industrialization and urbanization contribute to pollution in coastal environments (Akankali & Elenwo, 2015). The global trend towards eco-friendly tourism, focusing on minimizing ecological footprints and conserving natural habitats, is gaining traction in marine recreation, including eco-kayaking, snorkeling, and wildlife observation tours. Globally, eco-conscious travelers are influencing Nigeria's tourism policies, particularly in eco-friendly maritime leisure, due to their interest in sustainable tourism practices.

Nigeria's tourism industry, brimming with marine biodiversity, scenic coastlines, and cultural heritage, can significantly boost the nation's economy by promoting attractions like historical monuments and beaches (Tonbara & Chigozie, 2023). Eco-friendly marine tourism in Nigeria can mitigate environmental risks, attract eco-tourists, and promote community participation, thereby maximizing economic benefits and preserving marine ecosystems. Nigeria's commitment to sustainable practices aligns with global environmental goals, including the UN Sustainable Development Goals. Its vast coastline and marine biodiversity make it an attractive destination for coastal and marine tourism, attracting millions of tourists worldwide. Despite this promise, Nigeria's sector is still mostly unexplored, primarily due to environmental pollution (oil spills, plastic waste), inadequate infrastructure, and weak policy enforcement. However, with the global rise of ecotourism, there is a growing interest in sustainable marine recreation to balance economic benefits with environmental conservation. Compared to land-based tourist destinations, Nigeria's water-based tourism resources have not gotten as much attention or development. The research offers valuable insights for policymakers, investors, and tourism operators, promoting marine ecosystem preservation and community engagement in Bonny Island's tourism development. This study employed four objectives to buttress the point. This includes identifying marine tourism destinations in Bonny Island, identifying the existing and eco-friendly recreational activities suitable for Bonny Island, analyzing the challenges and opportunities in eco-friendly marine tourism in Bonny Island, and recommending strategies that could be adopted to promote ecotourism and responsible marine recreation in Bonny Island.

1.2. Study Area

Bonny Island, located in Rivers State, Nigeria, is a strategic coastal town with rich marine biodiversity, scenic beaches, and a deep-rooted cultural heritage. It is home to Finima Nature Park, Bonny Estuary, Bonny River, and extensive mangrove ecosystems, making it a prime destination for eco-friendly marine tourism. On December 26 and 31, hundreds of people flock to Bonny Island, an island settlement in Rivers State, South-South Nigeria, for beach carnivals. Geographically, it is located roughly at latitude 4.4492° or

4° 26' 57" north and longitude 7.24° or 7° 14' 24" east and south of the intertropical convergence zone (ITCZ), with 6,690,000 residents. Its primary river, the Bonny Estuary, eventually flows into the Southern Atlantic Ocean, which it shares with its neighbors. It is bordered to the west by the Billes and Kalabaris, to the east by the Andonis, to the north by the Okirikans and Ogonis, and to the south by the Atlantic Ocean. Located in Rivers State, Nigeria, approximately 40 kilometers southeast of Port Harcourt, is this industrial town in the Niger Delta (Akintoye et al., 2016).

All year long, Bonny Island experiences hot, muggy weather. The year-round temperatures are very stable, reaching their highest at the end of the dry season (around February) and their lowest during the height of the rainy season (about August) (Uhunmwangho et al., 2021) . Economic activities, including fishing, tourism, and oil exploration. Ferries are the primary mode of transportation; however, an airport was recently constructed and is operational, with flights to and fro the island operating out of Lagos, Abuja, and Port Harcourt, respectively. Igbo and Ibani are the local dialects used in Bonny Island. Forty kilometers southwest of Port Harcourt, the Nigerian capital of Rivers State, sits the Kingdom of Grand Bonny.

1.2.1 Major Marine Tourism Destinations in Bonny Island

From the fieldwork, the researcher identified four tourist destinations. These were discussed as follows:

1. **Finima Nature Park**

The Nigerian Natural Gas (NLNG) corporation created this protected conservation area. The area is abundant in biodiversity, featuring mangrove forests, wetlands, and rare wildlife species. It offers eco-tourism activities such as nature trails, birdwatching, and guided tours. Finima Nature Park serves as an educational and research hub for marine conservation and eco-tourism initiatives.

2. **Bonny Island Beaches**

Bonny Island has some of the most scenic and untouched beaches in Nigeria, including:

- **Finima Beach**: A popular beach for local and international tourists, ideal for picnics, bonfires, and leisure activities.
- **Bonny Beach**: This beach is renowned for its crystal-clear waters and soft sands, making it ideal for swimming and sunbathing.
- **Lighthouse Beach**: The site features a historic lighthouse, offering a panoramic view of the Atlantic Ocean.

These beaches provide opportunities for eco-friendly marine tourism, including sustainable water sports and conservation programs. Swimming is prohibited at beaches due to massive wave force, but tourists enjoy the ocean's size, sound, wind, and clean sand. Bonny beach has more turbulent waves than Port Harcourt beach (Ijeomah & Duke, 2016). The beach appears unmanaged and lacking facilities, with waste materials from boats, dead tree branches, and whale relics scattered along its edge. Ijeomah & Duke (2016) suggest that effective beach management with adequate facilities can attract tourists, increase visitation rates, and boost revenue.

3. **Bonny River and Estuary**

The Bonny River is a key waterway, connecting the island to Port Harcourt and other riverine communities. Offers boat cruises, canoeing, and fishing tours, providing tourists with a unique view of marine life. The estuary area supports a diverse ecosystem, including mangroves, seagrass beds, and breeding grounds for aquatic species.

4. Mangrove Forests and Coastal Habitats

The mangrove ecosystem in Bonny Island is vital for carbon sequestration, coastal protection, and marine biodiversity. Eco-tourists can explore these areas through canoe tours and guided nature walks. The region supports ecological research, conservation initiatives, and responsible tourism development.

2. Material and Method

The study adopted quantitative approach in the collection of data. The study utilized a structured questionnaire, field observation, and in-depth interviews to gather data. On hundred and thirty (130) questionnaires were distributed randomly to tourists, local communities head and management staff in order to collect information to suit the subject matter. One hundred and twenty (120) of questionnaires were retrieved. Descriptive statistics in the form of frequency, percentages, and tables were used to examine the data collected. The documentary approach was applied as an indirect mode of data collection, or as a secondary source of data.

A comprehensive desktop search was conducted for the internet review using the Google Scholar search engine, utilizing the primary search terms of the study topic. The quest started with an international viewpoint on eco-friendly marine recreation. For this study, more than 20 literature sources were reviewed, some of which were relevant to the Nigerian context and some of which had a worldwide viewpoint. Every literature source that was mentioned was acknowledged and properly referenced. Thus, the study utilizes a comprehensive literature review and case studies. The research utilized a qualitative method conducting unstructured thorough interviews and field observations to explore perceptions and experiences of eco-friendly marine recreation in Bonny Island, supplementing information obtained through questionnaires. This approach ensures an in-depth understanding of eco-friendly marine tourism in Bonny Island. Direct observation was conducted at beaches, conservation areas, and tourism sites. Random sampling was used to gather data from tourists and local residents to ensure diversity in responses. The target respondents were tourists/visitors engaging in marine recreation activities, local community members (fishermen, tour guides, and hospitality workers), business owners that were operators of hotels, eco-tourism services, and boat rentals, and government officials. Thematic analysis was used in analyzing interview and observation data. However, security concerns and environmental conditions limits access to some marine sites.

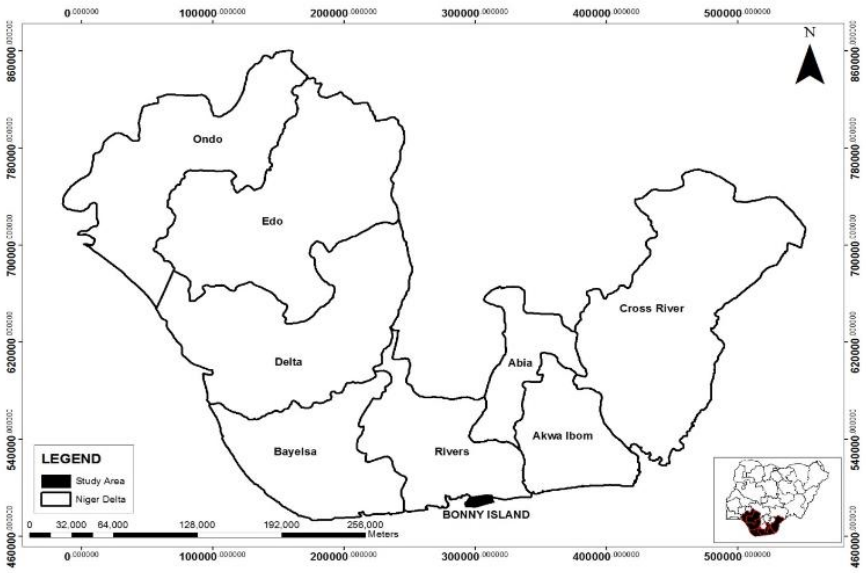

Fig 1: Map of Niger Delta showing the Study Area

3. Literature Review

3.1 The Concept of Eco-Friendly Marine Recreation

Eco-friendly marine recreation refers to sustainable tourism activities that minimize environmental impact while promoting conservation and community well-being. Eco-friendly marine recreation refers to tourism activities conducted in coastal and marine environments with a focus on minimizing ecological impact, preserving biodiversity, and supporting local communities. Unlike mass tourism, which often leads to environmental degradation, eco-friendly marine recreation focuses on:

- Sustainable water sports and activities (e.g., kayaking, snorkeling, low-impact boating).
- Marine wildlife conservation (e.g., turtle protection, dolphin watching).
- Waste-free tourism initiatives (e.g., beach clean-ups, responsible tourism).
  Community-led tourism that supports local economies and cultural heritage.

By adopting eco-friendly tourism practices, Bonny Island can enhance its global appeal as a model for sustainable marine tourism in Nigeria. Recreation is a leisurely activity, often involving sports and games in public areas, often featuring a children's playground.

3.2. Theoretical Framework on Eco-Tourism and Marine Recreation

Eco-tourism is defined as responsible travel to natural areas that conserves the environment, sustains the well-being of local communities, and involves interpretation and education (The International Ecotourism Society (TIES), 2015). It is based on principles such as sustainability, conservation, and community participation.

Theoretical Models Supporting Eco-Tourism and Marine Recreation:

1. Sustainable Tourism Development Theory (Butler, 1980) – Suggests that tourism should develop in a way that meets the needs of present and future generations while maintaining environmental and cultural integrity.
2. Carrying Capacity Model – Explains that tourism development should be controlled to prevent overuse of natural resources.
3. Triple Bottom Line (TBL) Framework – Focuses on balancing environmental, social, and economic impacts in tourism development (Butler, 1980).

These theories provide a foundation for understanding how eco-friendly marine recreation can be implemented in Bonny Island to achieve sustainability goals.

3.3 Sustainable Tourism Development in Bonny Island

The World Tourism Organization defines sustainable tourism development as meeting current needs while preserving future opportunities, managing resources effectively, and maintaining cultural integrity, ecological processes, and biological diversity (Cooper et al., 2005). Sustainable tourism balances economic, environmental, and societal impacts to meet current tourist needs and future generations' needs without compromising their capacity.

Sustainable tourism is guided by the following key principles:

- Environmental Responsibility: Minimizing environmental footprints by conserving natural resources, reducing pollution, and protecting biodiversity. Conservation efforts aim to enhance natural ecosystems, combat pollution, protect species, maintain water and air purity, promote coastal ecosystems, and ensure safe recreational activities.
- Economic Viability/Sustainability: Ensuring that tourism generates income and employment opportunities for local communities, contributing to economic growth. In terms of income and revenues, economic sustainability places an extreme value on ongoing benefits for all generations.
- Socio-Cultural Respect: Preserving local culture, traditions, and heritage while promoting cross-cultural understanding and community engagement. Sociocultural factors ensure that community identity is maintained in the growth of tourism.
- Stakeholder Collaboration: Involving all relevant stakeholders, including local governments, communities, and tourism operators, in planning and procedures for making decisions.
- Education and Awareness: Educating tourists and local communities about sustainable ‘practices and environmental conservation.

Tourism significantly contributes to economic empowerment and sustainability in developing countries by generating income, employment, and foreign-exchange earnings, thereby fostering economic growth and sustainability (Adeola et al., 2020). Therefore, nations should not be reluctant to use them, particularly emerging nations with tourism attractions (Purnomo et al., 2020). As a result, nations like Costa Rica, Ecuador, Tanzania, Kenya, and Nepal have adapted their tourism sectors to meet the aforementioned three objectives (Joo et al., 2020; Sarr et al., 2020). The desire of tourists according to According to Putri et al. (2020), travelers want to find new, appealing travel spots in order to have a unique or more fulfilling travel experience.

3.4 Eco-Friendly Marine Recreational Activities Suitable for Bonny Island

1. Sustainable Boating and Kayaking: Use of eco-friendly boats (solar/electric-powered) to minimize water pollution. Promotion of kayaking and canoeing for low-impact exploration of mangrove forests and coastal areas. Introduction of strict guidelines to prevent waste disposal in water bodies.

2. Snorkeling and Scuba Diving with Environmental Awareness: Development of designated snorkeling and diving zones to protect coral reefs and marine species. Implementation of eco-friendly diving practices, such as no-touch policies for coral reefs. Training divers and snorkelers in marine conservation awareness.

3. Wildlife and Bird Watching: Promotion of guided tours in Finima Nature Park and Bonny Island's estuaries to observe migratory birds, sea turtles, and marine mammals. Establishment of bird-watching platforms for nature enthusiasts and researchers. Engagement with conservation experts to ensure responsible eco-tourism.

4. Coastal and Beach Conservation Programs: Implementation of "Adopt a Beach" programs to involve tourists and locals in regular beach clean-ups. Use of recycling stations and waste disposal policies to minimize plastic pollution. Restoration of mangrove ecosystems to combat coastal erosion and support marine life.

3.5 Eco-Tourism and Marine Recreation

Tourism, a key global economy contributor, experienced a 3.5% GDP growth in 2019, but is expected to increase by 5.8% post-pandemic (Statista., 2024). Eco-tourism and marine recreation are closely linked as both focus on nature-based experiences and environmental conservation. Traveling to natural areas while preserving the environment and improving the well-being of local communities is known as eco-tourism. It emphasizes sustainability, education, and community participation. Marine recreation, when practiced with eco-tourism principles, enhances environmental awareness and promotes the preservation of marine habitats. For example, eco-friendly snorkeling tours educate participants about coral reef conservation, while guided wildlife observation fosters appreciation for marine biodiversity. This synergy between eco-tourism and marine recreation not only enriches the tourist experience but also contributes to the conservation of fragile marine ecosystems. Destinations for tourism and recreation can be man-made or natural, and they are divided into three categories according to geographic characteristics: urban, rural, and seashore. Rural tourism includes natural phenomena, while seaside tourism includes resorts and boating. Sustainable tourism uses natural phenomena, while ecotourism preserves ecosystems and promotes environmental knowledge (Igben et al., 2015).

In Nigeria, integrating eco-tourism principles into marine recreation presents a unique opportunity to develop sustainable tourism products that attract environmentally conscious travelers. It also supports local communities through job creation and cultural preservation, ensuring that tourism benefits are shared equitably. By aligning eco-friendly marine recreation with sustainable tourism and eco-tourism principles, Nigeria can achieve a balanced approach to tourism development that promotes environmental sustainability, economic growth, and community well-being. According to a study by Tonbara & Chigozie (2023)"Water Resources and Sustainable Development in Bayelsa State, Nigeria". The study

explored the link between water resources and sustainable development in Bayelsa State, Nigeria, using a cross-sectional cross-sectional method and a questionnaire-based sample of 400 respondents. A study found a positive correlation between water resources and sociocultural, environmental, and economic growth. This emphasizes the importance of developing a sustainable tourist industry and suggests funding, public-private partnerships, and private tourism specialists. Otabor (2024), in a study, investigates the prospects of coastal tourism in Lagos State, Nigeria. The study explores coastal tourism in Lagos State, Nigeria, revealing challenges like environmental issues, infrastructure issues, and regulatory issues. Despite these, the study suggests strategies like sustainable practices, partnerships, and infrastructure investment to boost tourism potential. Folami (2017) emphasizes the need for strong and workable solutions by pointing out that international conventions are insufficient in offering distinct maritime institutional frameworks and that there are no cogent Integrated Ocean Governance policies. Despite Nigeria's oil-based mono-economy, Oladele et al. (2018) point out the possibility for discovering and sustainably using aquatic resources for tourism, which might bring in money, create jobs, and conserve resources.

Oceans sustain 540 million people by providing vital nutrients, particularly to developing countries. However, these resources are under stress from species extinction, biodiversity loss, and overfishing. Eighty percent of marine pollution is caused by plastic litter, sewage, agricultural runoff, and the release of pesticides and nutrients, which closes beaches (Akankali & Elenwo, 2015). Nigeria's marine ecosystem is suffering greatly as a result of an increase in pollution from large enterprises like fertilizer, petrochemical, and oil-producing businesses. Akankali & Elenwo (2015), advocate for public education, legislation, and cooperation to address marine pollution in Nigeria's coastal waters, aiming for a sustainable marine ecosystem. The 1992 UNCED placed a strong emphasis on managing the effects of human activity on marine ecosystems sustainably, which resulted in the Rio Declaration, the Climate Change Framework, the Convention on Biological Diversity, and Agenda 21 (Agbeja, 2017; Cicin-Sain & Knecht, 1998). While taking into account their sensible use and development of living resources, Chapter 17 of Agenda 21 highlights the significance of conserving oceans, seas, and coastal areas (UNEP, 1992). The coastline faces challenges like climate change, flooding, overfishing, and pollution from various activities, leading to rapid degradation due to diversified uses like fisheries, gas exploration, shipping, agriculture, and tourism, affecting marine ecosystems (Agbeja, 2017). Nigeria may profit from a diversified economy that can manage the volatility of an oil-based mono-economy by using its aquatic resources responsibly for tourism, which would support resource preservation, job creation, and revenue generation (Oladele, Digun-aweto, et al., 2018). Water-based tourism, which can be classified as either inland or marine-based, entails leisure pursuits that require travel away from home and concentrate on the coastal region and marine environment (Orams, 1999). Coast and marine tourism encompasses a variety of activities, such as sports fishing, water sports, marine animals, cruises, seafood, coral reefs, boating, yachting, resorts, island tourism, underwater archeology, and polar tourism (Jennings, 2007).

A high rate of poverty (about 80%) and poor handling of the money from the sale of crude oil have made it difficult for Nigerians to explore other tourist attractions in the nation (Obeta & Onah, 2013; World Bank, 2016) Domestic tourism is struggling due to

societal needs being prioritized over tourism development. Coral reef ecosystems attract millions of tourists, generating revenue for island nations. Water sports like snorkeling, scuba diving, and boating contribute to the tourism market, making coral reefs valuable for marine-related tourism (Jones & Shimlock, 2003). According to the 2002 "Reefs at Risk" report by the World Resources Institute, the tourism value of coral reefs in Southeast Asia ranges from $700 to $111,000 per square kilometer (Jones & Shimlock, 2003).

3.6 Challenges Facing Eco-Friendly Marine Recreation in Bonny Island

Despite its rich marine biodiversity and tourism potential, Bonny Island faces several challenges that hinder the development of eco-friendly marine recreation. These challenges range from environmental threats to economic limitations, weak regulatory frameworks, and low community participation.

1. **Environmental Challenges (Pollution, Climate Change, Coastal Erosion)**

- **Marine and Coastal Pollution:** Oil spills from industrial operations, particularly offshore drilling, pose a severe threat to marine biodiversity. Plastic waste and non-biodegradable debris from tourism activities and local settlements pollute beaches and water bodies. Industrial and domestic waste dumping contaminates marine habitats, affecting fish populations and coral reefs. Fuels, oils and other toxins released from inadequately maintained vessels can stress and kill corals and other organisms in the marine environment. According to Umeh et al. (2024) in their study “Economic Impacts of Marine Pollution in Nigeria and the Need for Sustainable Policy Interventions” note that the economic impacts of marine pollution are complex, affecting several sectors such as fishing, tourism, and maritime industry. Spills, whether they are significant or subtle, have a lasting impact on the biodiversity of these waterways, influencing the aquatic ecosystem and the livelihoods that rely on the abundance of marine resources. Marine contamination in Nigeria is not limited only to local sources. The phenomenon of globalization is responsible for the discreet transportation of pollutants across borders, and marine litter has become as a worldwide symbol of environmental decline (Umeh et al., 2024). Plastics, which are widely used for their convenience, travel long distances to reluctantly settle in Nigerian seas, adding to a larger ecological imbalance. Careful management and sustainable practices are desperately needed in the face of these disturbing trends and patterns.

Fig 1: Marine Pollution in Nigeria
Source: (Umeh et al., 2024)

- ❖ Sea level rise and climate change: Rising sea levels raise the possibility of saltwater intrusion into freshwater supplies and endanger coastal communities. More frequent and intense storms accelerate coastal erosion, damaging beaches and tourism infrastructure. Coral bleaching and loss of marine species reduce the attractiveness of snorkeling and diving sites.
- ❖ **Deforestation of Mangroves and Habitat Destruction:** Mangrove forests, which serve as natural barriers against erosion and breeding grounds for fish, are being cleared for development and fuelwood. Unregulated sand mining and coastal construction contribute to habitat loss and shoreline instability.

2. Economic and Infrastructure Constraints

- **Inadequate Tourism Infrastructure:** Limited eco-friendly accommodations (e.g., green lodges and sustainable resorts) hinder tourist stays. Poor transportation facilities (e.g., lack of eco-friendly boats and limited road networks) make access difficult. Absence of waste disposal and recycling facilities leads to increased pollution.
- **High Cost of Eco-Tourism Development:** Developing sustainable tourism infrastructure requires significant investment, which many local businesses cannot afford. Government funding for eco-tourism projects is insufficient, limiting conservation efforts. The absence of financial incentives, such tax breaks for ecotourism businesses, deters investment.
- **Seasonal Nature of Marine Tourism:** Eco-tourism in Bonny Island is highly dependent on favorable weather conditions, leading to fluctuating visitor numbers. Many tourism businesses struggle to remain profitable during low seasons, affecting local livelihoods.

3. Policy and Regulatory Barriers

- ❖ **Weak Enforcement of Environmental Laws:** Existing environmental protection laws are poorly enforced, leading to continued marine pollution and habitat destruction. Illegal fishing and unregulated tourism activities contribute to biodiversity loss and ecosystem degradation.
- ❖ **Lack of Clear Guidelines for Eco-Tourism:** Absence of a structured policy framework for sustainable marine tourism creates uncertainty for investors and operators. No standardized certification for eco-friendly tourism operators, leading to varying sustainability practices.
- ❖ **Bureaucratic Challenges and High Costs of Compliance:** Lengthy permit approval processes discourage small businesses from engaging in eco-tourism. High costs of obtaining licenses and regulatory approvals make it difficult for local entrepreneurs to enter the sector.

4. Awareness and Community Participation Issues

- ❖ **Low Awareness of Eco-Tourism Benefits:** Many residents and business owners are unaware of the economic and environmental advantages of eco-friendly maritime tourism. Limited educational programs on sustainable tourism and marine conservation reduce public interest.
- ❖ **Resistance to Change in Traditional Livelihoods:** Local fishermen and coastal communities may be hesitant to adopt sustainable practices, fearing restrictions on their activities. Lack of alternative income sources discourages participation in conservation programs.

- **Limited Community Involvement in Tourism Development:** Eco-tourism projects are often developed without consulting local communities, leading to low engagement and resistance. Absence of incentives (e.g., employment opportunities, revenue-sharing schemes) reduces community support for conservation efforts.

Opportunities:

1. **Growing Demand for Sustainable Tourism** – Increasing awareness of eco-friendly tourism practices creates new market opportunities.
2. **Public-Private Partnerships (PPPs)** – Collaboration between government, NGOs, and private investors can drive eco-tourism development.
3. **Technological Innovations** – Use of digital marketing, eco-friendly boats, and smart waste management solutions can enhance eco-friendly tourism experiences.
4. **Education and Training Programs** – Establishing community-led tourism initiatives can empower locals to become eco-tourism entrepreneurs.
5. **International Funding & Grants** – Access to global conservation funds for marine protection and eco-tourism infrastructure development.

4. Findings and Discussion

The results were gotten from the field work through qualitative and quantitative data. In-depth interview with the indigenous communities, government staff, and tourists/visitors was conducted. One hundred and thirty (130) questionnaires were distributed, while one hundred and twenty (120) questionnaires were retrieved.

Table 1: Demographic Information

Variables		Frequency (120 respondents)	Percentage (100%)
Sex	**Male**	**64**	**53.3**
	Female	**56**	**46.7**
Age	**Below 18**	**20**	**16.7**
	18–30	**28**	**23.3**
	31–43	**23**	**19.2**
	44–56	**24**	**20**
	57 and above	**25**	**20.8**
Education Level	**No Formal Education**	**12**	**10**
	Primary	**18**	**15**
	Secondary	**51**	**42.5**
	Tertiary	**30**	**25**
	Postgraduate	**9**	**7.5**
Occupation	**Student**	**12**	**10**
	Tourism Operator	**19**	**15.8**
	Hospitality Manager	**21**	**17.5**
	Fisherman	**23**	**19.2**
	Government Official	**15**	**12.5**
	Tourist	**20**	**16.7**
	Business Owner	**10**	**8.3**

Are you a resident of Bonny Island	**Yes**	**76**	**63.3**
	No	**44**	**36.7**
Have you visited Bonny Island for tourism or recreational activities before?	**Yes**	**87**	**72.5**
	No	**33**	**27.5**
How often do you engage in marine recreational activities?	**Never**	**8**	**6.7**
	Occasionally	**63**	**52.5**
	Frequently	**17**	**14.2**
	Always	**32**	**26.6**

Gender distribution shows that male is 64 (53.3%), while female is 56 (46.7%). The slight male majority suggests a near-equal participation rate in tourism-related activities and opinions. This balance is essential for developing inclusive tourism policies that cater to both genders. For age distribution the 18–30 age group (23.3%) is the most engaged, followed closely by the older age groups (31–43, 44–56, and 57+). The relatively high participation of older individuals (20.8%) may indicate long-term interest or economic dependence on marine resources. The 16.7% participation of those below 18 suggests that younger individuals are also aware of tourism and marine recreational activities. However, eco-tourism programs should target younger demographics to encourage sustainable habits. Looking at the educational level, the majority (67.5%) have at least secondary education or higher, which indicates a relatively educated population that can understand and adopt sustainable tourism practices. Only 10% have no formal education, which might reflect educational access in the region. Higher education (postgraduate at 7.5%) is limited, possibly due to economic constraints or limited access to advanced education.

Occupation Distribution shows that fishermen (19.2%) make up the largest occupational group, showing how crucial the marine ecosystem is to the local economy. Tourism operators (15.8%) and hospitality managers (17.5%) indicate a strong marine tourism industry presence. Business owners (8.3%) and government officials (12.5%) suggest the role of private and public sectors in tourism management. The majority (63.3%) are local residents, meaning most respondents have a direct stake in the sustainable development of Bonny Island. The 36.7% non-residents likely represent visitors and external stakeholders interested in marine tourism. Eco-tourism initiatives should involve community-driven projects for sustainability. Tourism and Recreational Engagement revealed that 72.5% have visited Bonny Island for tourism or recreation, indicating that the island is an attractive tourism destination. 27.5% have never visited, suggesting room for improvement in tourism promotion and accessibility. More than half (52.5%) engage in marine recreational activities occasionally, having moderate interest, showing that many people engage in marine activities but may need better access, infrastructure, or incentives to participate more frequently. 26.6% always participate, indicating a committed group that could benefit from better infrastructure. Only 6.7% never participate, suggesting marine tourism is relevant to most people in the area.

Table 2: Marine Tourism Activities in Bonny Island

Variables		Frequency (120)	Percentage (100%)
What eco-friendly marine tourism activities suitable for Bonny Island?	**Eco-boat tours**	**8**	**6.7**
	Kayaking/Canoeing	**7**	**5.8**
	Snorkeling/diving	**5**	**4.2**
	Beach Cons. Programs	**9**	**7.5**
	Wildlife and Birdwatching	**2**	**1.7**
	Beach clean-ups	**6**	**5**
	Responsible fishing	**11**	**9.1**
	All the above	**72**	**60**
What factors influence your decision to engage in eco-friendly marine recreation?	**Environmental concerns**	**57**	**47.5**
	Availability of facilities	**14**	**11.6**
	Government policies	**5**	**4.2**
	Personal Interest	**44**	**36.7**
How would you rate the current state of marine tourism in Bonny Island?	**Good**	**40**	**33.3**
	Average	**44**	**36.7**
	Poor	**36**	**30**
What are the main attractions for marine tourism in Bonny Island?	**Finima Nature Park**	**20**	**16.7**
	Bonny Island Beaches	**26**	**21.7**
	Bonny River and Estuary	**22**	**18.3**
	Mangrove Forests and Coastal Habitats	**10**	**8.3**
	All of the above	**42**	**35**

60% of respondents believe all activities are suitable for Bonny Island, highlighting the demand for diverse eco-tourism opportunities. Responsible fishing (9.1%) and beach conservation programs (7.5%) are the most preferred individual activities. Then, Wildlife and birdwatching (1.7%) is the least chosen activity, possibly due to a lack of awareness or infrastructure. Environmental concerns (47.5%) are the top factor influencing participation, indicating strong awareness of ecological impacts. Personal interest (36.7%) also plays a significant role. Government policies (4.2%) have minimal influence, suggesting possible gaps in policy implementation or enforcement. The respondents provided their perceptions of the state of marine tourism in Bonny Island, categorized as Good, Average, and Poor. 40 respondents answered good (33.3%), showing a significant proportion of respondents believe marine tourism is in a satisfactory state. This could indicate that there are existing tourism attractions, some level of infrastructure, and positive experiences for tourists. Factors such as natural beauty, available recreational activities, and local tourism initiatives may be contributing to this perception.

The majority of respondents (44) rated marine tourism as average **(36.7%)**, suggesting that while there are positive aspects, there are also limitations or areas needing improvement. This could be due to factors such as inadequate infrastructure, lack of awareness, or inconsistent tourism services. This rating indicates that marine tourism in Bonny Island has potential but requires enhancements in planning, investment, and sustainability efforts. A substantial portion of **36** respondents perceive marine tourism as poor **(30%)**, highlighting major challenges in the sector. Possible reasons could include environmental degradation, poor tourism facilities, lack of government support, or pollution. This reflects a need for urgent action to address infrastructure gaps, improve environmental sustainability, and enhance tourism experiences. Enhancing infrastructure, promoting eco-tourism, and improving marketing could help shift perceptions from "average" to "good." Bonny Island Beaches and Finima Nature Park are the most popular. Bonny Island Beaches (21.7%) and Bonny River & Estuary (18.3%) are key tourist attractions. Mangrove Forests (8.3%) received the lowest votes, indicating a possible need for more awareness or development.

Table 3: Challenges Facing Eco-Friendly Marine Recreation in Bonny Island

Variables		Frequency (120)	Percentage (100%)
In your opinion, what are the challenges facing eco-friendly marine tourism in the Bonny Island?	**Pollution/Climate**	**12**	**10**
	Change/Deforestation	**18**	**15**
	Poor infrastructure	**15**	**12.5**
	High cost of sustainable tourism	**26**	**21.7**
	Inadequate government support	**14**	**11.7**
	Lack of awareness	**35**	**29.1**
	All of the above		
Have you noticed any negative environmental impacts caused by marine tourism in Bonny Island?	**Yes**	**113**	**94.2**
	No	**7**	**5.8**
What eco-friendly hospitality practices are suitable in the Bonny Island?	**Use of renewable energy**	**22**	**18.3**
	Waste management and recycling	**31**	**25.8**
	Water conservation	**17**	**14.2**
	Eco-lodges and sustainable accommodation	**50**	**41.7**

The biggest challenge identified is "All of the Above" (29.1%), indicating that multiple issues contribute to difficulties in promoting sustainable marine tourism. Inadequate government support (21.7%) is the second most significant challenge.

Suggesting the need for more policies, funding, and infrastructure investments**.** Other notable challenges include poor infrastructure (15%), high costs of sustainable tourism (12.5%), lack of awareness (11.7%), and pollution/climate change/deforestation (10%). This shows that environmental degradation is a major threat**.** A large majority (94.2%) of respondents observed negative environmental impacts from marine tourism. Only 5.8% did not notice any environmental impact, indicating widespread concern about the ecological effects. The most preferred eco-friendly hospitality practice is eco-lodges and sustainable accommodation (41.7%), indicating strong interest in environmentally friendly lodging options. Second most important concern for sustainable hospitality is waste management and recycling (25.8%). Use of Renewable Energy (18.3%) Shows some interest in shifting towards solar, wind, or other renewable energy sources. Water Conservation (14.2%). The least prioritized practice, but still relevant. This suggests that while water conservation is important, other sustainability practices are considered more urgent.

Table 4: Recommendations for Sustainable Marine Tourism Development

Variables		Frequency (120)	Percentage (100%)
What measures do you think should be taken to promote eco-friendly marine recreation in Bonny Island?	**Stricter environmental regulations**	**12**	**10**
	Improved infrastructure	**25**	**20.8**
	Increased awareness and education programs	**17**	**14.2**
	More community involvement in eco-tourism initiatives	**16**	**13.3**
	Public-private partnerships for sustainable tourism	**14**	**11.7**
	All of the above	**36**	**30**
Do you think eco-friendly marine recreation has the potential to improve tourism and hospitality in Bonny Island?	**Strongly Agree**	**72**	**60**
	Agree	**41**	**34.2**
	Neutral	**7**	**5.8**
	Disagree	**0**	**0**
	Strongly Disagree	**0**	**0**
Do you think the government and private sector are doing enough to promote sustainable marine tourism?	**Yes**	**10**	**8.3**
	No	**105**	**87.5**
	Not Sure	**5**	**4.2**

30% of respondents believe that a combination of all these measures is the best approach to sustainable marine tourism development. Infrastructure improvement (20.8%) and awareness programs (14.2%) are also highly prioritized. 94.2% of respondents (Agree & Strongly Agree) believe eco-friendly marine recreation will improve tourism and hospitality. Only 5.8% are neutral, and none disagree, showing strong public support. 87.5%

of respondents believe that the government and private sector are not doing enough to promote sustainable marine tourism. Only 8.3% think enough is being done, indicating a need for stronger policy implementation and stakeholder engagement.

5. Recommendations

To ensure the successful development of eco-friendly marine recreation in Bonny Island, the following strategic recommendations should be implemented. These focus on environmental conservation, infrastructure development, policy reform, and community engagement.

1. Strengthening Environmental Regulations and Policies

- **Enforce Strict Environmental Protection Laws:** In order to ensure that environmental offenders face consequences, the Nigerian Maritime Administration and Safety Agency (NIMASA) should increase its oversight of oil spills and the disposal of industrial waste.
- **Develop Clear Guidelines for Sustainable Marine Tourism:** Create standards for eco-friendly tour operators, including sustainable boating, responsible wildlife viewing, and waste management practices. The Rivers State Government should introduce eco-tourism certification for operators, ensuring boats, hotels, and recreational activities meet sustainability standards. Hotels and tour operators must meet environmental, social, and cultural sustainability criteria to attract eco-conscious tourists.
- **Improve Coordination Among Regulatory Agencies:** Streamline bureaucratic processes for eco-tourism business permits. Strengthen collaboration between government agencies, private investors, and conservation organizations to improve policy enforcement. Bonny Island Eco-Tourism Task Force should be established to coordinate policies between local councils, environmental agencies, and tourism boards.

2. Developing Eco-Friendly Tourism Infrastructure

- **Invest in Sustainable Accommodations and Facilities:** Encourage eco-lodges built with bamboo, recycled materials, and solar energy. Encourage solar-powered resorts to attract responsible tourists. Develop waste recycling systems and eco-friendly sanitation facilities at major tourist sites.
- **Improve Transportation and Accessibility:** Introduce solar-powered boats and electric water taxis to reduce carbon emissions from tourism activities in Finima Nature Park, Bonny River, and Lighthouse Beach. Upgrade roads and ferry terminals to enhance access to marine destinations.
- **Implement Proper Waste Management Systems:** Install recycling bins at Bonny beaches and waste collection stations at Finima Nature beaches and parks. Launch beach cleanup programs with tourist and community participation. Be aware that debris as small as a cigarette butt can be very harmful to animals such as sea turtles. If engaged in boating or coastal activities, always make sure that trash goes in its proper place and does not end up in the marine environment.

3. Promoting Awareness and Education on Marine Conservation

- **Launch Public Awareness Campaigns:** Use social media, tourism expos, and local events to educate the public on eco-friendly tourism benefits. Organize annual eco-tourism festivals in Bonny Island to educate locals and tourists on marine conservation. Introduce marine conservation education in schools, creating future eco-tourism advocates.

- **Train Local Tour Operators and Guides:** Develop certified eco-tourism training programs for local guides, equipping them with sustainability knowledge by collaborating with the University of Port Harcourt's Tourism Department. Encourage hotels and tour operators to adopt eco-friendly practices through incentive programs.
- **Involve Media and Influencers in Promoting Eco-Tourism:** Partner with travel bloggers, conservationists, and media houses to showcase Bonny Island's eco-tourism potential. Create documentaries and online content highlighting marine conservation efforts.

4. Enhancing Community Participation and Economic Benefits

- **Involve Local Communities in Eco-Tourism Projects:** Establish community-managed tourism enterprises, ensuring locals benefit directly from tourism revenue. Provide grants and microloans for small eco-tourism businesses run by fishermen, artisans, and local entrepreneurs.
- **Create Revenue-Sharing Models:** Implement a system where part of the tourism revenue from Finima Nature Park and Bonny Beaches goes directly to local community development projects (e.g., schools, healthcare).

5 Public-Private Partnerships in Eco-Tourism Development

- **Encourage Investment in Sustainable Tourism:** Offer tax incentives and low-interest loans to businesses investing in eco-friendly marine tourism in Bonny Island. Develop joint ventures between the government, private sector, and international eco-tourism organizations.
- **Implement programs associated with corporate social responsibility (CSR):** Encourage Bonny Island's oil and gas corporations to fund ecotourism and environmental restoration projects while supporting corporate social responsibility (CSR) programs for infrastructural development, marine protection, and community development.

6. Conclusion

Bonny Island holds great potential for marine tourism due to its idyllic beaches, diverse marine biodiversity, and rich cultural heritage. While existing tourism activities provide a foundation, strategic investments in eco-friendly tourism infrastructure, sustainable policies, and community involvement can transform Bonny Island into Nigeria's premier eco-tourism destination. Eco-friendly marine recreation in Bonny Island has the potential to become a model for sustainable tourism in Nigeria. Through community involvement, government support, and private sector investment, eco-tourism can boost economic growth while preserving the island's rich marine biodiversity. By implementing these proven strategies and learning from global best practices, Bonny Island can become a world-class eco-tourism destination while preserving its marine biodiversity and supporting local communities. The textual review emphasizes the significance of eco-friendly marine recreation as a means of promoting sustainable tourism. By analyzing global trends, case studies, as well as the financial and ecological benefits of environmentally friendly travel, this study provides a foundation for understanding how Bonny Island can adopt eco-friendly marine recreation. While challenges exist, the opportunities outweigh the constraints, making Bonny Island a potential eco-tourism hub in Nigeria

A Conflict of Interests

The author(s) have no conflict of interest to declare

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ETHICAL IMPLICATIONS OF POLLUTION AND WASTE MANAGEMENT IN IGBO TRADITIONAL SOCIETY

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Abstract
Environmental sustainability has become a global concern, yet indigenous African societies, such as the Igbo of southeastern Nigeria, have long upheld ethical frameworks that regulate human interactions with nature. This study explores the ethical implications of pollution and waste management in Igbo traditional society, focusing on indigenous ecological principles, religious beliefs, and communal responsibilities. Primary and secondary sources of data collection were adopted; Oral interviews form the primary source of data collection while secondary sources are ethnographic sources, and scholarly analyses. The finding reveals how Igbo cosmology perceives environmental stewardship as a moral obligation, with deities, ancestors, and sacred laws serving as enforcers of ecological balance. Ritual prohibitions, taboos, and communal sanctions historically played a crucial role in waste disposal and resource conservation, fostering a symbiotic relationship between humans and nature. However, modernization, urbanization, and globalization have significantly altered these traditional environmental ethics, leading to challenges such as plastic pollution, deforestation, and inadequate waste management systems. The implication / recommendation of the research states that revisiting and integrating Igbo indigenous environmental ethics with contemporary waste management strategies can contribute to more sustainable and culturally relevant ecological practices. It recommends that a hybrid approach combining indigenous wisdom with modern environmental policies offers a viable framework for addressing pollution and fostering ecological sustainability in Igbo society and beyond

Keywords: igbo traditional society, environmental ethics, pollution, waste management, indigenous knowledge.

Introduction

Environmental degradation is a growing global concern, with pollution and poor waste management being central challenges (UNEP, 2021). The rapid increase in industrialization, urbanization, and population growth has exacerbated these issues, leading to severe consequences such as land degradation, water contamination, and air pollution. While modern societies rely on technological solutions to mitigate these environmental problems, traditional ecological knowledge offers valuable insights that should not be overlooked.

In many African societies, including the Igbo of southeastern Nigeria, environmental consciousness has historically been rooted in religious beliefs, communal responsibilities, and cultural norms. The Igbo people perceive nature as an integral part of human existence, governed by deities, ancestors, and cosmic forces that ensure ecological balance. Environmental protection was historically enforced through sacred laws, taboos, and communal sanctions, which discouraged wasteful practices and indiscriminate pollution. Rivers, forests, and other natural resources were often regarded as sacred and treated with utmost reverence to maintain harmony between humans and nature ((Nnoli, 1998).)

However, as modernization and globalization continue to alter traditional ways of life, many of these indigenous environmental ethics have weakened, leading to an increase in pollution and ineffective waste management practices. Contemporary Igbo society faces significant environmental challenges, including plastic waste accumulation, deforestation, and inadequate disposal systems. Despite the erosion of traditional environmental ethics, there remains an opportunity to integrate indigenous knowledge with modern waste management strategies to create a more sustainable approach to environmental stewardship.

This paper examines the ethical implications of pollution and waste management within Igbo traditional society, exploring how indigenous principles can contribute to contemporary sustainability efforts. By analyzing the intersection between cultural beliefs, ethical considerations, and modern environmental practices, this study aims to provide a framework for addressing pollution and fostering ecological conservation through an integrative approach that respects both tradition and modernity.

Who are the traditional Igbo people of Nigeria

The Igbo people are one of the major ethnic groups in Nigeria, primarily inhabiting the southeastern part of the country. Their traditional society is known for its communal governance, strong cultural values, and deep connection to the environment (Isichei, 1976). Waste management in traditional Igbo society was guided by cultural norms, religious beliefs, and ecological consciousness. This paper explores the Igbo people's traditional beliefs and practices regarding waste management and highlights their relevance in contemporary environmental conservation. The Igbo people predominantly occupy five southeastern Nigerian states: Abia,Anambra, Ebonyi, Enugu and Imo, additionally, significant Igbo populations reside in parts of Delta and Rivers states (Uchendu, 1965).

Igbo Traditional Beliefs about Waste and Cleanliness

In Igbo cosmology, cleanliness is closely associated with spirituality and morality. The earth goddess, Ala, is regarded as the custodian of purity and environmental sanctity (Onwuejeogwu, 1981). Waste and filth are seen as nso Ala (taboos against the earth), which could lead to spiritual and social consequences if not properly managed. Shrines, ancestral groves, and marketplaces were kept clean as a sign of respect to the deities and spirits (Okpoko & Anigbo, 1987). Regular communal cleanups were performed before festivals like the New Yam Festival to purify the land and prevent diseases.

Igbo Traditional Waste Management Practices

Igbo traditional society emphasized waste minimization by repurposing materials. Items such as calabashes, broken pottery, and palm fronds were reused creatively (Okafor, 1992). Broken clay pots were repurposed into cooking hearths. Used palm fronds were turned into compost or woven into household items. Old fabrics were used as burial wraps or cleaning rags.Organic waste was efficiently handled in traditional Igbo society for instance leftovers foods and plant residues were composted and returned to farms as manure (Obasi, 2000).Domestic animals like goats, chickens, and pigs were fed food remnants, reducing waste (Nwosu, 1993). Waste was disposed of in designated areas known as *okpukpu nkụ*(waste pits), which were dug at a safe distance from living areas from fireplaces ashes was used as a natural disinfectant and pesticide. Rivers and streams were safeguarded against pollution due to their sacred significance (Ekechi, 1972). Traditional institutions played a crucial role in waste management for examples The Age Grades (Otu Ogbo): Organized regular sanitation exercises to maintain community hygiene (Achebe, 1958). Umuada (Daughters of the Clan): Enforced cleanliness norms in family compounds. Market Leadership: Ensured market spaces remained clean and enforced penalties for littering (Ilogu, 1974). Certain types of waste, such as menstrual products, human hair, and animal bones, were handled with caution due to their spiritual implications. Some were used in divination and rituals (Mbiti, 1969). Burning of spiritually sensitive waste was a common practice to prevent it from being used for witchcraft. Ritual sweeping before ceremonies symbolized cleansing and renewal.

Modern Challenges and Adaptation

However, with increasing urbanization and modernization, traditional Igbo waste management practices face several challenges such as increase in non-biodegradable waste (plastics, metals) which was not part of the traditional system. Decline in communal responsibility as individualism becomes more prevalent (Nnoli, 1998). Inadequate integration of traditional methods into modern waste management policies.

Nevertheless, elements of traditional Igbo waste management remain relevant in contemporary environmental conservation efforts. Reviving communal sanitation exercises and promoting biodegradable materials can help address modern waste issues sustainably. The Igbo traditional society had a well-organized system of waste management rooted in spirituality, communal responsibility, and ecological consciousness. Although modernization has disrupted some of these practices, they offer valuable insights into sustainable waste management. Integrating indigenous knowledge with modern waste disposal systems can promote environmental sustainability in contemporary Igbo society.

Conceptual Framework

The study is anchored in African environmental ethics, which emphasizes harmony between humans and nature. This framework draws from Igbo cosmology, where the natural environment is perceived as sacred, and pollution is viewed as a moral and spiritual transgression (Iroegbu, 1996). The ethical relationship between humans and their environment in traditional Igbo society is governed by the belief that nature is a living entity, imbued with spiritual significance. Any form of pollution or environmental degradation is

seen as a violation of this sacred balance, which can lead to divine retribution or misfortune within the community (Okafor, 1992).

To provide a comprehensive analysis of these ethical concerns, the research employs an interdisciplinary approach, integrating historical, religious, and environmental perspectives. The historical approach examines how pre-colonial Igbo societies structured their environmental policies through customs and taboos. The religious perspective explores how deities, ancestors, and spiritual beliefs shaped traditional environmental consciousness and governance. The environmental perspective evaluates the effectiveness of indigenous waste management practices in contrast to contemporary pollution control measures (Njoku, 2007).

Furthermore, the study applies a comparative framework to analyze the shift from traditional environmental practices to modern waste management approaches. This comparison highlights the strengths and weaknesses of each system and identifies potential areas where indigenous knowledge can complement contemporary sustainability efforts. By synthesizing insights from these various disciplines, the study aims to bridge the gap between traditional wisdom and modern scientific approaches to environmental conservation (Umeh, 2010).

Traditional Igbo Environmental Ethics

Cosmology and Environmental Stewardship

In Igbo cosmology, the universe is interconnected, and the environment is governed by spiritual forces, including deities (such as Ala, the earth goddess) and ancestors. These spiritual entities are believed to reward responsible environmental behavior and punish acts of pollution and ecological harm (Achebe, 1983). The belief in the sacredness of nature fosters a deep sense of environmental responsibility, as harming the land, rivers, or forests is seen as an offense against the gods and ancestors. Ala, as the custodian of the earth, plays a central role in ensuring ecological balance, and her displeasure manifests in natural disasters, poor harvests, or communal disharmony (Okeke, 2000). Consequently, traditional Igbo communities uphold customs and rituals that reinforce environmental stewardship, such as annual festivals that celebrate the renewal of nature and community-driven efforts to clean and maintain sacred spaces.

One prominent example is the Iri Ji (New Yam) Festival, which honors Ala for her provision of fertile land and bountiful harvests. During this festival, rituals and communal feasts emphasize gratitude and responsible land use, discouraging overexploitation of natural resources. Additionally, some Igbo communities perform purification rites when a river or forest is defiled, reinforcing the collective responsibility to maintain ecological integrity.

Sacred forests, known as *Ohia Nsọ*, serve as conservation zones where logging and hunting are prohibited. These areas are often protected by spiritual sanctions, with myths warning of dire consequences for those who violate the land (Obasi, 2015). Similarly, certain rivers and streams are regarded as sacred and must not be polluted. The maintenance of these natural sites demonstrates the Igbo people's deep-rooted belief in environmental sustainability. The belief that deities inhabit these spaces reinforces the communal obligation to preserve them, ensuring that resources remain available for future generations.

Ritual Prohibitions and Taboos

Traditional Igbo society maintained environmental sustainability through cultural taboos and ritual prohibitions. Sacred groves, rivers, and forests were protected as abodes of deities, and defiling them was strictly forbidden (Okafor, 1992). Waste disposal was regulated through communal laws, and offenders faced spiritual and social sanctions.

Taboos against wastefulness were prevalent in traditional Igbo culture. For instance, it was forbidden to dump refuse into rivers, as such actions were believed to anger the river deities, potentially leading to water scarcity or sickness in the community. Similarly, indiscriminate tree-cutting was discouraged, as it was thought to disrupt the balance between humans and nature. Elders and traditional priests enforced these prohibitions, ensuring that environmental ethics were maintained across generations.

Additionally, certain animals were considered totems and were not to be hunted or harmed. This cultural practice indirectly supported biodiversity conservation by limiting the exploitation of specific species. The combination of religious reverence and ecological wisdom helped sustain Igbo communities for centuries, offering valuable lessons for modern environmental management strategies.

Challenges of Modernization and Environmental Degradation

Despite the effectiveness of traditional ecological ethics, modernization has weakened these practices. Factors such as urbanization, industrialization, and population growth have contributed to environmental challenges, including:

Plastic Pollution

The increasing use of non-biodegradable materials has led to significant waste disposal issues (Nnorom & Osibanjo, 2008). Traditional Igbo societies primarily relied on biodegradable materials such as clay pots, calabashes, and woven baskets for storage and transportation. These materials naturally decomposed, ensuring minimal environmental impact. However, the influx of plastic products, particularly in the form of disposable bags, bottles, and packaging materials, has resulted in widespread environmental degradation.

One of the most severe consequences of plastic pollution in Igbo communities is the blockage of drainage systems, which exacerbates urban flooding during the rainy season. Poor waste disposal practices, such as indiscriminate dumping of plastic waste into rivers and open fields, have also led to contamination of water sources, endangering aquatic life and human health (Ogunwusi & Ibrahim, 2014). The chemical composition of plastics makes them resistant to natural decomposition, meaning that plastic waste accumulates over time, creating long-term ecological hazards.

For example, in major cities such as Onitsha and Aba, plastic waste frequently clogs drainage channels, leading to severe flooding that displaces residents and destroys property. Markets, which are economic hubs in Igbo society, generate large amounts of plastic waste from packaging materials. Due to inadequate waste collection systems, these plastics often end up in nearby rivers like the River Niger, affecting aquatic biodiversity and the livelihoods of fishermen who depend on the river for sustenance (Okafor, 2017).

Furthermore, the absence of efficient plastic waste recycling facilities in many Igbo communities has worsened the problem. Unlike organic waste, which can be composted or repurposed for agricultural use, plastic waste remains a persistent challenge due to its non-

biodegradable nature (Okeke, 2019). Efforts to address this issue remain largely inadequate, as government policies and waste management infrastructure have not kept pace with the rapid increase in plastic consumption.

To mitigate the impact of plastic pollution, there is a need for policies that promote the reduction, reuse, and recycling of plastic materials. Community-led initiatives, such as plastic buy-back programs and eco-friendly product alternatives, should be encouraged to reduce reliance on single-use plastics. Additionally, environmental education campaigns that emphasize the dangers of plastic waste and promote sustainable waste disposal practices can play a crucial role in fostering ecological responsibility among Igbo communities. A successful example is the introduction of waste-to-wealth initiatives in some local government areas, where plastic waste is collected and repurposed into useful items such as paving bricks and eco-friendly bags (Nwankwo, 2021).

Deforestation

Commercial logging and agricultural expansion threaten sacred forests and biodiversity (Umeh, 2010). In pre-colonial Igbo society, forests were considered sacred and served as spiritual and ecological sanctuaries (Iroegbu, 1996). These forests were often dedicated to deities, such as Ala (the earth goddess), and were protected by strict taboos that forbade unnecessary tree felling or hunting within their boundaries. Communities regarded these areas as sacred groves, where rituals were performed and ancestral spirits were believed to reside.

However, the rising demand for timber, coupled with shifting agricultural practices, has led to extensive deforestation, reducing biodiversity and disrupting traditional ecological balance (Eboh, 2005). The introduction of commercial logging, often driven by external economic pressures, has led to indiscriminate tree cutting, leaving large tracts of land bare and vulnerable to erosion. Additionally, expanding farmlands to meet growing food demands has resulted in the clearing of these forests, diminishing natural habitats for wildlife and reducing tree cover essential for maintaining climatic balance.

The effects of deforestation are evident in many parts of Igbo land, such as Anambra and Imo states, where rapid urbanization and commercial agriculture have drastically reduced forested areas. For instance, the sacred Ogbunike Caves and surrounding forest areas, once protected by indigenous customs, have suffered encroachment due to economic development projects (Nwosu, 2018). The depletion of these forests has adversely affected soil fertility, disrupted local water sources, and altered climate patterns, leading to increased desertification and irregular rainfall cycles.

To combat deforestation, there is a need to integrate traditional conservation ethics with modern environmental policies. Reintroducing communal forest management practices, where elders and local leaders enforce sustainable land use, can help curb excessive deforestation. Afforestation programs, where communities replant trees in degraded areas, should also be promoted. Additionally, government regulations should recognize and support the protection of sacred forests, incorporating them into national conservation efforts (Chukwu, 2020).

Urban Waste Management

Traditional waste disposal methods are inadequate for managing the scale of modern urban waste (Okechi, 2016). In rural Igbo communities, waste was traditionally managed through composting, animal feeding, and communal waste pits. However, rapid urbanization and increased consumption of processed goods have overwhelmed these traditional methods, leading to poor waste management infrastructure in urban centers (Chukwuma, 2021). The indiscriminate disposal of solid waste, especially in markets and residential areas, poses serious health risks and environmental hazards (Nnorom & Osibanjo, 2008).

For instance, cities such as Enugu and Owerri struggle with mounting waste, as the rapid influx of people has outpaced the capacity of waste management services. Open dumpsites have become common, creating breeding grounds for disease-carrying pests and contributing to air and water pollution (Eze, 2018). Markets such as Ariaria International Market in Aba and Ogbete Market in Enugu generate tons of waste daily, much of which ends up in unauthorized dumpsites or street corners, creating sanitation crises.

The lack of proper waste collection and disposal facilities has led to severe environmental consequences, including blocked drainage channels, which cause urban flooding during heavy rainfall. Additionally, the burning of waste, a common practice due to limited disposal options, releases harmful toxins into the air, contributing to respiratory illnesses and environmental pollution (Chukwu, 2020).

To address these challenges, local governments and traditional institutions must collaborate to implement effective waste management strategies. Community-based waste segregation programs, where biodegradable and non-biodegradable materials are sorted at the household level, can help streamline waste collection efforts. Incentives for recycling businesses, such as tax breaks and financial grants, can encourage private sector participation in waste management.

Furthermore, incorporating waste management education into school curricula and community outreach programs can instill proper waste disposal habits in younger generations. A practical example is the introduction of the 'Clean up Nigeria' initiative in some southeastern states, which involves regular community sanitation drives and government-sponsored waste disposal schemes (Nwankwo, 2022). By integrating traditional communal responsibility with modern waste management techniques, Igbo urban centers can develop sustainable and efficient waste disposal systems that mitigate environmental degradation.

Integrating Indigenous Knowledge with Modern Environmental Strategies

To address these challenges, there is a need to integrate Igbo indigenous environmental ethics with contemporary waste management policies. Strategies include:

Revitalization of Cultural Practices

Encouraging respect for traditional taboos and sacred sites to promote conservation is a critical step in revitalizing Igbo environmental ethics (Afigbo, 1981). In the past, sacred forests such as the Osun Sacred Grove in Yorubaland and similar Igbo sites served as biodiversity conservation areas, protected from deforestation and exploitation due to their spiritual significance. Re-establishing the sacredness of these natural spaces can contribute to environmental conservation and curb deforestation.

Traditional leaders and religious institutions can play a crucial role in reinforcing these values by incorporating ecological teachings into religious ceremonies and public discourse (Obasi, 2015). For example, priests of the earth goddess (Ala) can emphasize the spiritual consequences of environmental destruction, thereby discouraging harmful activities such as indiscriminate tree felling, mining, and improper waste disposal. Furthermore, festivals like the New Yam Festival and other agrarian rites can incorporate messages about sustainability and environmental responsibility.

Customary laws that once guided resource management should be revisited and adapted to modern environmental needs. In the past, Igbo communities practiced rotational farming, where land was left to fallow to restore its fertility. This practice, which aligns with modern sustainable agriculture principles, can be encouraged among contemporary farmers to prevent soil degradation. Similarly, communal sanctions against pollution such as public shaming or fines for individuals who defile streams and rivers can be reinforced to ensure compliance with environmental laws (Eze, 2018).

By empowering local authorities, communities can rekindle their cultural reverence for the environment and ensure its protection for future generations. Local councils can collaborate with environmental agencies to establish protected zones, implement recycling initiatives, and promote eco-friendly waste disposal systems. These efforts, when combined with indigenous ecological knowledge, can contribute significantly to contemporary sustainability practices and environmental conservation in Igbo society.

Community-Based Waste Management

Leveraging traditional communal governance to enhance modern waste disposal initiatives (Njoku, 2007). The Igbo practice of communal responsibility can be utilized to develop localized waste collection and recycling programs, reducing dependency on government-led initiatives (Okereke, 2020).

For instance, collective waste segregation programs can be introduced, where households and businesses sort waste into biodegradable and non-biodegradable materials before disposal. Composting organic waste for agricultural use can be encouraged within farming communities, reducing environmental waste while promoting sustainable agriculture. Similarly, community-driven recycling centers, where plastics, metals, and glass are repurposed into useful products, can improve environmental cleanliness while fostering social cohesion.

A successful example of such an initiative is the community-led waste management system in Umuahia, where local cooperatives have organized weekly waste collection drives. These efforts have significantly reduced open dumping and improved sanitation within the area. Additionally, some rural communities have reintroduced traditional communal waste pits, ensuring that refuse is properly contained and periodically disposed of in environmentally friendly ways (Nwogu, 2019).

Furthermore, local markets and institutions can be encouraged to reduce plastic waste through the use of biodegradable alternatives. Traditional marketplaces, such as Ogbete Market in Enugu, can implement incentives for responsible waste disposal, including discounts for customers who bring reusable bags or containers. In some Igbo communities, traders have begun adopting plant-based packaging, such as banana leaves,

as a replacement for plastic wraps, thereby reducing environmental pollution (Nnorom & Osibanjo, 2008).

Encouraging youth participation in community-based waste management through environmental clubs and grassroots advocacy programs can also play a crucial role. By integrating modern waste management technologies with traditional communal responsibility, Igbo communities can create sustainable and efficient waste disposal systems while maintaining cultural values of shared responsibility and environmental stewardship.

Education and Advocacy

Incorporating indigenous environmental ethics into formal education is essential for raising awareness and fostering sustainable practices (Chinwe, 2019). Schools and community programs can play a vital role in preserving traditional Igbo ecological knowledge while addressing contemporary environmental challenges. For instance, integrating environmental education into primary and secondary school curricula can help students understand the principles of conservation, waste management, and the spiritual significance of nature in Igbo culture.

Practical applications of this approach include school-based tree-planting initiatives where students are taught the importance of reforestation and biodiversity conservation. Traditional festivals, such as the Iri Ji (New Yam Festival) and Ofala Festival, can also be leveraged to educate the public about indigenous environmental ethics. During such events, elders and cultural custodians can engage younger generations in discussions about ecological responsibility, emphasizing the role of sacred forests, clean water sources, and communal waste management practices (Eze, 2018).

Furthermore, community-driven educational programs can be implemented through town hall meetings and cultural associations. Local radio stations, which remain a primary source of information in many Igbo communities, can be used to broadcast environmental awareness messages that highlight the dangers of pollution and the benefits of sustainable practices. Documentaries and storytelling, deeply rooted in Igbo oral tradition, can also serve as effective tools for disseminating ecological knowledge (Obasi, 2020).

Beyond traditional education systems, government agencies and non-governmental organizations (NGOs) should engage in public awareness campaigns to promote eco-friendly lifestyles. Successful case studies include waste segregation programs in parts of Enugu and Anambra states, where community-based advocacy groups have introduced separate collection points for recyclable and non-recyclable waste. Additionally, some local governments have implemented incentive programs where households receive small financial rewards or utility bill reductions for properly managing their waste (Chukwuma, 2021).

Collaborations between academic institutions and traditional leadership structures can further enhance the effectiveness of these efforts. Universities and research centers can work with local leaders to document and preserve indigenous waste management techniques, ensuring their integration into broader environmental policies. By fostering a connection between ancestral wisdom and modern scientific knowledge, education and

advocacy initiatives can create a sustainable and culturally relevant framework for environmental conservation in Igbo society.

Recommendations

To ensure sustainable environmental management while preserving Igbo traditional ecological ethics, the following recommendations are proposed:

Policy Integration

For environmental sustainability to be effective, the government should incorporate indigenous environmental ethics into national and regional environmental policies. Recognizing the value of traditional ecological practices in policy frameworks can enhance their effectiveness and cultural relevance (Okereke, 2020). Traditional Igbo environmental ethics, which emphasize communal responsibility, reverence for sacred spaces, and the moral obligation to protect nature, can provide a foundation for developing localized environmental policies that are both practical and culturally sensitive.

One way to achieve this is through the legal recognition of sacred forests and water bodies. In the past, sacred groves and rivers were protected by customary laws that forbade deforestation, pollution, and over-exploitation of resources. The government can work with traditional rulers and community leaders to officially designate and protect these sites under environmental conservation laws (Eze, 2018). For example, some parts of Anambra State have successfully integrated local conservation laws with modern environmental policies by recognizing sacred forests as biodiversity reserves, ensuring their protection from illegal logging and encroachment (Nnorom, 2021).

Another important policy initiative is the inclusion of indigenous waste management strategies in urban planning. Traditionally, Igbo communities relied on waste minimization practices such as composting, recycling, and communal sanitation. Modern waste management policies can benefit from integrating these approaches into municipal programs. For instance, local governments can create community-based waste collection systems, where traditional leaders oversee waste segregation and composting projects, reducing landfill reliance and encouraging community participation (Chukwuma, 2021).

Furthermore, environmental policies should support eco-friendly economic incentives that align with traditional Igbo practices. This includes promoting small-scale businesses that manufacture biodegradable alternatives to plastic, such as woven palm baskets and clay storage containers, which were widely used before the rise of synthetic materials. Government grants and tax incentives could encourage businesses to produce and promote sustainable materials, thereby reducing plastic pollution while simultaneously preserving indigenous crafts and local economies (Okafor, 2020).

To ensure the success of these policy integrations, there must be collaboration between government agencies, environmental NGOs, and traditional institutions. Local councils, in partnership with cultural organizations, can establish environmental task forces that merge scientific waste management approaches with indigenous knowledge. An example is the Green Rural Development Initiative (GRDI) in parts of Enugu State, which integrates local waste management traditions with contemporary recycling techniques to reduce environmental degradation (Okechi, 2022).

Additionally, policies should include public education and enforcement mechanisms. Just as traditional Igbo societies enforced environmental laws through

communal sanctions, modern policies should incorporate enforcement strategies that encourage compliance. Local environmental courts or committees could be established to handle cases of illegal dumping, deforestation, and pollution, with penalties ranging from fines to community service.

By embedding traditional Igbo environmental ethics into contemporary policy frameworks, the government can create a more holistic, culturally relevant, and sustainable approach to pollution control and waste management. The fusion of indigenous and modern strategies can not only strengthen environmental conservation efforts but also foster a sense of communal responsibility, ensuring that future generations inherit a healthier ecosystem.

Strengthening Traditional Governance

Traditional rulers, community leaders, and religious institutions have historically played a vital role in environmental governance in Igbo society. These authorities served as custodians of indigenous knowledge, enforcing customary laws that regulated human interactions with nature (Obasi, 2015). To effectively combat modern environmental challenges, it is crucial to empower these traditional governance structures to enforce environmental laws rooted in indigenous practices.

One effective strategy is the reinstatement of customary environmental laws. In pre-colonial Igbo society, communal land, forests, and water bodies were protected by traditional ordinances that prohibited excessive exploitation. These laws were enforced through a combination of moral persuasion, social sanctions, and spiritual deterrents. For example, the Nsukka community in Enugu State has recently revived customary laws that ban illegal logging in their sacred forests, imposing community-driven penalties for violations (Eze, 2018). By legally recognizing these indigenous laws within local government policies, environmental sustainability efforts can be strengthened.

Additionally, traditional institutions should be formally integrated into modern environmental governance structures. Local governments can work with traditional councils to create community-based environmental task forces that oversee waste management, deforestation control, and pollution prevention. In Imo State, some local councils have partnered with traditional rulers to establish community-led sanitation days, where residents collectively clean public spaces and monitor waste disposal practices (Nwankwo, 2020).

Religious institutions also play a crucial role in reinforcing environmental responsibility. Many Igbo communities view pollution as not just a physical offense but also a spiritual transgression against deities such as Ala, the earth goddess. By leveraging religious teachings and practices, local churches and shrines can advocate for better waste disposal habits and conservation efforts. A notable example is the Adazi-Nnukwu community in Anambra State, where traditional priests conduct yearly environmental purification rituals to remind people of their duty to protect nature (Okafor, 2021). These rituals, combined with modern awareness campaigns, help instill a sense of ecological responsibility.

Furthermore, traditional dispute resolution mechanisms can be employed to handle environmental offenses. In pre-colonial times, councils of elders settled

environmental disputes, ensuring that individuals who violated ecological laws compensated the community, often through communal labor or material restitution. Reviving this approach, some rural communities in Abia State now handle cases of illegal dumping or deforestation through town union mediations instead of relying solely on government interventions (Chukwuma, 2022).

By empowering traditional governance structures and integrating their practices into formal environmental policies, Igbo communities can develop sustainable and culturally relevant approaches to pollution control and waste management. This fusion of indigenous leadership with modern environmental governance offers a robust framework for fostering accountability and promoting long-term ecological sustainability.

Public Awareness Campaigns

Public awareness campaigns play a crucial role in promoting sustainable environmental practices by educating people on the dangers of pollution and improper waste management. In Igbo society, where traditional values emphasize communal responsibility, these campaigns can effectively blend indigenous ecological wisdom with modern sustainability principles to drive behavioral change (Chinwe, 2019).

One key approach is community-driven environmental education programs. Traditional town unions, cultural associations, and local government authorities can collaborate to organize awareness workshops on waste disposal, recycling, and pollution control. For instance, in Nsukka, Enugu State, a local youth group launched an initiative to educate market traders on the benefits of replacing plastic packaging with biodegradable alternatives, such as banana leaves and woven raffia baskets. Such grassroots movements can help shift public attitudes towards responsible waste management (Eze, 2021).

Additionally, churches and religious institutions can serve as platforms for promoting environmental awareness. Many Igbo communities regard pollution as a moral and spiritual transgression, making religious leaders influential advocates for ecological responsibility. In Anambra State, some Catholic and Anglican churches have incorporated environmental stewardship messages into their sermons, urging congregants to avoid littering and actively participate in community sanitation days (Okafor, 2022).

The use of media and digital platforms is another effective strategy. Radio and television programs in Igbo language can disseminate information about sustainable waste disposal practices, the dangers of plastic pollution, and the importance of conserving sacred forests and rivers. For example, the Imo State Environmental Protection Agency (ISEPA) has collaborated with local radio stations to broadcast weekly discussions on environmental ethics rooted in Igbo traditions (Nwankwo, 2020). Similarly, social media campaigns featuring local influencers and traditional leaders can engage younger generations and encourage them to adopt sustainable practices.

Furthermore, school-based environmental clubs can instill early awareness of ecological issues among children and adolescents. Schools in Abia State have implemented environmental education programs that integrate indigenous Igbo ecological knowledge into science and social studies curricula. Students learn about the role of Ala, the earth goddess, in environmental conservation and participate in hands-on activities such as tree planting and waste recycling competitions (Chukwuma, 2021).

By combining traditional wisdom with modern outreach strategies, public awareness campaigns can inspire a renewed commitment to environmental stewardship in Igbo communities. Government agencies, NGOs, and educational institutions must work together to sustain these efforts, ensuring that environmental consciousness becomes a core aspect of everyday life.

Waste Management Innovation

Localized and community-driven waste management systems should be established, integrating traditional waste disposal methods with modern technology. Recycling centers and composting initiatives should be promoted to reduce pollution and encourage eco-friendly practices (Nnorom & Osibanjo, 2008).

In rural Igbo communities, traditional waste disposal methods such as composting, controlled burning, and organic waste reuse have been practiced for generations. These methods ensured that biodegradable materials were naturally reintegrated into the ecosystem without causing pollution. However, with the increasing generation of non-biodegradable waste, particularly in urban areas, these traditional systems have become inadequate (Okereke, 2020).

To bridge the gap, localized recycling centers can be established in urban and semi-urban areas to process waste materials into reusable products. For example, in Enugu State, a community-led waste management initiative has introduced small-scale recycling plants that convert plastic waste into construction materials, such as pavement blocks and tiles. This has not only reduced environmental pollution but also created employment opportunities for the youth (Chukwu, 2019).

Additionally, composting initiatives should be encouraged to manage organic waste effectively. In Anambra State, local farmers have begun utilizing organic waste from markets to produce compost, which is then used as fertilizer for agricultural purposes. This practice reduces landfill waste while improving soil fertility and promoting sustainable farming methods (Eze, 2021).

Furthermore, modern technology such as biogas production can be integrated into traditional waste management systems. Household and community-based biogas digesters can convert organic waste into renewable energy for cooking and electricity. Several pilot projects in southeastern Nigeria have demonstrated the viability of biogas systems, provided an alternative energy source while reducing reliance on firewood and fossil fuels (Nwankwo, 2022).

Encouraging private-sector investment in waste recycling and management is another crucial step. Government incentives such as tax breaks and grants for waste-to-energy projects can attract investors to the sector. Partnerships between traditional rulers, local councils, and environmental organizations can help implement policies that support sustainable waste management while incorporating indigenous ecological ethics (Okafor, 2022).

Education and Advocacy

Incorporating indigenous environmental ethics into formal education is crucial to raising awareness and fostering sustainable practices (Chinwe, 2019). Schools and

community programs can teach younger generations about traditional Igbo ecological knowledge and its relevance in addressing contemporary environmental challenges (Eze, 2018). Educational curricula should integrate indigenous ecological principles alongside modern sustainability concepts to cultivate environmentally responsible attitudes.

Furthermore, government agencies and non-governmental organizations (NGOs) should engage in public awareness campaigns to highlight the significance of indigenous waste management strategies and promote eco-friendly lifestyles (Chukwuma, 2021). For example, educational institutions in Enugu and Anambra states have initiated eco-clubs that incorporate Igbo traditional ecological teachings into their environmental education programs. Such initiatives not only raise awareness but also encourage practical engagement through activities like tree planting, waste recycling, and clean-up drives.

Universities and research institutions should also take an active role in studying and documenting traditional Igbo ecological knowledge. This will not only preserve valuable indigenous wisdom but also provide scientific validation and potential integration into national environmental policies. Collaborative research projects between environmental scholars and custodians of traditional knowledge can facilitate the adaptation of indigenous waste management practices to contemporary urban settings (Okafor, 2020).

Additionally, media platforms, including radio, television, and social media, should be leveraged to disseminate information about sustainable waste management practices rooted in Igbo traditional ethics. Programs featuring community elders and environmental experts discussing the relevance of traditional ecological wisdom can foster broader acceptance and application of these practices in modern society (Nnorom & Osibanjo, 2008).

Conclusion

The ethical implications of pollution and waste management in Igbo traditional society reveal a deep-rooted environmental consciousness that can inform contemporary sustainability efforts. Traditional Igbo ecological ethics, anchored in religious beliefs, taboos, and communal governance, offer valuable insights into sustainable environmental practices. However, these principles are increasingly threatened by modernization, urbanization, and industrialization. The erosion of traditional environmental values has led to significant ecological degradation, necessitating urgent action to preserve and adapt these indigenous practices.

By integrating indigenous ecological wisdom with modern environmental policies, Igbo communities and broader societies can develop more effective and culturally relevant solutions to pollution and waste management. This integration requires a multi-stakeholder approach, involving government agencies, traditional institutions, environmental experts, and local communities. Policies that recognize and incorporate traditional ecological knowledge can bridge the gap between cultural heritage and contemporary sustainability demands.

Furthermore, education and public awareness play a crucial role in fostering environmental responsibility. Schools, religious institutions, and media platforms should promote indigenous environmental ethics alongside scientific approaches to conservation. Community-led initiatives, such as reforestation programs, recycling projects, and

sustainable agricultural practices, should be encouraged to reinforce environmental consciousness.

Ultimately, achieving environmental sustainability in Igbo society requires a hybrid approach that respects traditional ecological wisdom while embracing modern advancements. By fostering collaboration between traditional and contemporary environmental strategies, a more holistic and effective framework for pollution control and waste management can be established, ensuring a sustainable future for generations to come.

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PORT OPERATIONS AND PORT SUSTAINABILITY IN NIGERIA: A STUDY OF ONNE AND PORT HARCOURT PORTS

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Abstract
Port operations can impact negatively on ports, hence making the ports unsustainable for efficient use. Studies on port sustainability have also been found to be concentrated on the environmental aspects while neglecting the social and economic implications, making it impossible to generalize the conclusions. The management of ports is also said to pay more attention to economic gains with little or no focus on developing strategies toward achieving social and environmental sustainability. This study was undertaken to examine the impact of port operations on the Triple Bottom Lines of sustainability of Nigerian ports adopting the United Nations' Sustainable Development Goals (UN SDGs) approach. The objectives of study include assessing the relationship between shipping and land transport activities and port sustainability; determining the relationship between port expansion activities and port sustainability. A cross-sectional survey research design was adopted for this study. The population of study comprised key management and operational staff in the two ports. Primary data were collected through questionnaire and analyzed statistically using Pearson Products Moment Correlation Coefficient (PPMC). Study findings show that maritime transportation and land transport activities have positive effects on sustainability of ports. The study concluded that port expansion and shipping and land transport activities have significant and positive relationships with economics, social and environmental sustainability. It was recommended that there should be stakeholders' collaboration for a harmonized sustainability effort as per goal 17 of the UN SDGs on partnerships for the goals and investment in sustainable infrastructure by the management and stakeholders in the port and maritime industry to achieve UN SDGs 9 on industry innovation and infrastructure. The study was limited to Onne and Port Harcourt ports and findings cannot be generalized to other ports in Nigeria. Future research to include other ports in Nigeria is suggested.

Keywords: Port operations, sustainability, United Nations' Sustainable Development Goals, port sustainability, Nigerian ports.

1.0 Introduction

Ports play a crucial role in the economic growth of countries as they are essential to the well-being of mankind in addition to the provision of direct and indirect employment (Roh et al. 2016). Ports are also described as social caretakers for employees and communities, improving and supporting socio-economic concerns. Also, ports are inevitable nodes in maritime supply chains (Asgari et al. 2015; Poulsen et al. 2018; Notteboom et al.

2020). Considered as central nodes connecting ships globally, there are thousands of seaports handling seaborne trade. As of 2023, a total of 106, 700 ships carried 12.3 billion tons of seaborne trade, which grew to 109,000 ships with a 2% growth in tons of seaborne trade in 2024, representing around 90% and 70–80% of world trade volume and value, respectively (UNCTAD 2024). In 2023, container and tanker port calls by ships of 100 gross tons stood at 250, 000. In consideration to the level of activities in the port, ports as nodes in the global supply chains always create environmental and social impacts (Darbra et al. 2004; Dinwoodie et al. 2012) affecting economic growth. In general, ports produce environmental impacts through their various functions related to connectivity to maritime and land transport networks, cargo handling, industrial and semi-industrial activities, energy production and distribution and logistics and distribution activities, (Notteboom et al. 2020). Such external impacts emanating from port expansion and operations and activities of shipping and land transport, have severe impacts on the port environment (Darbra et al. 2004; Peris-Mora et al. 2005; Dinwoodie et al. 2012; Acciaro et al. 2014).

The concepts of reducing port environmental impacts, in addition to stimulating economic growth, and addressing societal concerns, are all included in the concept of port sustainability (Cheon 2017; Cheon et al. 2017; Laxe et al. 2017). In other words, sustainability comprises the triple bottom lines (TBLs), i.e., economic, environmental and social dimensions (Elkington 1998; Gimenez et al. 2012) and are also applicable to port sustainability.

Similar to the relevance of port sustainability in internal operations is that ports should equally extend sustainability externally to landside transport and shipping at the sea side (Roh et al. 2016; Laxe et al. 2017; Oh et al. 2018). It has been pointed out that, that the roles of ports in greening maritime transport and supply chains (Asgari et al. 2015; Notteboom et al. 2020) and in accelerating environmental upgrading cannot be over-emphasised (Poulsen et al. 2018). For example, ports facilitate shipping GHG emission reduction (ITF/OECD 2018; Alamoush et al. 2020). By so doing, ports have moved away from the customary environmental initiatives to a more holistic sustainability that integrate internal and external TBLs (I2S2 2013; Puig et al. 2014; Acciaro et al. 2014).

The push for port sustainability has accelerated due to increased scrutiny of ports and pressure to take actions and decrease impacts through sustainable and cleaner operations (UNCTAD 2019a). Such pressure inspires and encourages ports not to only focus on economic generation, but also to include resilient sustainable plans (Lu et al. 2016a). Consequently, ports are expected to balance economic growth against environmental and social sustainability (Stein and Acciaro 2020), in order to achieve competitive advantage and boost service quality. The pressure on ports for sustainable and cleaner operations is driven by local and international regulations, local communities and non-governmental organisations, corporate social responsibility (CSR), energy efficiency economic benefits, shippers, consignees, cargo owners and carriers, environmental awareness and pursuit of a green port image, Jasmi and Fernando 2018), (Notteboom et al. 2020).

This paper therefore seeks to adopt the Triple Bottom Line (TBL) sustainability measures comprising economic, environmental and social in addressing port sustainability concerns in the context of port operations. The paper will also consider the linkage between the UN SDGs and the role of ports in the implementation of port sustainability actions.

2.0 Need for the research

Port operations significantly impact the economic, social and environmental sustainability of the ports and its adjoining coastlines due to port expansion activities like berth construction, dredging activities, expansion of port's land areas, and C02 emissions, water/land pollution, energy consumption by ships and land transport vehicles in addition to the dangerous nature of the cargoes/goods carried by them. A research on port sustainability is therefore necessary to address the gaps emanating from previous researches. From an academic perspective, the existing literature presents a number of measures to reduce port impacts, either as a group of measures using the green port concept or in the sustainable port concept, Lirn et al. 2013; Chiu et al. 2014; Lam and Notteboom 2014; PIANC 2014; Davarzani et al. 2016; Bergqvist and Monios 2019), I2S2 2013; Asgari et al. 2015; Bjerkan and Seter 2019; Lim et al. 2019. Single port sustainability measures have also been studied, such as air quality improvement (Corbett et al. 2007), greenhouse gas (GHG) emission reduction (Alamoush et al. 2020), energy efficiency (Iris and Lam 2019), renewable energy (PIANC 2019), climate change adaptation (Wilmsmeier 2020) and alternative fuel (Zhong et al. 2019).

The first gap that can be gathered is that sustainability actions and measures are addressed mainly within the environmental dimensions, while neglecting the economic and social dimensions e.g., (Darbra et al. 2009; Lirn et al. 2013; Lam and Notteboom 2014; Acciaro et al. 2014; Davarzani et al. 2016), although few studies have addressed all the three sustainability dimensions (TBLs), e.g., (Shiau and Chuang 2013; Sislian et al. 2016; Roh et al. 2016; Laxe et al. 2017; Oh et al. 2018; Lim et al. 2019).

Secondly, port sustainability within internal operations is the centre of attention in many studies while other relevant areas such as land transport and shipping are not widely addressed (Roh et al. 2016; Lim et al. 2019. The United Nations Sustainable Development Goals (UN SDGs)—2030 Agenda— were introduced in 2015 as a solution to wide-ranging global sustainability (United Nations, 2015). The UN SDGs aim at "eradicating poverty in all its forms and dimensions, combating inequality within and among countries, preserving the planet, creating sustained, inclusive and sustainable economic growth and fostering social inclusion" (United Nations, 2015). Ports functions are various, enabling them to have a broader role in UN SDGs implementation and promotion (WPSP 2020). Looking at it from a global perspective, it could be argued that port sustainability actions contribute to sustainability in general and more specifically to achieving the UN SDGs due to some commonality in addressing the TBLs. However, studies rarely shed light on this important association.

Considering the pressure on ports to maintaining a sustainable performance, in addition to having a broader role in sustainable development, and given the gaps identified, this study aims at examining the impact of port operations on the sustainability of Onne and Port Harcourt ports. Specifically, the objectives of the paper include to: assess the relationship between shipping and land transport activities and port sustainability; determine the relationship between port expansion activities and port sustainability.

3.0 Literature review

The concept of port operations and port sustainability

Port operations encompass the wide range of activities and processes involved to move and handle goods and passengers through the seaport. The activities include vessel services, cargo and passenger handling, port management and other logistics functions such as transport, terminal handling, warehousing and storage, Customs clearance and inspections, documentation and industrial functions including energy and goods production, assembly and disassembly and recycling, etc. (Notteboom et al. 2020).

To achieve the above functions, ports make use of various cargo handling equipment such as the Ship-To Shore (STS), Rubber-Tired Gantry (RTG), and Rail-Mounted Gantry (RMG) cranes, trucks and tractors for yard operations, straddle carriers, forklifts, chassis, reach stackers, etc. for container handling, pumps for liquid bulk ships, and loaders, dozers, cranes, and forklifts for bulk handling (IAPH 2008; PIANC 2014; Bailey and Solomon 2004; IMO 2018a). Equally, ports use vehicles and shuttles for local transfer, and storing cargo in storage facilities and warehouses, and provide nautical services for ships calling at the port through tug, pilot, and towing boats.

While carrying out most of the functions, environmental and social impacts are generated as most of the operations uses fossil fuel and other sources of energy consumption. In the same vein, interaction of transport chains with ports generates various ecological, environmental and social impacts, such as the activities of ships, inland trucks, railways and locomotives. Liquid bulk ships also bring the risk of oil spills, while cruise ships generate large amount of sewage and trash. Such issues would cause environmental deterioration if not monitored, controlled and treated sustainably.

The concept of sustainability and UN SDGs

United Nations Brundtland Commission defined sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 2022).

It is a concept that signifies the improvement and sustainment of environmental (ecological), economic, and social systems for humans (Stoddart et al. 2011)

Sustainability is based on the principle that everything that we need for our survival and well-being depends, either directly or indirectly on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations.

The concept of sustainability in ports call for the integration of economic prosperity, environmental quality and social responsibility (Psaraftis & Kontovas, 2021). Economic stability highlighted by the economic crisis and corporate responsibility issues may shed new light on port operations. Moreover, recently, owing to the growing environmental and social concerns regarding potential environmental impacts, “sustainability” has been increasingly framed in port operations (Mudronja et al., 2020; Özer et al., 2020).

Sustainable port development strategies not only address problems in port areas including safe handling of goods or environmental management, but also includes the actual capacity development for the ports and the establishment of related training capacities in the region, aiming to develop a port and the area surrounding the port through a systematic approach

working with the ports and addressing their specific needs" (UNCTAD, 2021). Sustainable development themes such as safety, health and environment should therefore be a top priority on the shipping companies' list (Weerasinghe & Perera, 2021).

The concept of sustainability cannot be complete without mentioning the United Nations Development Goals (UN SDGs). The UN SDGs are necessary to ensure ports put in the necessary measures and actions towards ensuring the sustainability of the ports and its environment. The Sustainable Development Goals were adopted by the United Nations in 2015 as a call to action to end poverty, protect the environment and ensure that by 2030, people enjoy peace and prosperity. The seventeen Sustainable Development Goals adopted in this study and shown in Figure 1 are all integrated. The goals recognise that action in one area will affect the outcomes in other areas and that its development must ensure a balanced economic, social and environmental sustainability. The inclusion of the United Nation Sustainable Development Goals (UN SDGs) in this study will permit the linkage between the UN SDGs and the port measures and actions in view of three pillars of sustainability referred to in this study as the Triple Bottom Lines, comprising, economic, social and environmental sustainability.

Figure 1: United Nations Sustainable Development Goals

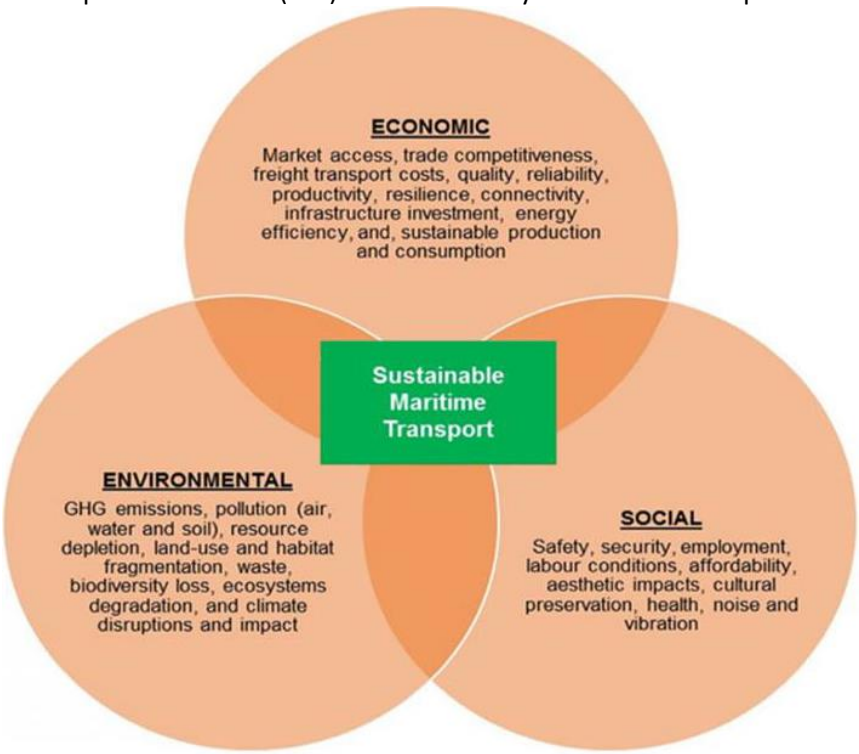
Source: www.un.org/sustainabledevelopmentgoals/

The Triple Bottom Lines of port sustainability

Port sustainability is defined as the strategies and activities adopted to ensure that the current and future needs of the port and stakeholders are met while protecting and sustaining human and natural activities (Denktas-Sakar and Karatas-Cetin 2012; Oh et al. 2018). Nevertheless, ports need to recognise that their actions today affect and influence the lives of future generations and the environment we live and work in. Thus, ports operate sustainably only when decisions are made based on long-term economic growth and reflecting a deep and comprehensive commitment to environmental stewardship, while

integrating community aspirations into business (I2S2 2013). Therefore, port sustainability covers much more than strictly environmental issues such as GHG Emissions, water, air and soil pollution, resources depletion, land use and habitat fragmentation, waste, biodiversity loss, ecosystem degradation, and climate disruptions, that is, it includes the Triple Bottom Lines (TBLs) concept which extends the frame of sustainability to include economic (comprising market access, trade competitiveness, freight transport costs, quality, reliability, productivity, resilience, connectivity, infrastructure investment, energy efficiency and sustainable production and consumption); social which involves safety, security, employment, labour conditions, affordability, cultural preservation , health , noise and vibration (UNCTAD, 2015; PIANC 2014; Lim et al. 2019). Figure 2 shows the Triple Bottom Line concept in the context of port sustainability.

Figure 2: The Triple Bottom Line (TPL) of sustainability in the context of port and shipping



Source: UNCTAD, 2015

Lim et al. (2019) demonstrated the interaction of TBLs indicating that they all interact together. Port environmental sustainability reduces the harmful impact that comes from port operation, ships, and land transport. Social sustainability improves the quality of employees' lives and of neighbouring communities. Economic sustainability boosts port economic performance as a consequence of sustainability implementation while maintaining environmental and social sustainability (Lim et al. 2019). From the foregoing, sustainability dimensions are interconnected, and so cannot be pursued separately. Social issues may be influenced by environmental issues, and environmental aspects might be improved by ports' economic support. A case in point is the modal split measure which

targets the reduction of trucks' emission and congestion; it reduces CO2 emissions and air pollutants (environment), improves efficiency by reducing time and wasted efforts (economy), and eventually contributes to health and safety by decreasing accidents and fatalities and improving port employees and community health (social).

Port economic sustainability is considered a driver for better environmental and social sustainability. Contrary to smaller ports, larger ports which have economically sustained are able to implement environmental and social measures due to availability of funding (Kuznetsov et al. 2015).

Linking port sustainability actions with UN SDGs in the context of Triple Bottom Lines

Port sustainability actions and measures and the sustainable development goals could act as catalysts for global sustainability. As previously noted, ports can apply actions and measures to enhance sustainability while considering the Triple Bottom Lines (TPL). Similarly, but in a wider standpoint, the United Nations Sustainable Development Goals address world economic, environmental and social and issues - the Triple Bottom Lines. A question that calls for answers is whether ports' sustainability measures and actions can be a foundation and contribute to the UN SDGs?

As indicated in Figure 3, and based on similarities between port sustainability actions and measures and UN SDGs, ports' actions and measures contribute to the actualisation of the UN SDGs, directly and indirectly as explained below.

Linkage with environmental actions

Port environmental actions can contribute to many SDGs. For example, the air emissions reduction action and measures support Goal 3 (good health), for employees, and surrounding communities, and protect against ocean acidification (Goal 14 marine life). In addition, lower emissions contribute to Goal 9 (innovation and infrastructure) by using innovative technologies such as electrification, hybridisations, and alternative fuels, and Goal 11 (sustainable cities) considering that ports are integrated with cities. Port air pollution if not reduced would undermine Goal 15 (life on land—forest and ecosystem). Though most air emissions measures target the reduction of ambient air emissions, they still contribute to reduction of GHG emissions (Goal 13 climate actions).

Water pollution and waste actions and measures are important to maintain a good water quality on land, thereby sustaining Goal 6 (clean water and sanitation). On the other hand, while ports control and minimise shipping and port residue, and waste discharge to seas and oceans; life below water improves (Goal 14). Even health of locals and tourists (swimmers), and economics of coastal population, and wildlife ecosystems are protected by actions to prevent water pollution (e.g., from ballast water, and oil spills), which indicates association with Goal 3 (health), Goal 1 (poverty), and Goal 15 (wildlife), respectively.

Noise pollution actions protect against deterioration of marine life (Goal 14 life underwater), and protect the safety and health of port workers, seafarers, and communities (Goal 3 health and wellbeing). Visual pollution actions such as building colouring and camouflage and planting trees improve the aesthetics of the city, Goal 9 (innovation and infrastructure), and Goal 11 (sustainable cities and communities). Measures to reduce light pollution improve the health of employees and surrounding people (Goal 3 health). Notably,

sustainable water consumption actions will preserve drinking water and thus contribute to Goal 6 (sustainable management of water).

Marine biology conservation actions contribute to different goals. For example, limiting sediments and dredging improve marine life, and stop damage to biodiversity (Goal 14). Flood control measures protect habitat quality and flora and fauna (Goal 15 wildlife), and the quality of drinking water (Goal 6). In addition, marine biology measures protect coastal cities' economies by not harming fishing stocks and tourism, thus fighting poverty (Goal 1). Innovation of the circular economy contributes to many goals. For example, reuse and recycling of materials contributes to Goal 12 (responsible consumption), and Goal 11 (sustainable cities). In addition, reduction of waste in and around ports protects underwater life (Goal 14), and wildlife and the land ecosystem (Goal 15), and also protects the health of communities and tourists (Goal 3 good health).

Ports can also take mitigation and adaptation actions against climate change, and hence, they all contribute to Goal 13 (climate actions), and once ports improve infrastructure, they contribute to Goal 9 (innovative infrastructure) and Goal 11 (sustainable cites). Developing efficient hinterland connections and intermodal links has a similar impact. Reduction of GHG emission, for example by electrification and onshore power supply, also protects against ocean acidification and underwater noise (Goal 14). Energy efficiency measures minimise energy consumption (Goal 12 responsible consumption), widen the access to renewable energy such as wind, solar, ocean, and geothermal (Goal 7 clean energy), and improve profitability thus contributing to Goal 8 (economic growth) and Goal 1 (reduction of poverty). Reduction of congestion in and around the port, and improving mobility of cargo and employees are examples that boost city and community sustainability (Goal 11), and improve the health by reducing accidents and ambient air pollutants (Goal 3).

Linkage with social actions

Port workers and employees, in addition to seafarers, truck drivers, customers and surrounding communities all are impacted by port operations and administrative decisions. Similar to the environmental dimensions, social actions and measures also significantly contribute to the UN SDGs. Support of local employment and employees' right to good welfare and health are a foundation for Goal 3 (health) and Goal 8 (good jobs and economic growth), which ultimately reduce poverty (Goal 1). The non-discriminative employment, and gender inclusion contribute to Goal 10 (reduced inequality) and Goal 5 (gender equality), respectively. The safety and security actions and measures protect ships and ports against terrorism, sabotage and armed robbery, and provide safe shelter, thus maintaining peace in cities and societies, i.e., Goal 3 (health and wellbeing), Goal 16 (peace), and Goal 11 (sustainable cities). Collaboration with communities and supply chains, for example with ships and trucking companies and other stakeholders, leverage Goal 17 (partnerships). Community actions contribute to societal health (Goal 3 health), and education (Goal 4 quality education), and city and community sustainability (Goal 11 sustainable cities), while at the same time integrating and creating synergies with academic institutions improves collaboration (Goal 17 partnerships). Paying considerable attention to seafarers' rights and welfare is considered a catalyst for sustaining their physical and mental health (Goal 3),

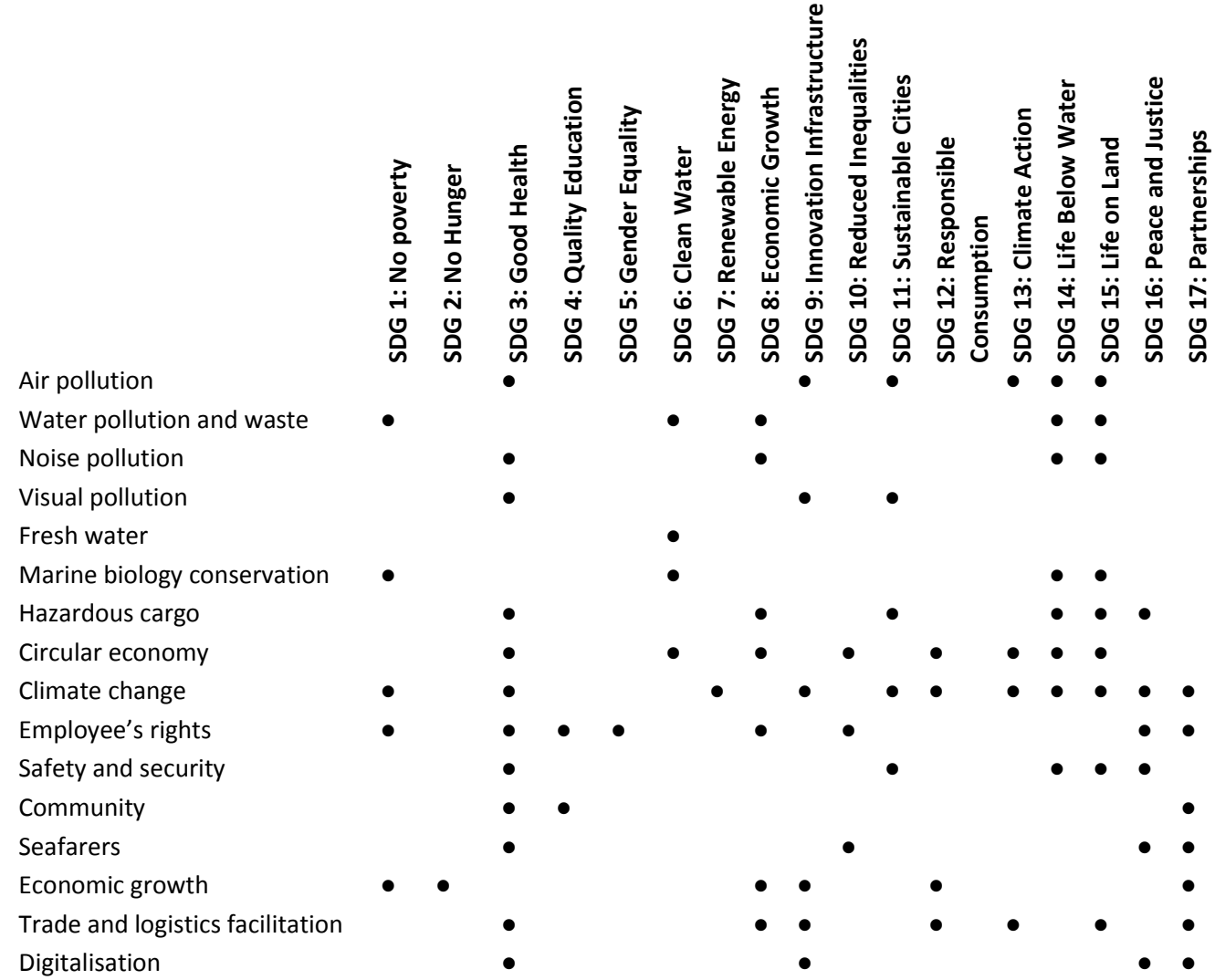
reducing unequal treatment (Goal 10), and supporting the collaboration with shipping companies (Goal 17 partnerships). Ports' actions toward CSR undoubtedly create synergies that open the space for better collaboration and partnerships (Goal 17).

Linkage with economic actions

Port economic actions and measures are interconnected with other environmental and social dimensions. Ports implement actions toward attracting public private partnerships (Goal 17 partnership), thus improving infrastructure (Goal 9 innovation and infrastructure), supporting city economy (Goal 8 economic growth and Goal 1 minimising poverty) and contributing to import and export of food and agricultural production in a way that minimises hunger in countries (Goal 2). So does trade and logistics facilitation, that is partnerships (Goal 17), economic growth (Goal 8), and responsible consumption and production (Goal 12) through Just In Time, responsible procurement and inventory and automation. Such measures yield trade efficiency and minimise delays and congestion and thus reduce air emissions that influence health (Goal 3), and CO2 that stimulate climate change (Goal 13). Digitalisation measures facilitate efficient trade and bring about technological innovations (Goal 17 partnership and Goal 9 innovations) and maintain transparent communication, while addressing cyber security issues thereby contributing to Goal 16 (peace and strong institutions).

Digital technologies minimise human interaction as seen during COVID-19 pandemics and thus protects the health of port related workers (Goal 3 health) and maintains continuous maritime trade.

Figure 3: Potential linkages between port sustainability actions and UN SDGs



Source: Researchers Compilation, 2025

4.0 Methodology

A survey research design was adopted for this paper. This method made it possible to collect data from group of respondents using the questionnaire. The content validity method was adopted in this research. This entailed the use of experts in the field to ascertain that the questions asked cover the objective of the research and are capable of being tested. The respondents' informed consent was sought by informing them that their response was only for academic purposes and would be used solely for the purpose of research.

The study area comprises Nigerian Port Authority Onne and Port Harcourt ports, both located in Rivers State, Nigeria.

Table 1: Target population distribution

Source: Field study, 2025

The target population of the study comprised staff of the two ports with Port Harcourt port and Onne having 363 and 293 respondents respectively and totaling 658 distributed as shown in Table 1:

The sample size of this study was 248 determined using Yamane (1967) formula.

S/N	Name of Port	Number of Staff
1	Port Harcourt port	365
2	Onne Port	293
Total		658

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

Where

n = The sample size required

N = The total (finite) Population

1 = Constant

e = Tolerable error (5%)

Therefore:

$$n = \frac{658}{1+ 658(0.05)2}$$

$$n = \frac{658}{2.65}$$

$$n = 248$$

The actual sample for Port Harcourt port and Onne port were 138 and 110 respectively and determined as shown in the Table 2. The respondents were selected using simple random sampling.

Table 2: Actual sample determination

Ports	Percentage of sample	Actual sample
Port Harcourt Port	$\frac{365}{658} \times \frac{248}{1}$	138
Onne Port	$\frac{293}{658} \times \frac{248}{1}$	110
Sample size		248

Source: Field study, 2025

Table 3 shows the questionnaire average response rate of 93% with a total of eighteen (18) copies of questionnaire not retrieved, representing 11 and 7 for Port Harcourt and Onne ports respectively, representing an average of 7% non-response rate.

Table 3: Questionnaire response rate

Name of Port	Copies of questionnaire administered	Copies of questionnaire filled and returned	Copies of questionnaire not retrieved	Response rate (%)
Port Harcourt port	138	127	11	92
Onne Port	110	103	7	94
Total	248	230	18	93

Source: Field study, 2025

Pearson Products Moment Correlation Coefficient (PPMC was used to analyse the primary data collected through the questionnaire.

5.0 Results and discussion

Test of Hypothesis one: There is no significant relationship between shipping and land transport activities and port sustainability in Onne and Port Harcourt ports.

The Tables 4 and 5 show the respondents' perception on shipping and land transport activities and port sustainability in Onne and Port Harcourt ports.

Table 4: Respondents' perception on shipping and land transport activities

S/N	Question Items	SA	A	D	SD	Total
1	To what extent do you agree that Green House Gas (GHG) emissions from ships can affect the sustainability of the port?	120	90	15	5	230
2	To what extent do you agree that carbon dioxide emissions from land transport vehicles can affect the sustainability of the coastal areas of the port?	120	80	20	10	230
3	How much do you agree that Invasive Aquatic Species (IAS) carried by ships to the port can impact the sustainability of the port?	100	120	5	5	230
4	To what extent do you agree that oil carried by tanker ships and other dangerous cargoes transported by ships to the port can affect the sustainability of the port?	115	90	10	15	230
5	To what extent do you agree that the garbage and sewage carried by ships can affect the economic, social and environmental sustainability of the port?	120	85	10	15	230

Source: Field study, 2025

From the table above, question item 1 on the extent of Greenhouse gas emissions from ships affect the sustainability of the port attracted 120, 90, 15 and 5 strongly agree, agree, disagree and strongly agree responses. The positive responses of 210 against 20 negative responses show that greenhouse emissions affect port sustainability negatively. Question item 2 on the extent of agreement of which carbon dioxide emissions from land transport vehicles can affect coastal area of the port received 120, 80, 20 and 10 responses of strongly agree, agree, disagree and strongly disagree respectively. The positive responses of 200 against 30 negative responses show that carbon dioxide emissions from land transport vehicles can affect coastal area of the port negatively. Question item 3 as to whether Invasive Aquatic Species (IAS) carried by ships to the port can impact the sustainability of the port received 100, 120, 5 and 5 responses of strongly agree, agree, disagree and strongly disagree respectively. The positive response of 220 against 10 negative responses show that Invasive Aquatic Species (IAS) carried by ships to the port can impact the sustainability of the port negatively. Question item 4 on whether oil carried by tanker ships and other dangerous cargoes transported by ships to the port can affect the sustainability of the port received 115, 90, 10 and 15 responses of strongly agree, agree, disagree and strongly disagree respectively. The positive responses of 205 against 25 negative responses show that oil carried by tanker ships and other dangerous cargoes transported by ships to the port can affect the sustainability of the port negatively. Question item 5 on whether garbage and sewage carried by ships can affect the economic, social and

environmental sustainability of the port received 120, 85, 10 and 15 strongly agree, agree, disagree and strongly disagree responses respectively. The positive response of 205 against 25 negative responses indicate that garbage and sewage carried by ships can affect the economic, social and environmental sustainability of the port negatively. The implication of the above responses indicate that the variables verified can affect the achievement of UN SDGs six (clear water and sanitation), eleven (sustainable cities and communities), fourteen (life below water) and fifteen (life on land).

Table 5: Respondents' perception on port sustainability

S/N	Question Items	SA	A	D	SD	Total
1	To what extent do you agree that electric vehicles and alternative fuels can make the ports and land areas sustainable?	150	80	Nil	Nil	230
2	To what extent do you agree that effective terminal designs can result in efficient port operations and sustainable ports?	130	90	10	Nil	230
3	How much do you agree that effective management of waste generated by ships can lead to the sustainability of the port and the adjacent coastlines?	125	100	5	Nil	230
4	To what extent do you agree that effective collaboration amongst the stakeholders can result in sustainable ports?	140	70	15	5	230
5	To what extent do you agree that investment in sustainable infrastructure can improve port operations towards the sustainability of the port?	120	95	10	5	230

Source: Field study, 2025

The table above shows the respondents' perceptions on how some activities/variables can affect port sustainability. Question item 1 on whether electric vehicles and alternative fuels can make the ports and land areas sustainable received all total positive responses of 150 and 80 strongly agree and agree respectively. This indicates a strong perception that electric vehicles and alternative fuels can make the ports and land areas sustainable. Question item 2 on whether effective terminal designs can result in efficient port operations and sustainable ports received positive responses of 130 and 90 strongly agree and agree as against 10 negative responses. This shows that effective terminal designs can result in efficient port operations and sustainable ports. Question item 3 on whether effective management of waste generated by ships can lead to the sustainability of the port and the adjacent coastlines received positive responses of 225 comprising 125 strongly agree and 100 agree with only 5 negative responses, indicating that effective management of waste generated by ships can lead to the sustainability of the port and the adjacent coastlines. Question item 4 on whether effective collaboration amongst the stakeholders can result in sustainable ports also received positive responses of 210

comprising 140 and 70 strongly agree and agree respectively with only 20 negative responses indicating that effective collaboration amongst the stakeholders can result in sustainable ports. Question item 5 on whether investment in sustainable infrastructure can improve port operations towards the sustainability of the port received 120, 95, 10 and 5 strongly agree, agree, disagree and strongly agree responses respectively. This indicates that with a positive response of 215 as against 15 negative responses, investment in sustainable infrastructure can improve port operations towards the sustainability of the port. the implication is that electric vehicles and alternative fuel, effective terminal design, effective waste management, collaboration amongst stakeholders and investment in sustainable infrastructure can impact positively on UN SDGs 7, 11, 13, 14, 15, and 17 on affordable and clean energy, sustainable cities and communities, climate action, life below water, life on land and partnerships for the goals respectively.

Table 6 shows the output result of the PPMC between shipping and land transport activities and port sustainability in Onne and Port Harcourt ports.

Table 6: PPMC output result between shipping and land transport activities and port sustainability in Onne and Port Harcourt ports

Correlations

		Shipping and land transport activities	Port sustainability
Shipping and land transport activities	Pearson Correlation	1	.965**
	Sig. (2-tailed)		.000
	N	230	230
Port sustainability	Pearson Correlation	.965**	1
	Sig. (2-tailed)	.000	
	N	230	230

**. Correlation is significant at the 0.01 level (2-tailed).

Source: SPSS, 2025

The result was significant at .000 (2-tailed) indicating that significant relationship exists between shipping and land transport activities such as GHG emissions from ships, CO2 emissions from vehicles, invasive aquatic species carried by ships to ports, etc. and port sustainability.

The finding is in line with Tierney et al. (2019) who confirmed that maritime transportation has a positive effect on sustainability of ports as it creates a pool of investors and business opportunities that transporters can tap into for positive performance results. Also, Serra *et al*. (2020), opined that among the logistics functions, transportation induces highest environmental hazard, hence sustainable logistics practice becomes a popular approach among service providers.

Psaraftis, & Kontovas, (2021), highlighted that the importance of incorporating sustainable transportation practices for logistics service providers in port cannot be over emphasized. The authors further stressed that proper practice on sustainable logistics helps

in reducing carbon footprint, reduces travel time, increases truck load utilization and improves proper planning on use of resources. The finding of the study further confirmed that a positive and significant relationship exists between transportation and social orientation as a measure of sustainability of ports in Nigeria (Bankole *et al.*, 2017).

Equally, a critical analysis of the finding also revealed that a positive and significant relationship exists between transportation and environmental orientation as a measure of sustainability of ports in Nigeria. The findings agreed with Wong et al. (2017) where the results showed that engagement of suppliers with higher environmental management capabilities will help a firm to perform better financially and environmentally.

Test of Hypothesis Two: There is no significant relationship between port expansion activities and port sustainability in Onne and Port Harcourt ports

Table 8 shows the respondents' perception on port expansion activities. Question item 1 on whether berth construction can affect the sustainability of the port received 110, 105, 5 and 10 strongly agree, agree, disagree and strongly disagree responses. Total positive responses of 215 as against the negative responses of 15 indicate that berth construction can affect the sustainability of the port negatively. Question item 2 on whether the implementation of new technology can affect the sustainability of port received 120, 90, 10 and 10 strongly agree, agree, disagree and strongly disagree responses with only 20 negative responses indicate that the implementation of new technology can affect the sustainability of port. question item 3 on whether dredging activities can affect the sustainability of the port received 125, 85, 5 and 15 strongly agree, agree, disagree and strongly disagree responses respectively. With the total positive responses of 210 as against the negative responses of 20, this indicates that dredging activities can affect port sustainability negatively. Question item 4 on whether expansion of the port's land area for more storage /stacking space can affect the sustainability of the port received 115, 100, 10 and 5 strongly agree, agree, disagree and strongly disagree responses respectively. The total positive responses of 215 exceed negative responses of 15, indicating that expansion of the port's land area for more storage /stacking space can affect the sustainability of the port. The last question item on the table on whether expansion of landside infrastructure like rail connections and roads can affect the sustainability of the port received 115, 95, 13 and 7 strongly agree, agree, disagree and strongly disagree responses respectively. This implies that with the total positive responses of 210 as against 20 negative responses, expansion of landside infrastructure like rail connections and roads can affect the sustainability of the port negatively. The general implication is that construction of berths, new technology implementation, dredging activities, expansion of port land area and expansion of landside infrastructure can hamper the overall achievement of UN SDGs 11, 13, 14, 15, and 17 on sustainable cities and communities, climate action, life below water, and life on land respectively.

Table 8: Respondents' perception on port expansion activities

S/N	Question Items	SA	A	D	SD	Total
1	To what extent do you agree that berth construction can affect the sustainability of the port?	110	105	5	10	230
2	To what extent do you agree that the implementation of new technology can affect the sustainability of port?	120	90	10	10	230
3	How much do you agree that dredging activities to deepen the waterways can affect the sustainability of the port?	125	85	5	15	230
4	To what extent do you agree that expansion of the port's land area for more storage /stacking space can affect the sustainability of the port?	115	100	10	5	230
5	To what extent do you agree that expansion of landside infrastructure like rail connections and roads can affect the sustainability of the port?	115	95	13	7	230

Source: Field study, 2025

Table 9 shows the output result of the PPMC between port expansion activities and port sustainability in Onne and Port Harcourt ports.

Table 9: PPMC output result between port expansion activities and port sustainability in Onne and Port Harcourt ports.

Source: SPSS, 2025

Correlations

		Port expansion activities	Port sustainability
Port expansion activities	Pearson Correlation	1	.967**
	Sig. (2-tailed)		.000
	N	230	230
Port sustainability	Pearson Correlation	.967**	1
	Sig. (2-tailed)	.000	
	N	230	230

**. Correlation is significant at the 0.01 level (2-tailed).

The result was significant at .000 (2-tailed) indicating that significant relationship exists between port expansion activities such as berth construction, dredging, expansion of landside infrastructure, etc. and port sustainability.

This finding affirms the fact that port expansion activities can impact port sustainability negatively. From the environmental impacts point of view, port expansion activities can lead to air and water pollution through emissions from ships and fuel powered

equipment. It can also lead to noise pollution in the surrounding communities. Port expansion activities can equally lead to biodiversity loss by damaging coastal ecosystems.

Socially, port expansion activities can lead to community disruptions where communities are displaced and traditional livelihoods disrupted. The air and water pollution from port expansion activities can also have negative impacts on public health with associated difficulties in respiration and other health challenges.

Economically, an unplanned and a poorly managed expansion project can lead to increase in the total cost of port management, hence resulting in reduced efficiency in port operations.

6.0 Conclusions and recommendations

Sustainable port operations are no longer optional but essential for the future of the port and the maritime industry. From the results, the study concluded that:

1. There is a significant relationship between shipping and land transport activities and port sustainability in Onne and Port Harcourt ports;
2. There is a significant relationship between port expansion activities and port sustainability in Onne and Port Harcourt ports.

The paper recommended that adopting the following best practices will significantly reduce the economic, social and environmental impacts in the ports.

1. There should be a transition to electric vehicles and renewable energy to achieve United Nations' Sustainable Development Goals 7 and 11 on affordable and clean energy and sustainable cities and communities.
2. There should be effective management of wastes in Nigerian ports to ensure UN SDGs 3 and 6 on good health and well-being and clean water and sanitation respectively.
3. There should be stakeholders' collaboration for a harmonised sustainability effort as per goal 17 of the UN SDGs on partnerships for the goals.
4. There should investment in sustainable infrastructure by the management of the ports and other stakeholders in the port and maritime industry to achieve UN SDGs 9 on industry innovation and infrastructure.
5. The port terminals should be effectively designed to ensure decent work and economic growth as per UN SDG 8.

The study was limited to Onne and Port Harcourt ports and findings cannot be genaralised to other ports in Nigeria. Future research to include other ports in Nigeria is hereby suggested.

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MARITIME POLLUTION MITIGATION: TECHNIQUES FOR LONG TIME ECONOMIC DEVELOPMENT.

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Abstract
The study examined Maritime Pollution Mitigation: Techniques for Long-Term Economic Development. The study specifically examined the primary sources and impacts of maritime pollution on the environment and economy, existing maritime pollution mitigation strategies and their effectiveness, explored innovative and sustainable technologies that can reduce maritime pollution while fostering economic development and provided policy recommendations for stakeholders to promote eco-friendly maritime operations without compromising economic growth. The study adopted a qualitative research approach, involving a comprehensive review of existing literature, case studies, and policy analysis. The study was analyzed using Pearson correlation, the analysis revealed that major pollutants, including oil spills, ballast water discharge, greenhouse gas emissions, and plastic waste, significantly affecting marine ecosystems. It was also observed that measures, such as the use of cleaner fuels, ballast water treatment systems, and strict regulatory frameworks, have shown varying degrees of success in controlling pollution. The study recommended among others that Governments and international organizations should enhance existing regulations and ensure strict enforcement to minimize maritime pollution.

Keywords: International Maritime Organization, Maritime pollution, oil spills, plastic waste, ecosystems.

Introduction

1.1 Background of the Study

Maritime pollution is a significant environmental challenge, affecting marine ecosystems, human health, and economic activities. As global trade relies heavily on maritime transport, the increasing number of vessels contributes to various types of pollution, including oil spills, chemical discharges, plastic waste, and greenhouse gas emissions (GESAMP, 2019). Addressing these issues is crucial for achieving sustainable development and preserving marine biodiversity.

One of the primary concerns of maritime pollution is its impact on marine biodiversity. Pollutants such as oil, plastics, and hazardous chemicals can disrupt aquatic ecosystems, leading to the loss of marine species and the degradation of natural habitats (UNEP, 2021). These disruptions not only threaten biodiversity but also affect fisheries and tourism, which are essential for the economies of coastal communities. For example, it is

estimated that about 8 million tons of plastic enter the ocean every year, with shipping and fishing activities accounting for a significant portion of marine litter (Jambeck et al., 2015). Despite international conventions such as MARPOL, weak enforcement in many developing nations means that illegal dumping and insufficient waste management remain widespread.

In addition to environmental concerns, maritime pollution poses significant health risks. Contaminants released into the ocean can enter the food chain, affecting human populations that rely on seafood as a primary source of nutrition. Long-term exposure to polluted waters has been linked to various diseases, including respiratory problems, skin conditions, and gastrointestinal disorders (WHO, 2020). Yet, monitoring technology remains a barrier. For instance, less than 30% of global maritime traffic is effectively tracked for compliance with sulfur emission regulations, leaving large "blind spots" where violations can occur undetected (IMO, 2020). This technological limitation exacerbates the difficulty of ensuring accountability at sea.

Thus, mitigating maritime pollution is vital for public health. Strengthening enforcement mechanisms, expanding satellite-based vessel tracking, and investing in cleaner fuel technologies are essential steps toward reducing pollution and safeguarding both marine biodiversity and human well-being.

Furthermore, maritime pollution leads to substantial economic losses. Oil spills and other contaminants damage fisheries, aquaculture, and tourism, resulting in financial setbacks for industries and local economies. For example, the Deepwater Horizon oil spill in 2010 caused extensive damage to the Gulf of Mexico's economy, with billions of dollars spent on cleanup efforts and compensation (National Academies of Sciences, 2017). Implementing effective mitigation strategies can help prevent such economic disruptions.

To address these issues, international regulations and policies have been established to control maritime pollution. Organizations such as the International Maritime Organization (IMO) have introduced regulations such as the MARPOL Convention, which aims to reduce ship-based pollution through stricter waste disposal measures and fuel quality controls (IMO, 2022). However, enforcement gaps remain a major challenge. A 2020 report by the European Maritime Safety Agency (EMSA) revealed that nearly **30% of ships inspected in EU waters were found to be non-compliant** with pollution-prevention standards, often due to weak monitoring capacity and inconsistent enforcement across jurisdictions. These gaps limit the overall effectiveness of global regulatory frameworks.

Investing in innovative pollution mitigation technologies can further support long-term economic development. Advances in green shipping technologies, such as alternative fuels, exhaust gas cleaning systems, and ballast water treatment, offer promising solutions to minimize the environmental footprint of maritime operations (European Maritime Safety Agency, 2021). Yet, the adoption of these technologies remains limited. For instance, as of 2021, less than **5% of the global merchant fleet used alternative fuels**, largely due to high costs, inadequate fueling infrastructure, and technological uncertainties (International Energy Agency, 2021). Addressing these limitations is crucial for scaling up sustainable practices.

Maritime pollution has been a growing concern since the industrialization of shipping and marine-based industries. With the increase in global trade and maritime traffic, pollution levels have escalated, leading to widespread environmental degradation.

Industrial discharges, ballast water contamination, and waste dumping have compounded the problem, necessitating urgent mitigation measures (GESAMP, 2019).

A striking example is the **Niger Delta in Nigeria**, where oil-related maritime pollution has persisted for decades. According to the United Nations Environment Programme (UNEP, 2011), over **1.5 million tons of oil** have been spilled in the region since the 1950s, contaminating water bodies, destroying fisheries, and threatening livelihoods. Despite Nigeria's adoption of international maritime pollution frameworks, enforcement has been weak due to corruption, inadequate monitoring technology, and limited institutional capacity. Furthermore, cleanup technologies remain outdated, with most remediation efforts relying on manual cleanups rather than advanced oil recovery or bioremediation methods. This case highlights how enforcement failures and technological constraints can undermine the effectiveness of pollution control policies, especially in developing economies heavily reliant on maritime industries.

Historically, oil spills have been among the most visible and catastrophic forms of maritime pollution. Notable incidents such as the Exxon Valdez spill in 1989 and the Deepwater Horizon disaster in 2010 highlighted the severe environmental and economic consequences of uncontrolled oil discharges. These events underscored the need for stringent regulations and advanced cleanup technologies to minimize pollution (National Academies of Sciences, 2017).

Table 1: Major Oil Spill Incidents and Their Estimated Economic Costs

Incident	**Year**	**Estimated Economic Cost (USD billions)**
Exxon Valdez	1989	7.0
Deepwater Horizon	2010	61.6

The data indicate that the Deepwater Horizon disaster in 2010 had a significantly higher economic impact than the Exxon Valdez spill of 1989, reflecting both the scale of the spill and the broader economic dependencies on the Gulf of Mexico. This highlights the growing need for advanced preventive and remedial measures in maritime oil transport.

Plastic pollution in the ocean has also emerged as a critical issue, with millions of tons of plastic waste entering marine ecosystems annually. Microplastics pose a particular threat, as they are ingested by marine organisms and accumulate in the food chain, affecting both wildlife and human populations (UNEP, 2021). Strategies to reduce plastic waste, such as recycling initiatives and alternative packaging solutions, are essential in tackling this crisis.

The introduction of greenhouse gas emissions regulations in the maritime sector is another significant development in pollution mitigation. Shipping accounts for approximately 3% of global carbon dioxide emissions, prompting calls for cleaner fuel alternatives and energy-efficient vessel designs (IMO, 2022). Technologies such as liquefied natural gas (LNG) propulsion and hydrogen fuel cells are being explored to reduce the sector's carbon footprint. The issue is exacerbated by the continuous growth in global trade,

which relies heavily on maritime transport. According to UNCTAD (2022), over 80% of global merchandise trade by volume is carried by sea, contributing significantly to the rise in maritime emissions and pollution.

International collaboration has played a crucial role in addressing maritime pollution. The IMO, in coordination with regional bodies and national governments, has implemented global standards for pollution control, such as the Ballast Water Management Convention and the International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC) (IMO, 2022). These agreements aim to create a unified approach to pollution prevention and response.

The integration of economic incentives and regulatory frameworks has encouraged industries to adopt sustainable practices. Market-based mechanisms such as carbon pricing, green shipping certifications, and financial incentives for low-emission vessels promote environmentally responsible operations. By aligning economic and environmental goals, maritime industries can contribute to sustainable development while ensuring profitability (European Maritime Safety Agency, 2021).

1.2 Statement of Problem

Despite the existence of international regulations and technological advancements, maritime pollution remains a persistent challenge. The increasing demand for global trade and shipping activities has led to a continuous rise in pollution levels, exacerbating environmental degradation and economic losses. For instance, the International Maritime Organization (IMO) reports that shipping accounts for nearly **3% of global greenhouse gas emissions**, and without stronger measures, this could increase by **50–250% by 2050** (IMO, 2020). Current mitigation measures are often hindered by regulatory enforcement gaps, limited adoption of green technologies, and inadequate investment in sustainable infrastructure. For example, although the IMO's 2020 Sulphur Cap regulation mandates a significant reduction in sulphur emissions, a 2022 Transport & Environment study found that **up to 30% of ships were still non-compliant due to weak enforcement mechanisms**, especially in developing regions.

Moreover, many developing nations lack the financial and technological resources to implement effective pollution control measures. This has left vulnerable coastal communities to face the brunt of environmental damage, affecting their livelihoods and economic stability. In West Africa, for instance, oil spills and ballast water discharges have severely impacted fisheries, with the **Niger Delta losing an estimated $1 billion annually in fisheries revenue** due to marine pollution (UNEP, 2019). The disparity in pollution management between developed and developing nations underscores the urgent need for global cooperation and equitable resource distribution to ensure that no region disproportionately bears the costs of maritime pollution.

Table 1: Compliance with IMO Sulphur Cap Regulation (2020–2024)

Region	Estimated Compliance Rate (%)	Key Enforcement Challenges
Europe (EU Ports)	90	Strong enforcement; use of monitoring technologies
North America	85	High compliance but costly monitoring
Asia-Pacific	65	Inconsistent enforcement; limited port inspections
Africa	55	Lack of monitoring equipment; financial constraints
Latin America	60	Limited adoption of scrubber technology

The table shows significant regional disparities in compliance with the IMO Sulphur Cap. Developed regions such as Europe and North America report higher compliance due to robust enforcement mechanisms and advanced monitoring systems. In contrast, Africa and parts of Latin America exhibit compliance rates below 60%, largely due to weak regulatory enforcement and financial constraints. This highlights the enforcement gap and limited adoption of green technologies in developing nations, leaving them more vulnerable to maritime pollution.

There is also a need for stronger monitoring and compliance mechanisms to ensure adherence to pollution regulations. Many shipping companies prioritize cost-saving measures over environmental responsibility, leading to non-compliance with established standards. Strengthening regulatory enforcement and imposing stricter penalties for violations can enhance compliance and accountability.

Additionally, public awareness and stakeholder engagement in pollution mitigation efforts remain insufficient. Many industries and consumers are unaware of the long-term economic and environmental consequences of maritime pollution. Educational initiatives, corporate responsibility programs, and policy advocacy can help drive a collective effort toward sustainable maritime practices.

Finally, the slow adoption of alternative energy solutions and green technologies in the maritime sector presents a significant barrier to pollution mitigation. Research and development investments, along with government incentives, are crucial in accelerating the transition toward cleaner and more efficient maritime operations. Addressing these challenges will be instrumental in achieving long-term economic development while safeguarding marine ecosystems.

1.3 Purpose of the Study

The aim of this research work is to examine maritime pollution mitigation: techniques for long-term economic development. The specific objective of the study include the following;

1. To examine the primary sources and impacts of maritime pollution on the environment and economy,

2. To evaluate the existing maritime pollution mitigation strategies and their effectiveness.
3. To explore innovative and sustainable technologies that can reduce maritime pollution while fostering economic development

1.4 Scope of the Study

This study focuses on maritime pollution mitigation techniques for long-term economic development, with a particular emphasis on Nigeria as the geographical scope. Nigeria is a significant case study for several reasons. First, it has a vast coastline of approximately 853 kilometers along the Atlantic Ocean, which hosts major seaports such as Lagos, Port Harcourt, Calabar, and Warri. These ports serve as gateways for international trade, making maritime activities a critical component of Nigeria's economy.

Second, Nigeria is Africa's largest oil producer, and offshore oil exploration, drilling, and transportation expose its marine environment to frequent risks of oil spills, gas flaring, and chemical discharges. These activities, combined with growing shipping operations, contribute substantially to maritime pollution.

Third, maritime pollution poses direct threats to Nigeria's blue economy, including fisheries, aquaculture, and coastal tourism, which provide livelihoods for millions of people. Furthermore, pollution in Nigerian waters has transboundary implications, affecting the Gulf of Guinea region, a global hotspot for shipping and trade.

By focusing on Nigeria, this study not only highlights the environmental and economic risks posed by maritime pollution but also underscores the urgency of adopting sustainable mitigation techniques that can secure both ecological health and long-term economic development.

2.0 Literature Review

2.1 Data Sources, Refining, and Extraction

The purpose of this systematic review was to examine chronological trends and the usage of technologies in marine pollution research. To achieve this, the authors used the **Scopus database** to collect citation information and author keywords from relevant articles. Although other indexing databases such as Web of Science and Dimensions were considered, Scopus was chosen because it offers wider coverage of journal articles and a more rigorous regulatory policy compared to Dimensions.

For the search process, the authors employed a set of keywords. These included: *"Marine," "Ocean," "Sea," "Pollution," "Oil spill," "Plastic," "Eutrophication," "HNS" (Hazardous and Noxious Substances), "Waste," "Sewage," "Runoff,"* and *"Heavy metal."* The keywords were applied to article titles, abstracts, and author keywords during the initial screening stage.

This search yielded a total of 90,893 peer-reviewed Scopus-indexed journal articles published up to 2022. These articles formed the dataset for further analysis. Where necessary, statistical techniques such as the Pearson correlation were applied to identify relationships and co-occurrence patterns among keywords, publication years, and subject areas. Although the dataset is primarily qualitative, Pearson correlation was used here in a

bibliometric context—to measure the strength of association between numerical values assigned to keyword frequencies, citation counts, and publication outputs.

To refine the search results, the built-in filters of Scopus were employed to exclude articles that were not journal articles or were written in languages other than English. The authors thus present a comprehensive analysis of the trends and technological advancements in marine pollution research based on a large set of high-quality peer-reviewed journal articles. The bibliometric analysis method which was followed in this study was employed by multiple studies to carry out a comprehensive analysis to identify the development, status and the gaps in knowledge (Lee & Khim, 2022).

2.2 Preparation and analysis of network diagrams of keywords

The present study involved the extraction of bibliographical information and author keywords from journal articles using the Scopus database. If the number of journal articles for a given year exceeded 2000, a relevance-based sorting method was employed due to Scopus's restriction on user access to search records beyond the first 2000 (Elsevier, 2022b). To analyze research trends and technological developments over time, the authors classified four decades as follows: (a) 2022-2012, (b) 2011-2001, (c) 2000-1990, and (d) 1990 >. The bibliographic dataset from the Scopus database was used to generate keyword network diagrams using the VOS Viewer software which is a versatile software used in multiple studies which incorporates bibliometric keyword analysis (Lee et al., 2023). Specifically, the software was used to create diagrams based on the 100 most frequently occurring keywords in each decade.

2.3 Critical Review on Detection and Mitigation Technologies for Marine Pollution

In this study, a critical review of literature was conducted to identify the various detection and mitigation technologies for marine pollution. The search string described in Section 2.1 was applied to obtain the initial dataset. A second screening process was then carried out, focusing specifically on technological approaches such as image processing, biomonitoring, spectroscopy, and microscopy.

The publications were filtered across three standardized decades: 1990–1999, 2000–2010, and 2011–2022. This categorization allowed for the identification of chronological shifts in the use of detection and mitigation technologies. Only journal articles published in English within the specified period were included, using the in-built filters in the Scopus database.

To enhance understanding of the thematic structure of this research field, keyword network maps were generated from the screened dataset. These maps visually display the co-occurrence of author keywords, thereby highlighting the relationships and emerging trends among different technological approaches. For example, frequent clustering of terms such as *“remote sensing”*, *“biomarkers”*, and *“spectroscopic analysis”* illustrates their interconnected roles in advancing pollution detection. By making these associations visible, keyword network maps help reveal research gaps, interdisciplinary linkages, and the evolution of technological focus over time.

Overall, this approach not only allowed for a systematic assessment of published works but also provided a visual analytical framework for interpreting how detection and mitigation technologies for marine pollution have developed over the last three decades.

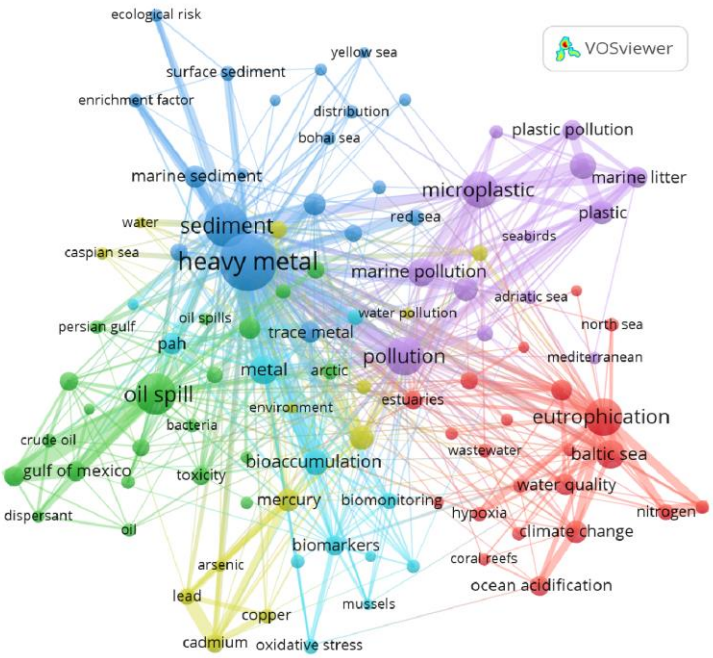
Furthermore, the study provided an exclusive extension by analyzing the contribution of countries with the longest coastline and evaluating their research interest based on the number of publications over the study period. The countries selected for this analysis were Canada, Germany, Russia, Japan, Australia, the USA, and China. The aim of this analysis was to interpret the correlation between the number of research publications on the technologies to detect marine pollutant levels and its spatial significance over countries.

To isolate studies related to each emerging technology, Boolean search strings were used, and specific search strings with the keywords associated with the said technologies were applied to ensure the relevance of search results. These datasets were used to identify the chronology of involvement of the emerging technologies for the studies related to marine pollution and the correspondence of each sub-discipline of AI and ML (Machine Learning) towards the research on marine pollution.

2.4 Keyword networks of marine pollution mitigation studies

Figure 1 shows the keyword networks illustrating the prominent research interests for (a) 2022-2012, (b) 2011-2001, (c) 2000-1990 and (d) 1990> periods. Each bubble represents a keyword while the diameter of the bubble is proportional to the number of occurrences of the same. The thickness of lines is proportional to the number of co-occurrences of the relevant two keywords across the selected range of literature. Distance between bubbles is inversely proportional to the similarity between them and keywords with higher similarities are clustered using similar colours. Figure 1 presents the keyword network maps illustrating the major research interests across four decades: (a) 2022–2012, (b) 2011–2001, (c) 2000–1990, and (d) before 1990. Each bubble represents a keyword, with its diameter proportional to the frequency of occurrence within the selected literature. The connecting lines indicate co-occurrence between keywords; thicker lines represent stronger associations. The distance between bubbles is inversely proportional to their similarity, while color clusters group closely related keywords.

Keyword network maps aid understanding by visually capturing the evolution of research themes, showing not only which topics have been most studied but also how they interrelate. This approach allows for quick identification of emerging trends, dominant research clusters, and shifts in scholarly focus over time. For example, closely connected keywords in the same cluster highlight interdisciplinary areas, while isolated bubbles may indicate niche or underexplored topics.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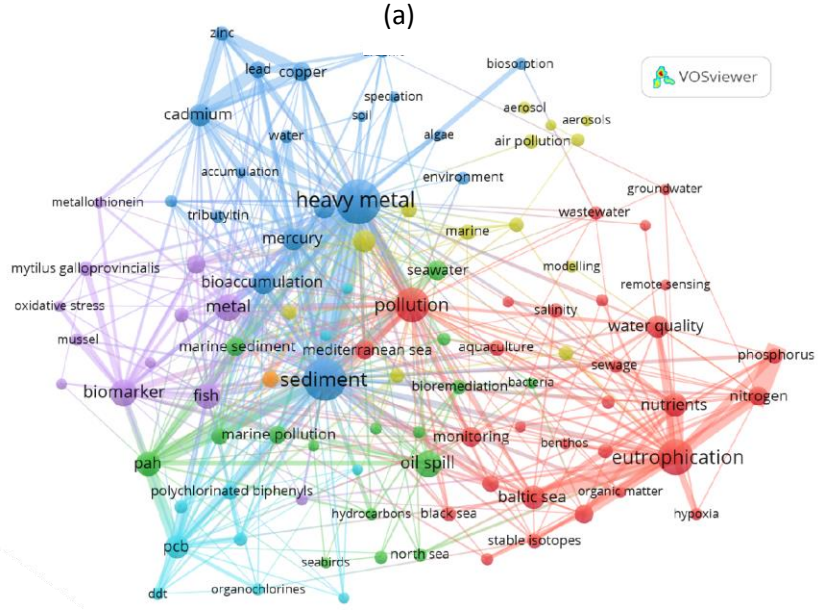
(a)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polychlorinated biphenyls
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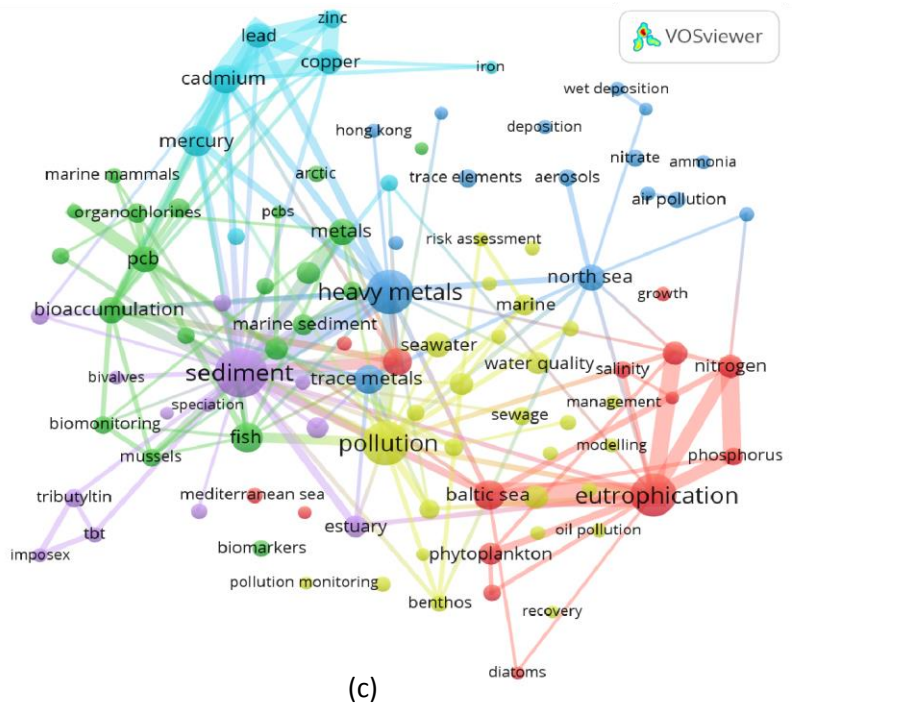

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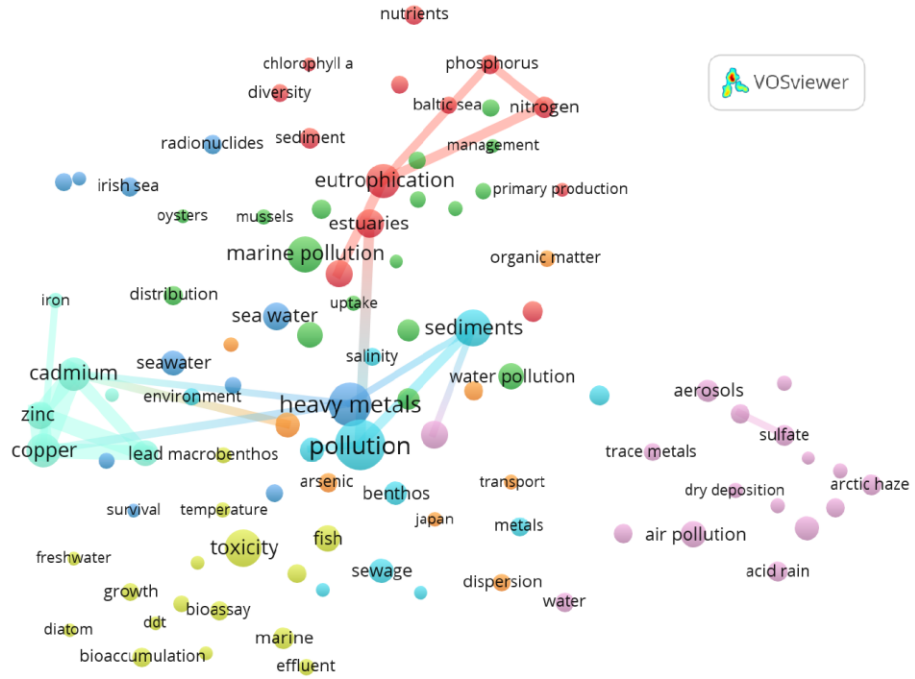


(d)

Figure 1: Author keyword Network maps for period (a) 2022-2012, (b) 2011-2001, (c) 2000-1990, and (d) 1990>

The keyword network for period (a) 2022–2012 (Figure 1(a)) reveals that heavy metal pollution, sediment contamination, oil spills, eutrophication, and microplastic pollution are the dominant phenomena associated with marine pollution. Heavy metal pollution, in particular, has been extensively studied and discussed during this decade, as well as in other periods. The long-standing interest in heavy metal pollution is attributed to several factors, including changes in heavy metal sources, increasing atmospheric concentration of heavy metals due to industrialization and urbanization, atmospheric–ocean heavy metal exchange, ocean acidification, and chronic disposal of industrial waste into the ocean (Duan and Li, 2017; Lee et al., 2007; Ji et al., 2019; Adeleke et al., 2020).

Despite decades of research, heavy metal pollution in the ocean persists as a significant problem. Heavy metal pollution is closely associated with sediment, bioaccumulation, fish, contamination, enrichment factor, surface sediment, ecological risk, and microalgae. Sediments play a crucial role in heavy metal accumulation in marine environments since they act as both sources and sinks for heavy metals (Kang et al., 2017; Wang et al., 2021). Consequently, heavy metal accumulation in marine organisms, such as microalgae and fish, has been the focus of significant research attention during the last decade (Chakraborty et al., 2014). The most frequently investigated heavy metals were Hg, Cd, Pb, As, and Cu, respectively, during all periods.

However, enforcement gaps and technological limitations continue to hinder mitigation. For example, the International Maritime Organization (IMO) has set guidelines for ballast water treatment and heavy metal discharge, but a 2020 UNEP report revealed that only 38% of coastal nations had fully implemented monitoring programs for marine heavy metal pollutants. Similarly, advanced detection technologies such as inductively coupled plasma mass spectrometry (ICP-MS) and remote sensing remain costly, limiting their deployment in many developing countries (Adeleke et al., 2020). In West Africa, for instance, studies show that less than 25% of coastal monitoring stations are equipped with modern heavy metal detection systems (Onyema et al., 2021), leading to underreporting of contamination hotspots. These limitations have contributed to persistent ecological risks, with mercury levels in some Nigerian coastal sediments exceeding WHO safe thresholds by up to 4.5 times (Okoye et al., 2019). Heavy metal pollution research has been extensively conducted in several seas, such as the Caspian Sea, Black Sea, Persian Gulf, Bohai Sea, East China Sea, and Yellow Sea. These seas are mainly adjacent to industrialized countries such as China, Russia, and Ukraine, and a few agriculturally driven countries such as Turkmenistan, which could have contributed to heavy metal pollution (Duan and Li, 2017).

During the decade **2012–2022**, research on oil spills became strongly linked to the **Deepwater Horizon oil spill** in the Gulf of Mexico, widely regarded as the largest oil spill in history. Although this event occurred in 2010, towards the end of the preceding decade **2001–2011**, its long-term impacts stimulated a significant rise in marine pollution studies on oil spills during 2012–2022.

One notable development in the **2012–2022** period was the emergence of **microplastics** as a major hotspot in marine pollution research. A distinct cluster of studies formed around this theme, in contrast to earlier decades where the term did not appear in keyword networks. Microplastics were first mentioned in scientific literature in 2004, and their definition as plastic particles < 5 mm in diameter was established toward the end of

2001–2011, recognizing their long-term adverse effects (Moore, 2008; Fendall and Sewell, 2009).

The use of **keyword network maps** is particularly valuable in understanding these shifts in research focus. Each map visually represents the prominence and interconnections of keywords within a given decade. Larger nodes indicate frequently studied topics, while thicker connecting lines highlight stronger relationships between themes. For example, the maps clearly illustrate how microplastics evolved from being absent in earlier decades to forming a distinct and influential research cluster in 2012–2022, thereby providing insights into the chronological progression and transformation of marine pollution research.

The initial recognition of microplastics as a threat to oceanic health, and subsequent research highlighting their abundance in oceans worldwide (Perera et al., 2022) even in regions with minimal human activity such as Antarctica (Zarfl and Matthies, 2010), high accumulation rates (Browne et al., 2011), and growing ecological impacts (Zhang et al., 2019) motivated extensive research on this topic. It is noteworthy that studies on plastic pollution had been conducted since the early 1970s, although it was not a prominent research interest (Carpenter and Smith, 1972). Additionally, in addition to heavy metal contamination in sediments, sediment contamination with microplastics, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), and oil were also studied (Ratnayake et al., 2017).

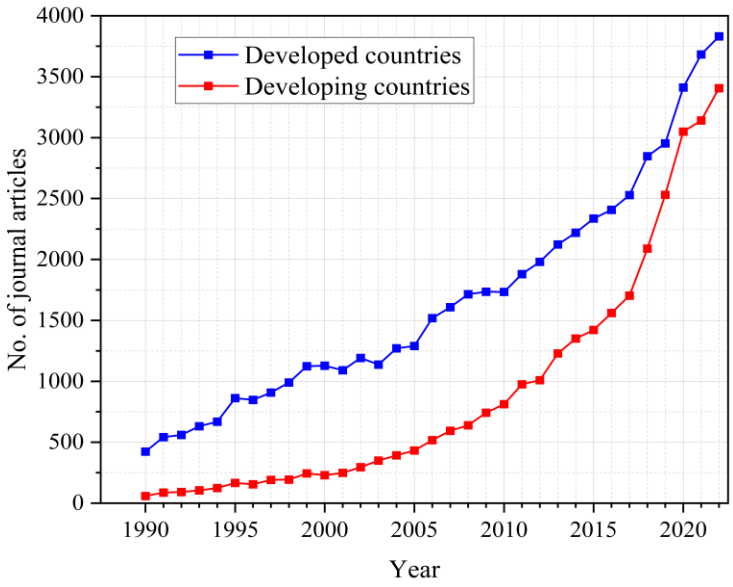
During the period (b) 2011-2001, heavy metal pollution, sediment contamination, eutrophication, oil spills, pollution due to PAHs and PCBs, and bioaccumulation were the prioritized phenomena. However, these phenomena were also considerably studied later in decade (a). It was observed that microplastics and the Deepwater Horizon oil spill were the main factors that caused the changes between keyword networks for the two decades. PAHs and PCBs were identified as hydrophobic, toxic, mutagenic, and persistent organic pollutants, and their longer lifespan, ubiquitous existence in oceanic environments, and bioaccumulation in marine organisms caused a relatively large number of studies during the (a) 2022-2012, (b) 2011-2001, and (c) 2000-1990 decades (Figure 1a, b, and c). Notably, oil spills were not a major research area during the period (c) 2000-1990, but they reappeared in the keyword network for the period (d) 1990 and onwards.

Eutrophication has remained a significant area of interest in marine pollution research over the last four periods. This is because its underlying factors have undergone chronological changes, including alterations in nutrient cycles within the ocean, macronutrient and micronutrient loads to the sea, and anthropogenic pressures (Ratnayake et al., 2018). The Baltic Sea has been of particular concern in eutrophication studies because of the excessively high nutrient inputs to this region from both land-based and ocean-based sources (McCrackin et al., 2018; Stigebrandt and Andersson, 2020). To mitigate this issue, several policies and measures have been implemented to decrease land-based nutrient inputs to the Baltic Sea. However, these actions face various challenges due to socioeconomic and political differences between the Nordic countries and Germany, as well as the former socialist states, particularly Russia (Kern, 2011; Tynkkynen et al., 2014). Interdisciplinary research collaborations among fields like ecotoxicology, marine biology, oceanography, environmental science, biochemistry, and engineering have increased in a chronological order, indicating a growing trend (d to a) (Ratnayake et al., 2018).

2.5 Developing and developed countries' contributions to marine pollution mitigation studies

Figure 2 shows the number of publications related to marine pollution per year since 1990 in both developed and developing countries as per the United Nations economic classification of countries (United Nations Department of Economic and Social Affairs (UN DESA),2022). Though the number of developed countries is small compared to the number of developing countries, developed countries had approximately twice the number of publications as developing countries. Since 2017, there has been a rapid development in the rate of marine pollution-related publications in both groups of countries. Nevertheless, the growth rate of publications in developing countries has exceeded that of developed countries since 2017, narrowing down the gap between the number of publications of the two groups of countries. This is mainly caused by the USA which is responsible for the highest number of publications from developed countries having a decline in their rate of publications. China is responsible for the increased growth rate with the highest number of publications from developing countries. Since 2018, Chinese publications per year have exceeded that of the USA. On the other hand, a few other developing countries such as India and Brazil are also having a considerably increasing publication growth rate. The overall dominance of developed countries in the number of publications is caused by their economic superiority, albeit national policies on research and public perception also have a significant impact on the matter (Rodríguez-Navarro and Brito, 2022).

Figure 1: Number of yearly publications related to marine pollution in both developed and developing countries



2.6 Diverse disciplines contribute to the mitigation of marine pollution

The present study investigated the subject-wise distribution of journal papers on marine pollution in addition to country-wise distribution. For this purpose, 77,171 journal articles published up to 2020 were analyzed (Figure 3). Scopus employs the All-Science Journal Classification (ASJC) system to categorize serial titles (journal titles in this case) into different subject areas. This classification system has been shown to be accurate in citation-based bibliographic accuracy tests (Wang and Waltman, 2016). The ASJC system divides journal titles into five broad subject clusters: physical sciences, life sciences, health sciences, social sciences, and multidisciplinary. The subject clusters are then further divided into 27 major subject areas (Elsevier, 2022a, 2022c).

The analysis revealed that journals dedicated to physical sciences and life sciences contributed the most (67.8% and 24.8%, respectively) to the number of publications on marine pollution research. Further analysis of the major subject areas under these two subject clusters revealed that environmental science, earth and planetary science, engineering, and chemistry journals made the highest contributions to the number of publications under the physical sciences subject cluster. Notably, engineering journals accounted for only 10.1% of journal articles related to marine pollution in physical sciences and 6.8% of the total journal articles on marine pollution. While science studies the physical world and its phenomena, engineering applies scientific principles for the efficient use of natural resources (Smith, 2022). Agricultural and biological sciences dominated the life sciences due to the impact of marine pollution on ocean agriculture activities such as fishing and shrimp farming. Multidisciplinary research connecting different subject clusters was rare.

Social sciences contributed the least to marine pollution research, with limited research focused mainly on legislation and economy (Dolores Garza et al., 2009; Xu, 2009). These studies identified many flaws in legal frameworks related to marine pollution, particularly in developing countries (Kularatne, 2020). However, social science research needs to expand to address other aspects of marine pollution, such as economic impacts, public perception, national policies, legal frameworks for prevention and compensation, and corporate responses for remediation. Therefore, it is crucial to encourage contributions from the disciplines of engineering and humanities to proactively mitigate marine pollution.

Methodology

This study employs **a mixed-methods approach**, which integrates both quantitative and qualitative research techniques to provide a comprehensive analysis of maritime pollution mitigation strategies and their implications for long-term economic development. The **quantitative component** focuses on numerical data collection and statistical analysis, while the **qualitative component** emphasizes in-depth insights and contextual understanding.

Primary Data Collection and Analysis:

Primary data were gathered through structured surveys and semi-structured interviews. Surveys were distributed to maritime operators, regulatory agencies, and environmental organizations, with questions designed to capture information on the sources, impacts, and costs of maritime pollution. Semi-structured interviews were

conducted with industry experts and key stakeholders from environmental agencies and shipping companies to obtain deeper insights into the challenges and opportunities of implementing mitigation strategies. The survey responses were analyzed using descriptive statistics (frequency distributions, percentages, and mean scores) to identify common patterns and trends, while interview transcripts were coded and thematically analyzed to uncover recurring themes and stakeholder perspectives. Secondary data were obtained from peer-reviewed research papers, industry reports, and government policy documents related to maritime pollution and its mitigation.

Analytical Techniques:

- **Descriptive Statistics:** Applied to survey data to quantify the prevalence of pollution sources and perceived impacts.
- **Comparative Analysis:** Used to evaluate the relative effectiveness of current mitigation strategies across different regions and sectors.
- **Trend Analysis and Case Studies:** Employed to examine emerging technologies (e.g., green shipping practices, advanced waste treatment systems) and assess their potential economic implications.

Sampling Technique:

A **stratified sampling method** was adopted to ensure balanced representation of key stakeholder groups, including regulatory authorities, shipping companies, and environmental organizations. This approach improved the reliability and generalizability of the findings.

ANALYSIS AND INTERPRETATION

Table 1: Primary Sources of Maritime Pollution

Source of Pollution	Frequency (%)
Oil spills	30%
Ballast water discharge	20%
Ship emissions	25%
Plastic and solid waste	15%
Chemical leaks	10%

The table illustrates that oil spills (30%) and ship emissions (25%) are the most significant contributors to maritime pollution. These two sources together account for over half of the total pollution, underscoring the need for stricter preventive and control measures in these areas.

Table 2: Economic Impacts of Maritime Pollution

Economic Impact	Estimated Cost (in billion USD)
Loss in fisheries revenue	5.2
Cleanup and restoration cost	7.8
Tourism revenue loss	4.1
Health-related expenses	3.6
Damage to marine biodiversity	6.3

The economic costs of maritime pollution are substantial, with cleanup and restoration efforts (7.8 billion USD) being the most expensive. Damage to marine biodiversity (6.3 billion USD) also represents a major burden, followed closely by losses in fisheries (5.2 billion USD). This highlights the necessity of preventive measures to reduce both environmental damage and financial burdens.

Table 3: Effectiveness of Existing Mitigation

Mitigation Strategy	Effectiveness (%)
Regulations & policies	70%
Advanced waste treatment	60%
Use of cleaner fuels	80%
Ballast water management	50%
Monitoring & enforcement	65%

The table suggests that using cleaner fuels (80%) is currently the most effective strategy, followed by regulations and policies (70%). However, ballast water management (50%) lags behind other methods, indicating a need for enhanced measures and stricter enforcement in this area to ensure comprehensive pollution control.

Table 4: Adoption of Innovative Technologies for Sustainable Development

Technology	**Adoption Rate (%)**	**Expected Reduction in Pollution (%)**
LNG-powered vessels	65%	50%
Ballast-free ship designs	40%	30%
Carbon capture technology	55%	45%
AI-based emission control	35%	25%
Renewable energy usage	50%	40%

The table highlights that LNG-powered vessels (65% adoption) are the most widely embraced technology, offering the highest pollution reduction potential (50%). Carbon capture technology also shows strong adoption (55%) and a notable pollution reduction effect (45%). Renewable energy usage, while adopted at a moderate level (50%), contributes significantly to reducing emissions (40%). In contrast, ballast-free ship designs (40%) and AI-based emission control (35%) exhibit relatively lower adoption rates, though they still present valuable contributions to pollution mitigation. These findings suggest that while advanced fuel and carbon management technologies lead current adoption trends, emerging digital and structural innovations remain underutilized despite their potential benefits.

Conclusion

This study has explored maritime pollution and its mitigation strategies, focusing on their effectiveness in ensuring long-term economic development. The key findings of the research include:

1. The primary sources of maritime pollution identified include oil spills, ballast water discharge, plastic waste, and air emissions from ships. These pollutants significantly impact marine ecosystems, biodiversity, and human health. Additionally, maritime pollution imposes economic costs on coastal communities, fisheries, and tourism industries.

2. Current mitigation efforts involve regulatory frameworks such as MARPOL conventions, ballast water management, and the adoption of cleaner fuel alternatives. While these measures have reduced pollution levels to some extent, gaps remain in enforcement, compliance, and global cooperation.
3. Emerging technologies such as green shipping, zero-emission vessels, and advanced waste treatment systems present promising solutions. The integration of digital tools like artificial intelligence and blockchain enhances monitoring and enforcement. Sustainable practices, such as circular economy approaches and carbon capture technologies, can further aid in pollution reduction while promoting economic growth.

The study concludes that maritime pollution remains a significant challenge to both environmental sustainability and economic progress. While existing regulations and strategies have made notable progress, their effectiveness is often undermined by implementation gaps, weak enforcement, and technological limitations. Advancing sustainable innovations and fostering stronger international collaboration are crucial for reducing maritime pollution while maintaining a balance between ecological preservation and economic development.

A call to action:

The maritime industry, governments, and international organizations must act decisively and collaboratively to ensure that sustainable practices move from policy frameworks into widespread implementation. Without urgent and coordinated action, maritime pollution will continue to threaten marine ecosystems, human health, and long-term economic growth.

Recommendations

To provide clarity and direction, the recommendations are categorized as follows:

A. Policy and Governance

1. Governments and international bodies should enforce stricter maritime pollution policies, improve compliance monitoring, and impose significant penalties for non-compliance.
2. Regional collaborations should be strengthened through international agreements and joint enforcement mechanisms to harmonize standards across borders.

B. Technological Innovation

3. Increased funding and incentives should be provided to encourage the adoption of eco-friendly shipping technologies such as hydrogen-powered, LNG-powered, and electric vessels.

4. Research and development (R&D) into advanced carbon capture, ballast-free ship designs, and AI-based emission control systems should be prioritized.

C. Industry Practices

5. Ports and shipping companies should implement advanced waste treatment and recycling programs to minimize pollution.

6. Industry stakeholders should establish sustainability benchmarks and reporting systems to promote transparency and accountability.

D. Capacity Building and Awareness

7. Training programs should be developed for maritime workers on best practices for pollution control and environmental safety.
8. Public awareness campaigns should be launched to emphasize the economic and ecological benefits of sustainable maritime practices.

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CORPORATE SOCIAL RESPONSIBILITY IN NIGERIA'S MARITIME SECTOR: FOSTERING SUSTAINABLE GROWTH, IMPACT AND IMPLICATIONS FOR HUMAN RESOURCE MANAGEMENT

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Abstract
This paper examined the function of corporate social responsibility (CSR) in Nigeria's maritime sector and its implications for human resource management using Stakeholder Theory and Legitimacy Theory. It looks at how CSR projects propel sustainable development, lower social and environmental hazards, and improve organizational legitimacy in an industry vital to Nigeria's economy if properly carried out. Using case studies and sector-specific challenges, the paper offers practical suggestions for matching CSR initiatives with stakeholder expectations and societal demands while enabling significant industrial and human resource benefits.

Keywords: Corporate Social Responsibility; Human Resource management; Sustainable Development; Nigerian Maritime Sector; Environmental Stewardship

1.0 Introduction

Nigeria's maritime industry, with nearly 10,000 km of inland rivers and 853 km of coastline, is the lifeblood of its economy. It accounts for around 4% of the country's GDP, supports 70% of its industrial activity, and facilitates 90% of its foreign trade (Adenigbo et al., 2023). With 80% of government income and 90% of foreign exchange earnings derived from exporting crude oil, Nigeria, the top oil producer in Africa, mainly depends on maritime infrastructure (Okotie, 2018). Unquestionably, the industry is essential for the development of the country. This economic behemoth does, however, work in a paradox: although it promotes national prosperity, its actions sometimes aggravate environmental damage, widen social inequalities, and sour ties with host communities.

The environmental impact of the sector is clear-cut. Gas flaring, dredging-induced erosion, and regular oil spills from ageing vessels have devastated mangrove ecosystems and essential carbon sinks supporting coastal communities(Henry et al., 2023). For example, the Niger Delta, which hosts Nigeria's most significant ports, has had over 16,000 oil leaks since 1976, ruining farms and displacing fishing villages (Osuagwu & Olaifa, 2018).

Concurrent with fast port developments in Lagos and Calabar, approximately 20,000 people have been evacuated since 2010, leading to demonstrations and legal action (Dan-Woniowei, 2020). These problems highlight a systematic gap between business goals and society's welfare, casting doubts on the industry's long-term viability.

Globally, maritime sectors use CSR as a strategic reaction to similar issues. While the United Nations Global Compact helps port operators to match Sustainable Development Goals (SDGs), the International Maritime Organization (IMO) demands emission reductions (Caliskan, 2022). By comparison, Nigeria's marine CSR policies remain scattered and frequently reduced to token gestures like school donations or periodic clean-up projects (Duruigbo, 2004). Lack of enforceable CSR measures in regulatory systems such as the Nigerian Maritime Administration and Safety Agency (NIMASA) Act helps companies prioritize short-term profits over systematic responsibility (Oguagha, 2017). This disparity emphasizes how urgently a paradigm change is needed, from reactive philanthropy to proactive, theory-based CSR models.

Strong models for such a change come from Legitimacy Theory and Stakeholder Theory. Freeman (1984) developed Stakeholder Theory, which stresses that companies flourish by attending to the requirements of all stakeholders, including communities, workers, governments, and investors, rather than only shareholders (Dmytriyev & Freeman, 2023). In Nigeria's marine environment, this could include co-designing port improvements with impacted populations or funding for skill development for displaced fishermen. Suchman's (1995) Legitimacy Theory holds that companies must match their activities with society's values to keep their "social license to operate (Mahmud, 2019)." For Nigerian companies, this means open environmental reporting and implementing global best practices like the Global Reporting Initiative (GRI), restoring public confidence. Aligning with these theories has significant possible advantages since it provides a way to balance Nigeria's aspirations for maritime development with the demands of sustainable development.

This paper contends that including these theories in CSR plans will help Nigeria's maritime development objectives align with sustainable development requirements. Examining case studies from the Nigerian Ports Authority (NPA), Shell Petroleum Development Company (SPDC), and indigenous businesses helps us to identify how stakeholder inclusivity and legitimacy-building could reduce conflicts, improve reputational capital, and promote fair growth. For example, although SPDC's open environmental reporting has improved its legitimacy among stakeholders, the NPA's community involvement activities have helped to lower operating disputes (Okoro, 2017). While suggesting policy and operational changes to institutionalize CSR as a driver of transforming impact, the study also tackles ongoing issues like regulatory inertia and resource constraints.

2.0 Review of Literature

Corporate Social Responsibility (CSR) has developed from a side project into a fundamental business strategy, particularly in sectors with significant environmental and social impact (Sergeeva & Kapetanaki, 2022). CSR is becoming increasingly important in the marine industry for guaranteeing regulatory compliance, improving community relations,

and lessening environmental damage. Studies worldwide have underlined how CSR helps lower carbon emissions, enhance waste management, and build stakeholder confidence. For example, studies by Gil-Saura et al., (2018) highlight how European ports have embraced green technologies and community involvement initiatives to complement the International Maritime Organization's (IMO) sustainability targets. Likewise, Acciaro et al., (2014) looks at how CSR projects in Singapore's marine industry have improved social license to operate and lessened operational conflicts by strengthening ties with nearby populations.

CSR studies conducted in Africa have mainly concentrated on extractive sectors, notably oil and gas, paying less attention to the maritime industry. Research by Idemudia, (2010) and Nwankwo, (2017) shows that rather than focusing on long-term projects lacking sustainability, CSR in Nigeria's oil sector frequently neglects systematic problems, including environmental degradation and community relocation. This criticism is also pertinent given comparable trends of reactive CSR in the marine industry. Nigerian ports, for instance, have come under fire for emphasizing one-time projects as medical outreaches or school restorations over long-term environmental restoration or community capacity-building. These results highlight Nigeria's maritime environment and the need for a more strategic, theory-driven approach to CSR.

Theoretical models, including Legitimacy Theory and Stakeholder Theory, provide a prism through which one might view and enhance CSR policies. As Freeman (1984) pointed out, Stakeholder Theory holds that companies must balance the needs of many stakeholders, including communities, workers, governments, and investors, to attain long-term viability. The marine industry has used this idea to explain how inclusive participation may lower conflict rates and improve project results. For example, research by Notteboom & Jean-Paul, (2005) shows how stakeholder consultations in port expansions have reduced opposition and hastened project schedules throughout Asia and Europe. However, in Nigeria, where stakeholder involvement is sometimes shallow or exclusive, similar programs nevertheless go understudied.

Conversely, Legitimacy Theory stresses matching organizational activities with societal principles to keep credibility and trust. Parikh et al., (2023) contends that companies, especially those with significant social and environmental effects, must proactively address society's expectations. This has translated into projects in the maritime industry, including open sustainability reporting, acceptance of international standards, and NGO alliances. For instance, studies by Mousa & Hassan, (2015) and Deegan, (2002) show how Australian ports have used environmental disclosures to improve their legitimacy among global investors and authorities. However, the legitimacy theory is not applied in Nigeria as institutional support for CSR reporting is lacking, and insufficient regulatory enforcement exists.

Notwithstanding these theoretical revelations, the literature still shows notable inadequacies. First, there is little actual study on CSR in Nigeria's marine industry, especially about its influence on sustainable development: most research either ignores CSR's social and environmental aspects, regulatory compliance, or economic performance. Second, a limited, firm-centric viewpoint is sometimes used in current research, excluding the part played by multi-stakeholder cooperation in producing CSR results. Third, few studies

combine several theoretical models, including Stakeholder and Legitimacy Theories, to offer a whole picture of CSR dynamics.

New studies point to a change from descriptive analyses to prescriptive, action-oriented studies as necessary to close these disparities. For example, recent research by Fabozzi & Tunaru, (2022) advocates sector-specific CSR frameworks that consider Nigeria's socioeconomic and environmental problems. Eyab, (2023) similarly support including local NGOs and community leaders, traditional governance structures, in CSR decision-making procedures. These revelations underline the need for context-specific, theory-grounded CSR strategies based on inclusivity, openness, and long-term impact that provide priority.

Studies reveal that corporate social responsibility (CSR) is growingly essential globally in the maritime sector. This is especially true in areas like Europe and Asia, where CSR is deliberately connected to sustainability goals, including cutting emissions and community involvement (Acciaro et al., 2014; Gil-Saura et al., 2018). On the other hand, CSR studies conducted in Africa have primarily focused on extractive sectors such as oil and gas, condemning their reactive, charitable, industry-driven tactics devoid of systemic solutions (Idemudia, 2010). Using an emphasis on inclusiveness and social alignment, several theories, such as Stakeholder Theory and Legitimacy Theory, have been applied globally to describe how CSR functions.

However, their significance to Nigeria's maritime industry has not been thoroughly investigated. Knowledge still lags significantly in several areas, including few empirical studies on how CSR influences sustainable development in Nigeria's maritime environment, a limited emphasis on regulatory compliance at the expense of social and environmental outcomes, and a dearth of multi-theoretical approaches considering the particular complexity of the sector (Acciaro et al., 2014; Gil-Saura et al., 2018; Sergeeva & Kapetanaki, 2022). This work closes these gaps by grounding its legitimacy and examining stakeholder theories. It presents a complete methodology for assessing how CSR could support legitimacy, stakeholder confidence, and sustainable development in Nigeria's maritime sector.

3.0 Theoretical Framework

Freeman's (1984) Stakeholder Theory

According to stakeholder theory, companies must take care of every stakeholder's needs, including those of NGOs, governments, workers, and communities, to succeed in the long run. In Nigerian maritime affairs, this entails:

- Involving coastal towns impacted by port growth.
- Working with authorities such as NIMASA to match CSR with national development agendas.
- Giving environmental protection priority to please world partners.

Suchman, (1995) Legitimacy Theory

Legitimacy Theory holds that companies must match their behaviour with society's values to keep their social license to operate. For Nigerian maritime companies, this means:

- Open reporting on oil spill cleanup.
- Funding regional infrastructure to challenge impressions of exploitation.

- Using worldwide reputation enhancement by adopting international sustainability criteria.

Synergy of Ideas

These ideas offer a dual focus: Legitimacy Theory stresses society alignment, thereby balancing profit and purpose; Stakeholder Theory guarantees inclusive engagement.

Case Studies and Study Analysis

Authority Nigerian Ports (NPA)

Involving Stakeholders:

Recognizing the many interests of coastal communities, government agencies, and international partners, the Nigerian Ports Authority (NPA) has taken a multi-pronged approach to stakeholder engagement. For example, its community health projects in Lagos, including potable water projects and free malaria screenings, directly addressed complaints brought about by port congestion and pollution (Edelman, 2015). The NPA demonstrated the Stakeholder Theory's Emphasis on Dialogue and Mutual Benefit by working with local leaders, reducing resistance to its Lekki Deep Sea Port development (Ali, 2023; Omotayo, 2020).

Targeting young unemployed in riverine villages, the NPA also sponsored marine studies scholarships in collaboration with colleges such as the University of Lagos. This program developed technical capability and promoted goodwill among next-generation business leaders. Critics counter that, given that only 15% of recipients find maritime employment, such initiatives lack scalability. The NPA has to institutionalize feedback loops in line with Stakeholder Theory, ensuring that communities co-design CSR agendas instead of relying on passive aid (Brammer et al., 2012).

The NPA's involvement has a third dimension related to conflict resolution. In 2022, it set up grievance panels in Delta State to arbitrate port project property acquisition conflicts (Ali, 2023). The NPA reduced conflicts that previously caused litigation delays by including traditional leaders and civil society groups in decision-making (Nigerian Ports Authority, 2022). This underscores Freeman's (1984) claim that reconciling conflicting stakeholder priorities depends on inclusive government structures.

Legitimacy Constructing

Environmental responsibility, a top concern for international partners like the International Maritime Organization (IMO), grounds the NPA's legitimacy-building activities. Restoring 1,000 hectares of mangroves in the Niger Delta in collaboration with the Nigerian Conservation Foundation not only helped to offset carbon but also matched worldwide SDG 14 (Life below Water) (Nigerian Ports Authority, 2024). Such initiatives support Suchman's (1995) thesis that conformity with society's values, including environmental preservation defines legitimacy.

Launching a transparency portal in 2023, the NPA revealed real-time emissions and community development investment statistics, strengthening its social license. This action reversed perceptions of public sector corruption, a long-standing problem in Nigeria (Nigerian Ports Authority, 2024). The NPA improved its reputation with foreign investors by following Global Reporting Initiative (GRI) guidelines; however, domestic NGOs object to

the portal for omitting sensitive information, including CEO remuneration (Dan-Woniowei, 2020). Comprising solar-powered terminals and zero-discharge trash systems, the NPA's "Green Port Initiative" also designated Onne Port as Nigeria's first environmentally friendly port. Approved by the IMO, this certification helped Nigeria become a regional pioneer in ecologically friendly marine technologies (Markit, 2018). Legitimacy theory explains strategic reactions to institutional pressures, where companies adopt externally verified techniques to achieve society acceptance.

SPDC, Shell Petroleum Development Company

Participant Involvement

Engagement of SPDC's stakeholders in the Niger Delta provides lessons on the results of ignoring Stakeholder Theory. Although oil royalties help states, SPDC's legacy of gas flaring and oil disasters has bred mistrust even from this source (Daniil et al., 2012). For instance, although the 2011 Bonga oil leak impacted 168 coastal towns, compensation delays set up demonstrations and piracy (Usman, 2021). Although Freeman's approach emphasizes the need for proactive participation, SPDC's ad hoc community discussions failed to address the underlying reasons for discontent.

Changing its strategy, SPDC started the Niger Delta Livelihood Program, teaching 5,000 young people aquaculture and renewable energy (Ogunji & Wuertz, 2023). Although this lowers youth engagement in illicit bunkering, beneficiaries mentioned insufficient initial money. According to Stakeholder Theory, SPDC could include communities into value chains, that is, source equipment from nearby vendors, to generate shared value instead of one-off charity.

Another excellent example is SPDC's cooperation with the Rivers State Government to establish Port Harcourt model schools. Involving parents and teachers in curriculum development helped the project lower the vandalism of SPDC infrastructure and improve educational results (Barrett et al., 2019). This is consistent with the emphasis of Stakeholder Theory on empowering underprivileged groups through participatory development; nonetheless, critics point out that such program mainly target metropolitan regions, disregarding rural communities.

Legitimacy Enhancement

SPDC's legitimacy challenge results from its environmental record, which contradicts Nigeria's Climate Change Act (2011). To offset this, SPDC sponsored the Ogoni Cleanup Project approved by the UN Environment Program (Nwozor, 2020). Although this enhanced its international profile, local NGOs claim that contracts for cleanup benefit politically connected companies, erasing credibility (Adam & Fazekas, 2021). As shown in SPDC's residual mistrust among Ogoni people, symbolic gestures devoid of real action run the danger of "legitimacy decay," says (Suchman, 1995).

Following global environmental management guidelines, SPDC aimed to restore legitimacy in 2023 by certifying its Bonny Oil & Gas Terminal ISO 14001 (Amiolemen et al., 2024). Although this accreditation impressed outside consumers such as BP and Total Energies, it did not significantly improve artisanal refinery pollution, a significant issue for local stakeholders. The legitimacy theory holds that companies must mix grassroots influence and outside validation to maintain credibility.

Finally, 20,000 Niger Delta people received subsidized treatment from SPDC's "Community Health Insurance Scheme," therefore filling in for healthcare deficiencies caused by oil development. Through a partnership with Nigeria's National Health Insurance Authority, SPDC matched its CSR with national priorities, demonstrating how legitimacy is strengthened when business activities reflect official policy (Aaron, 2012). But the program's omission of artisanal fishermen, a population disproportionately affected by oil leaks, exposes holes in inclusive legitimacy-building.

Dangote Ports, New Case Study, New Approach

Stakeholder Involvement

The Lekki Free Trade Zone project of Dangote Ports gave stakeholder mapping priority to avoid opposition. It paid displaced families equity shares in the port while holding town meetings throughout 15 towns (Adunbi, 2022). Rooted on Stakeholder Theory, this creative strategy turned possible enemies into allies, lowering project delays by forty per cent.

Developing Legitimacy

After adopting AI-powered emission monitoring technologies, Dangote was named a UN Global Compact signatory. This technological revolution improved Nigeria's credibility among investors who care about climate change by matching its marine industry decarbonization trends.

4.0 Implications for Human Resource Management

Corporate Social Responsibility in the Nigeria's maritime sector has series of implications on human resource management; hence, it influences the company's ability to manage their human resources especially in such areas like employee engagement, community relations as well as sustainable practices in the sector.

Employee engagement: the value of relationship management cannot be over emphasized, hence, its role in the sustainability of the maritime sector through employee engagement by recognition of workforce diversity as well as unity in management will ultimately translate to improved productivity. Hence. It aligns human resource management practices with the dominant organizational values and ethos. Essentially, corporate social responsibility incorporates both social and environmental considerations in human resource management practices

Sustainable Human Resource Management Practices: Through corporate social responsibilities, the Nigerian maritime sector can attract and retain wide-range of talents in the organization and this is in addition to retention of positive reputation. Therefore, corporate social responsibility impacts on human resource management through enhancement of employee engagement, talent management as well as sustainable practices

Corporate Social Responsibility and Community Relations: this can impact community relations positively through consistent support to community development practices and trust building. This will ultimately improve the community perception of the organization and create a stronger community relationship.

5.0 Challenges

Inadequate Regulation Authority

Nigeria's maritime industry cannot enforce CSR rules under organizations like the Nigerian Maritime Administration and Safety Agency (NIMASA) in a disjointed regulatory environment(Bassey, 2020). For environmental protection, for example, the NIMASA Act of 2007 calls for non-compliance but does not prescribe fines. As shown by the regular oil spills and gas flaring events in the Niger Delta, this regulatory void lets companies put profit over sustainability.

Short-Termism in Applied CSR Strategies

Many companies in the sector take a short-term, reactive approach to CSR, emphasizing one-off projects like school renovations or medical outreaches over long-term investments in community development or environmental restoration. According to an Okafor et al. (2021) study, seventy per cent of CSR projects implemented by Nigerian ports lasted less than a year and had little discernible effect on host communities.

Restricted Incinctivity of Stakeholders

In Nigeria's marine industry, stakeholder involvement is sometimes surface-level, excluding women and artisanal fishermen, among other underprivileged groups. For example, projects involving port expansion in Lagos and Calabar have drawn criticism for not sufficiently consulting impacted populations, which has resulted in lawsuits and demonstrations (Opon, 2017). A report by the Niger Delta Environmental Justice Network emphasizes, this exclusive strategy erodes confidence and fuels conflict (Mandeiya, 2022).

SMEs' Resource Limitations

Small and medium-sized businesses (SMEs) have significant technical and financial obstacles to carrying out meaningful CSR projects in the maritime industry. Unlike international companies, small businesses lack resources for projects, including community capacity-building or emission monitoring, as well as knowledge or technology. Just 15% of SMEs have specific CSR budgets, according to a 2023 Nigerian Chamber of Shipping poll, compared to 85% of more prominent companies (Fcmb, 2023).

Insufficient responsibility and openness

Transparency remains a significant obstacle since many companies fail to reveal their CSR operations or results. For instance, according to Nigerian Extractive Industries Transparency Initiative NEITI, (2024) audit, just 30% of marine companies issued sustainability reports, and even fewer followed worldwide standards like the Global Reporting Initiative (GRI). This opacity undermines public confidence and reduces the sector's capacity to draw ethical investors.

6.0 Recommendations

Strengthen Systems of Governance

The Nigerian government should change the NIMASA Act to incorporate explicit CSR requirements, non-compliance fines, and best practices incentives to handle inadequate enforcement. For instance, companies participating in community development or earning ISO 14001 certifications could get tax savings or accelerated permit applications. NIMASA should also set up a specific CSR monitoring team to guarantee responsibility and openness.

Advanced Extended CSR Approaches

Companies should move from reactive, short-term CSR to long-term, strategic projects consistent with national and worldwide sustainability targets. Port managers might, for example, create 10-year CSR strategies combining stakeholder involvement, community capacity-building and environmental rehabilitation. Local communities should co-design these strategies, which should be reviewed yearly to guarantee relevance and impact.

Improve the inclusion of stakeholders.

Companies should institutionalize participatory stakeholder involvement methods to solve the problem of excluding policies. Establishing multi-stakeholder forums involving community leaders, NGOs, and underprivileged groups in CSR decision-making can help accomplish this. To help resolve conflicts and promote cooperation, the Nigerian Ports Authority (NPA) can, for instance, copy its Delta State grievance panels elsewhere.

Help SMEs use of funds and capacity-building.

The government and development partners should establish financial sources and technical support systems to enable SMEs to conduct meaningful CSR projects. The Nigerian Central Bank might set up a Maritime CSR Fund, for example, providing grants and low-interest loans for initiatives like young talent development or adopting sustainable energy sources. The Nigerian Chamber of Shipping and other industry groups could plan seminars on CSR best practices and international standards.

Boost openness and documentation quality.

Companies should embrace globally accepted sustainability reporting systems like the GRI or the Sustainability Accounting Standards Board (SASB) to improve openness and responsibility. NIMASA might impose yearly CSR reports covering thorough information on environmental performance, community investments, and stakeholder participation results. These studies should be independently audited and available via Internet portals to gain public confidence.

7.0 Conclusion

Based on Stakeholder Theory and Legitimacy Theory, this paper argued that Corporate Social Responsibility (CSR) offers a transforming solution to the most urgent problems facing Nigeria's maritime sector at a turning point when economic development must match environmental sustainability and social equity. Naval companies can improve their social license to operate and propel sustainable development by prioritizing inclusive stakeholder engagement, matching operations with society values, and implementing internationally accepted sustainability standards. With projects like mangrove restoration and livelihood programs demonstrating positive impacts, case studies of the Nigerian Ports Authority (NPA), Shell Petroleum Development Company (SPDC), and indigenous businesses expose both the potential and constraints of CSR in Nigeria's maritime sector; persistent issues including regulatory gaps, short-termism, and exclusionary practices highlight the need for systemic reforms.

While Legitimacy Theory promotes matching corporate activities with society' ssocietal expectations, Stakeholder Theory advocates inclusive, participatory ways that balance various stakeholder interests, presenting a double focus on inclusion and

responsibility. Realizing this vision calls for cooperation among government, business, civil society, and academia and using newly developed technology like blockchain and renewable energy to inspire CSR ideas. Nigeria's maritime industry can position itself as a leader in sustainable development by matching with global frameworks, including the Sustainable Development Goals (SDGs) and the targets of the International Maritime Organization (IMO), so turning CSR from a cost centre into a strategic investment in long-term resilience and competitiveness.

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NAVIGATING THE LEGAL IMPLICATIONS OF CARGO THEFT: THE ROLE OF AI IN MARITIME SECURITY.

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Abstract
This study investigates the role of artificial intelligence (AI) in enhancing marine security, with a specific focus on curbing cargo theft in the maritime sector. The objective is to evaluate how AI-driven technologies can be deployed to improve threat detection, ensure real-time monitoring, and support decision-making in maritime operations. Using a doctrinal legal research methodology, the paper reviews existing international and national legal frameworks, alongside case studies and technological applications within the maritime domain. The findings reveal that while AI offers significant potential in mitigating cargo theft—through predictive analytics, surveillance, and automated response mechanisms—its integration is hampered by legal uncertainties, data privacy concerns, and high implementation costs. The study recommends the harmonization of international maritime laws to support the legal deployment of AI technologies, promote data governance frameworks, and encourage investment in digital infrastructure to advance secure and sustainable maritime transport.

Keywords: maritime, security, cargo, theft, carriage of goods, international law and convention.

Introduction

Global trade relies on the maritime transport of goods, yet cargo theft remains a persistent threat, undermining economic security and legal frameworks. Despite its importance to international trade, maritime transportation is fraught with dangers and operational difficulties. Maintaining safety is crucial for preserving the environment, human life, and financial stability. Theft has remained a persistent problem in Nigeria, leading to significant financial losses. According to the United Nations Office on Drugs and Crime (UNODC), cargo theft in Nigeria resulted in estimated losses of over $1 billion in 2021, highlighting the urgent need for effective security measures. According to a 2007 European Parliament report, cargo theft across the EU transport network costs an estimated €8.2 billion per year, averaging around €6.7 per trip

In order to ensure the secure and effective transit of products across the world's oceans, maritime security is an essential part of international trade and transportation. Traditional security measures frequently fail to meet contemporary dangers as maritime activities become more complicated and large. With its cutting-edge solutions to improve maritime security, track possible threats, and guarantee adherence to international standards, artificial intelligence (AI) is becoming a game-changer. Artificial intelligence (AI)-powered

technologies offer creative ways to improve maritime security, including real-time monitoring, predictive analytics, enhanced decision-making skills, and crew resource management.

By offering sophisticated capabilities to identify, evaluate, and react to possible threats, artificial intelligence (AI) technologies like machine learning, computer vision, and natural language processing are transforming marine security. These are some significant ways that AI is improving marine security. For example the **Nigerian Ports Authority (NPA)** has begun implementing AI-assisted surveillance systems to improve monitoring at major ports. These systems are part of the **Smart Port Transformation Agenda,** integrating **CCTV with intelligent video analytics** to detect unauthorized access, loitering, and suspicious cargo movements. AI-driven marine security has many advantages, e.g Predictive Analysis and Early Warning, and Improved Decision-Making but there are also some issues that must be resolved, which include, data quality and integration, Technological adoption, Cyber security concerns and regulatory issues. The objective of the research is to explore the legal implications of cargo theft and evaluate how AI can enhance maritime security.

Understanding Cargo Theft in Maritime Transport

A cargo theft gang is a group of individuals who receive orders from brokers to steal specific high-value products during transit by gathering intelligence on transportation patterns and targeting loaded trailers at their point of departure[1]. With over 80% of worldwide trade by volume, the maritime sector is an essential economic sector that supports the expansion of the world economy.[2] The industry is anticipated to bring in billions of US dollars annually, mostly benefiting large maritime nations and others. For example, the global seaborne trade was predicted to be worth 11.5 billion tons as of 2022.[3] However, it is evident that as the industry grows more open and advanced, it becomes more susceptible to being exploited by security threats like terrorism, armed robbery, piracy, cargo theft, drug trafficking, human trafficking, stowaway, and other illegal activities that occasionally take place at the port or sea.

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Cargo theft happens at warehouses, freight-forwarding yards, on ships, and during transit. Nigeria loses $182,200 per shipment to maritime crime[4] This statistic highlights the serious problem of cargo theft in Nigeria's maritime sector and shows how much of an impact it has on the nation's maritime trade. Types of cargo theft are Piracy, organized crime, insider threats, cyber theft.

United Nations Conventions on the Law of the Sea known as the Law of the Sea Convention (LOSC) defines maritime piracy in its article 101 and consisting of the following acts: (a) any illegal acts of violence or detention, or any acts of depredation , committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed: (i) on the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft; (ii) against a ship, aircraft, persons or property in a place outside the jurisdiction of any State; (b) any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of facts making it a pirate ship or aircraft; (c) any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b).

Insider threat refers to the risk that arises from maritime employee carrying out or enabling a security incident either through a lack of awareness, complacency or maliciousness.[5] Since insiders have privileged access to restricted areas, objects, or private data, they can provide a tactical edge to terrorists and organized crime groups, who are always attempting to take advantage of weaknesses in port and ship security measures.

Maritime cyber risk refers to a measure of the extent to which a technology asset is threatened by a potential circumstance or event, which may result in shipping-related operational, safety, or security failures as a consequence of information or systems being corrupted, lost or compromised"[6]An increase in connectivity and reliance on global navigation systems has led to a rise in cyber dangers.

Legal Frameworks Governing Cargo Theft.

Most jurisdictions have specific criminal laws addressing theft, including cargo theft. Penalties vary by country and may include fines, imprisonment, or restitution. Victims of cargo theft may pursue civil claims for compensation. Contracts between shippers, carriers, and insurers often outline liabilities in case of theft. To guarantee a more equitable distribution of risks between cargo owners and carriers, international conventions on the transportation of commodities by sea were established. These treaties, which include the Rotterdam Rules, Hamburg Rules, and Hague-Visby Rules, contain provisions governing the carrier's obligation for goods that are lost or damaged. Liability under the Hague-Visby Rules is fault-based[7]. Just as in common law, the burden of proving unseaworthiness lies on the cargo owner. The carrier can limit its liability for loss or damage to the cargo in line with the monetary provisions contained in the Rules.

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While AI technologies offer promising solutions for maritime security, the absence of harmonized international laws creates significant legal hurdles. Maritime operations often involve multiple jurisdictions, and the cross-border nature of AI systems amplifies regulatory complexities. Several challenges emerge from this lack of legal coherence:

(a) **Diverse National Regulations**

While AI technologies offer promising solutions for maritime security, the absence of harmonized international laws creates significant legal hurdles. Maritime operations often involve multiple jurisdictions, and the cross-border nature of AI systems amplifies regulatory complexities.[8] Several challenges emerge from this lack of legal coherence. maritime companies must navigate conflicting national laws, leading to higher compliance costs and potential legal exposure. E.g A shipping company operating between the EU and Asia may need to comply with GDPR in Europe while navigating less-defined privacy laws in certain Asian ports, complicating data-sharing practices.

(b)Absence of Comprehensive International Treaties on AI Use

Although conventions like the International Ship and Port Facility Security (ISPS) Code address traditional threats, they lack provisions for AI technologies. No global treaty currently governs AI deployment in maritime security, resulting in regulatory gaps.[9] Some nations rapidly implement AI solutions, while others delay due to legal uncertainties, creating inconsistent security measures along global trade routes. In the absence of uniform standards, cross-border cooperation is limited, weakening coordinated efforts against cargo theft. Joint anti-theft operations between two countries may falter if one nation lacks the legal infrastructure to support AI-based security measures.

(c) Jurisdictional Disputes in Liability and Accountability

Determining liability when AI systems malfunction or produce incorrect outputs is complex, especially in international waters where jurisdiction is unclear. Without clear rules, disputes over responsibility can delay resolution and increase legal costs. Companies might exploit jurisdictional ambiguities to avoid accountability. For example If an AI system reroutes a vessel based on a false threat, causing delivery delays, stakeholders may argue over which country's courts should handle the claim.

AI has the potential to improve and enhance a variety of tasks on the vessels because of its processing power and capacity to integrate multiple systems. The marine sector is becoming more and more interested in using cutting-edge AI and ML technology to solve problems with efficiency, sustainability, and regulatory compliance.[10] The following are only a few of the contentious concerns facing the use of AI in maritime transportation:

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(a) Data Input Mistakes: The analysis of AI software in charge of handling hazardous cargo may be hampered by errors or malfunctions. Spills and other incidents on board the ship, such improper cargo handling, may worsen as a result of such faults. Regular maintenance, methodical program upgrades, and comprehensive software cleaning to ensure that only the safe ones are still packed are all appropriate steps to minimize these hazards. Because of the software's functionality and readiness, it offers assurance of the system's integrity.

(b) SoftwareErrors
Additionally, AI software that handles dangerous goods may have errors or malfun ctions that interfere with its analysis.The vessel may experience spills and other m ishaps, like improper cargo handling, as a result of these faults.Appropriate steps t o minimize these dangers include regular maintenance, methodical program upgr ades, and comprehensive software cleaning to ensure that only the safe versions a re still included.The system's integrity is guaranteed because of the software's fun ctionality and readiness.

(c) Problems with System Integration
AI integration issues might arise even when AI systems are included into ship systems. The safety of the cargo operations may not be ensured if the two systems are not properly integrated, which could lead to inadequate information exchange. To ensure that there are no issues with the information provided and that all the systems will exchange information effectively, it is crucial to test the integration as a whole.

(d) Risks to Cybersecurity
AI systems are vulnerable to cybersecurity risks due to their growing interconnectedness. Vulnerabilities in the system could allow unauthorized access or tampering, leading to the manipulation of cargo segregation settings. On board, this could lead to hazardous situations. Strong cybersecurity measures, such encryption and access limits, must be put in place to reduce this risk. A strong cybersecurity foundation will shield the system from outside threats.

The Role of Artificial Intelligence in Maritime Security.

Advanced technologies like artificial intelligence (AI) and machine learning provide logistics managers with efficient means of detecting and proactively preventing cargo theft when it is a persistent problem. For instance, predictive analytics can foresee possible risks before they materialize, enabling businesses to take preventative measures and stop theft. Technology makes it easy to prioritize security where it's most required by flagging shipments that may be at increased danger based on location, timing, or trends in recent thefts.

(a)Predictive analytics to identify high-risk shipments.

One important use of AI in maritime risk management is predictive analytics, which forecasts future risks and their possible effects by utilizing machine learning models and

historical data.[11] Maritime operators can proactively implement preventative measures and avoid potential dangers by forecasting the possibility of different risk situations. Improving decision-making is one of the main advantages of predictive analytics in maritime transportation. Compared to conventional techniques, AI models may examine multiple risk indicators at once, yielding a more thorough risk assessment. To estimate the likelihood of mechanical problems or accidents, for instance, predictive models can examine variables including crew experience, route parameters, maintenance history, and vessel age[12].

Forecasting Additionally, by anticipating equipment problems before they happen, predictive analytics helps optimize maintenance plans. This method, called predictive maintenance, lowers maintenance expenses, increases overall vessel reliability, and lessens unscheduled downtime. One important use of AI in marine risk management is analytics.

The sensor data is processed by machine learning algorithms to find trends and abnormalities that point to possible malfunctions. These algorithms are able to continuously increase their accuracy in anticipating equipment problems by learning from past data. Predictive models developed by AI estimate how long equipment components will remain useful. By assisting maintenance teams in planning interventions at the best times, these models lower the likelihood of unplanned malfunctions. AI systems can deliver real-time notifications when performance deviates from typical parameters, signaling the need for maintenance, thanks to ongoing equipment condition monitoring.[13]

There are various obstacles to overcome when implementing AI-driven predictive maintenance in the maritime sector. Because of incompatibilities with older systems, integrating AI systems with the current maritime infrastructure can be challenging. Frequently, extensive renovations and alterations are required, which can be expensive and time-consuming. Predictive maintenance also depends on real-time data transmission, which can be difficult in isolated maritime areas with poor connectivity. To overcome these implementation issues, a large investment in infrastructure and technology is needed.[14]For maritime operations, implementing AI-driven predictive maintenance has several important advantages. AI makes it possible to perform timely maintenance interventions and avoid unscheduled downtime by anticipating equipment breakdowns before they

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[11]Durlik I etal (2024) Artificial Intelligence in Maritime Transportation: A Comprehensive review of Safety and Risk Management Application, Retrieved from https://www.mdpi.com/2076-3417/14/18/8420#:~:text=One%20of%20the%20primary%20benefits,risk%20assessment%20than%20traditional%20methods .o n 20th January 2025 at 12am

[12] Tu, E.; Zhang, G.; Rachmawati, L.; Rajabally, E.; Huang, G. Exploiting ais data for intelligent maritime navigation: A comprehensive survey from data to methodology. *IEEE Trans. Intell. Transp. Syst.* **2018**, *19*, 1559–1582.

[13] Baraeinejad, B.; Shayan, M.F.; Vazifeh, A.R.; Rashidi, D.; Hamedani, M.S.; Tavolinejad, H.; Gorji, P.; Razmara, P.; Vaziri, K.; Vashaee, D.; et al. Design and implementation of an ultralow-power ecg patch and smart cloud-based platform. *IEEE Trans. Instrum. Meas.* **2022**, *71*, 2506811. [**Google Scholar**] [**CrossRef**

[14] Gutierrez-Estevez, D.M.; Wang, Y.; Gramaglia, M.; De Domenico, A.; Dandachi, G.; Khatibi, S.; Tsolkas, D.; Balan, I.; Garcia-Saavedra, A.; Elzur, U. Artificial intelligence for elastic management and orchestration of 5g networks. *IEEE Wirel. Commun.* **2019**, *26*, 134–141. [**Google Scholar**] [**CrossRef**

happen. This minimizes delays in marine transportation by guaranteeing that ships stay operational and on schedule[15].

While AI offers significant advantages in predictive maintenance, it is essential to critically examine the potential risks and limitations. Over-reliance on AI systems can lead to complacency, where seafarers and maintenance personnel may neglect traditional maintenance practices and their own vigilance. Additionally, AI systems are only as good as the data they are trained on; poor-quality or biased data can lead to inaccurate predictions and potential failures. There are also concerns about the workforce implications, as increased automation could reduce the demand for certain roles, necessitating retraining and upskilling of affected workers[16].

These hazards as well as the advantages of AI in predictive maintenance must be taken into account in a fair discussion. AI should be seen as a supplemental tool that supports human expertise and decision-making rather than replacing it, even though it has the potential to greatly improve maritime safety and efficiency. Maintaining a high level of safety and operational dependability requires that seafarers continue to participate actively in maintenance procedures.

(b) Real-time tracking and anomaly detection using IoT sensors.

Ensuring the safety and effectiveness of the ship during operations requires the detection of anomalies in engine and machinery data. Ships carry more than 80% of the world's trade volume. [17]Enhancing operating efficiency, ensuring safety, and identifying any problems before they become serious all depend on analyzing the engine and machinery sensing data from ships. IoT-based smart shipping is essential for improving the performance of vessels.[18]minimizing downtime, facilitating prompt intervention, guaranteeing safety, and anticipatorily identifying unforeseen problems (anomaly detection). This entails keeping an eye on a number of variables, including temperature, humidity, engine performance, and fuel consumption[19].

Furthermore, IoT-enabled sensors are revolutionizing shipboard systems and enhancing communication. These sensors, which are integrated into vital machinery, enable real-time tracking of the ship's fuel usage, ambient conditions, and operational health. When combined with edge computing, these data are analyzed locally on the ship,

1. [15] Wu, X.; Han, Y.; Zhang, X.; Zhou, Z.; Lu, C. Large-area compliant, low-cost, and versatile pressure-sensing platform based on microcrack-designed carbon black@polyurethane sponge for human–machine interfacing. *Adv. Funct. Mater.* **2016**, *26*, 6246–6256. [**Google Scholar**] [**CrossRef**]

[16] Ibid

[17] Launch of the Review of Maritime Transport. 2024

1. [18] Xu, G.; Shi, Y.; Sun, X.; Shen, W. Internet of things in marine environment monitoring: A review. *Sensors* **2019**, *19*, 1711. [**Google Scholar**] [**CrossRef**] [**PubMed**]

[19] Androjna, A.; Brcko, T.; Pavic, I.; Greidanus, H. Assessing cyber challenges of maritime navigation. *J. Mar. Sci. Eng.* **2020**, *8*, 776. [**Google Scholar**] [**CrossRef**]

eliminating the need for large onboard servers and utilizing cloud computing to examine intricate trends in navigation routes and equipment performance.[20]

But even with these developments, it's still very difficult to integrate contemporary AI systems with antiquated maritime infrastructure. AI and IoT technologies were not considered in the design of many of the ships that are already in service. Because of this, upgrading these vessels necessitates a significant investment in software (such as AI-compatible platforms) and hardware (such as sensors and communication modules).[21]

(c) AI-powered surveillance and behavioral recognition systems.

Conventional navigation technologies, manual surveillance, and ongoing environmental condition monitoring have always been the mainstays of marine security. Nevertheless, new technologies have been used to better address these issues and to anticipate and prevent disasters since the development of artificial intelligence (AI). Prior to artificial intelligence, marine surveillance relied on cameras and radar equipment that operators manually monitored in real time. Despite their effectiveness, these systems had drawbacks, including the inability to understand vast amounts of data, their need on ideal weather, and their vulnerability to human mistake.

AI has improved the intelligence of monitoring systems. For example, real-time data analysis from various sensors and sources, such as satellite photos, radars, security cameras, and even meteorological data, is now possible with AI-based monitoring systems. The presence of items in the water that pose a collision risk, changes in weather that could impact navigation, or ships approaching hazardous locations are just a few examples of the patterns of behavior that these systems can automatically detect.

Prior to the use of AI, a human operator watching a radar would spot a ship approaching an exclusion zone, but he or she would have difficulty estimating the likelihood of a collision, particularly in low visibility situations. AI-powered systems can determine the likelihood of a collision based on navigation routes, weather patterns, and historical data in addition to detecting the vessel. After that, the system may notify operators of what has to be done, significantly cutting down on reaction times and accident risk.

Using AI in maritime operations presents a number of difficulties that need to be properly resolved. Data privacy is a major worry since maritime surveillance technologies have the potential to gather and use private data about people and ships. To protect personal information, it is essential to ensure adherence to privacy laws and have strong data protection mechanisms in place. The possibility of biased or prejudiced results from AI systems is another important consideration. Transparency and accountability must be given top priority when developing and deploying AI systems in decision-making processes that

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[20] Ji, Q.; Zhu, Z.; Lan, P. Real-time nonintrusive monitoring and prediction of driver fatigue. *IEEE Trans. Veh. Technol.* **2004**, *53*, 1052–1068. [**Google Scholar**] [**CrossRef**

1. [21] Ilias, L.; Tsapelas, G.; Kapsalis, P.; Michalakopoulos, V.; Kormpakis, G.; Mouzakitis, S.; Askounis, D. Leveraging extreme scale analytics, ai and digital twins for maritime digitalization: The vesselai architecture. *Front. Big Data* **2023**, *6*, 1220348. [**Google Scholar**] [**CrossRef**] [**PubMed**]

affect the safety and security of maritime transportation. This entails actively recognizing and reducing biases, maintaining equity, and routinely assessing the systems' functionality.

Furthermore, there are legal concerns around accountability and liability when utilizing AI for marine domain awareness. Determining accountability in circumstances involving accidents or mishaps with autonomous patrolling vessels, for instance, involves the adoption of proper legal frameworks and standards. For AI to be used safely and responsibly in the marine industry, these frameworks should address concerns of liability, responsibility, and the distribution of legal and ethical requirements.

Recent advancements in communication technology, especially 5G networks and Non-Terrestrial Networks (NTNs), including satellite-based systems, have greatly improved the integration of AI systems into maritime operations. The absence of dependable connectivity in isolated and open-sea settings is one of the biggest obstacles to the adoption of AI in the maritime sector, which these technologies attempt to solve. Previously limited by sporadic or low-bandwidth connections, 5G allows real-time decision-making for navigation, risk management, and predictive maintenance by guaranteeing continuous data transmission between ships, ports, and cloud-based infrastructures.[22]

Legal Implications of AI in Maritime Security.

Concerns about data privacy, cybersecurity risks, and possible violations of international law in the use of AI for military maritime operations are among the major legal ramifications of AI in maritime security. These primarily relate to liability and accountability in situations where AI systems make crucial decisions on board ships, especially autonomous vessels, and current maritime laws are frequently ill-equipped to handle such scenarios, raising questions about who is responsible in the event of accidents or incidents. Conventional maritime law holds the ship's owner, master, or crew accountable for negligence or noncompliance with safety standards. However, establishing culpability is challenging because Autonomous vessels lack human crews.[23]Given that maritime surveillance systems may gather and process sensitive data about people and vessels, data privacy is a major concern that must be carefully addressed when using AI in maritime domain awareness. It is imperative to ensure compliance with privacy regulations and put strong data protection measures in place to protect personal information. Another significant obstacle is the cost of modernizing maritime infrastructure to facilitate AI integration. Smaller operators would find it difficult to pay for the required modifications, but larger shipping businesses with significant fleets might have the funds to invest in state-of-the-art technologies. .

[22] Leite, W.; Moraes, C.; Albuquerque, C.; Machado, R.; Sá, A. A triggering mechanism for cyber-attacks in naval sensors and systems. *Sensors* **2021**, *21*, 3195. [**Google Scholar**] [**CrossRef**

[23] Th Amicus Qriae ,Legal Implication of Autonomous Maritime Vessels, retrieved from https://theamikusqriae.com/legal-implications-of-artificial-intelligence-in-autonomous-maritime-vessels/ on 29th January 2025 at 10am

Conclusion

International trade and transportation depend heavily on maritime security to guarantee the safe and efficient passage of goods across the world's waters. As maritime activities grow larger and more complex, traditional security measures sometimes fall short of modern threats. Artificial intelligence (AI) is changing the game with its innovative ways to enhance maritime security, monitor potential threats, and ensure compliance with international standards. Technologies driven by artificial intelligence (AI) provide innovative approaches to enhancing maritime security, such as crew resource management, real-time monitoring, predictive analytics, and improved decision-making abilities. However, there are a few contentious concerns facing the use of AI in maritime transportation which include. Software errors, data impute mistake, problems with system integration and risk to cyber security.

To address these moral and legal issues, cooperation amongst many parties is essential. Guidelines, norms, and laws that support AI's ethical and responsible usage in maritime domain awareness must be developed in collaboration with researchers, practitioners, politicians, and regulatory authorities. By doing this, we can fully utilize AI while maintaining moral standards, safeguarding privacy, guaranteeing equity, and guaranteeing the security and safety of marine operations.

Secondly, providing incentives for the adoption of AI technologies in combating cargo theft can motivate key stakeholders in the maritime industry—such as shipping companies, port authorities, and insurers—to invest in and implement advanced security solutions. These incentives may take various forms. For instance, **financial incentives,** such as tax breaks or government subsidies, can be offered to companies that deploy AI-based security systems. Additionally, **insurance incentives** may include reduced premiums for organizations that utilize AI tools proven to lower the risk of cargo theft..

Also, the International Maritime Organization (IMO) should lead efforts to create uniform guidelines for AI use in maritime security.

Finally, emerging AI tools offer transformative solutions to combat cargo theft in the maritime industry. However, their deployment must consider legal implications, including liability, privacy, and compliance. By adopting a balanced approach that integrates technological advancement with clear regulatory frameworks, the industry can enhance security while navigating potential legal challenges.

THE IMPLICATION OF POPULATION PRESSURE ON MARINE/RURAL RESOURCES OF IBINI COMMUNITY, BIASE LOCAL GOVERNMENT AREA OF CROSS RIVER STATE, NIGERIA

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Abstract

Rural and marine resources are increasingly becoming depleted, posing a serious threat to the survival of rural populations. The sharp decline in yields from land and water sources highlights this growing danger. Environmental conservation seeks to regulate human exploitation of resources in the face of rising population pressures, ensuring sustainability for future generations. Traditionally, religious beliefs, superstitions, and totemic practices served as effective means of protecting both terrestrial and aquatic ecosystems, successfully preserving them for future use. In contrast, modern government policies on biodiversity conservation have largely failed to safeguard these resources. This suggests that fear of religious and cultural consequences once served as a more powerful deterrent than current regulatory laws. The Ibini community, a rural settlement largely dependent on farming and fishing, serves as the case study for this paper. The study investigates how population growth has affected these primary economic activities. Data were collected through questionnaires and analysed using the Pearson Product Moment Correlation in SPSS. Findings reveal that population growth has significantly harmed rural resources, leading to land fragmentation, declining yields, reduced income, and increased social challenges. The paper recommends establishing cottage industries, improving infrastructure, and strengthening government interventions through grants, loans, and empowerment programmes to ease population pressure.

Keywords: Ibini, population, Rural Resources, Conservation, Exploitation, Fishing and Farming

1. Introduction

Ibini community is a riverine settlement beautifully adored on every side by natural lakes, streams and the Cross River. It is known for her excellent local technicalities for fishing, culminating in good fish catch. Most communities depend on her for their fish supplies. The community also works hard on land for agricultural supplies with yam and cassava as the major products (crops).The amount of fish catch is measured in the number of basins ($60cm^3$) of fish brought home in a day (Ukam, 2021) and quantity of yams is measured in the number of yam bans with 4500 seeds of yams of different sizes (Ukam, 2021).The forest, the waters (lakes and streams) were protected by the villagers using religion, superstition and totemism (Ukam and Obongha, 2023). There were beautiful sceneries in form of forest and sand beaches that can pass for nature monuments. These places have all been tampered with because of increase in population. As such, what we

see these days is the relics of what used to keep or house fishes as a breeding ground for other free fishing zones.

The aquatic community in terms of fishes is the worst hit by this population increase. A situation where the forbidden places and even crocodile tunnels have been cleared leaves much to be desired. This situation also has a negative effect on the marine environment with its consequent impact on the economy (income) of the people. The forest or farmlands are equally not spared due to increase in population. This culminated in the fragmentation of land to capture the teeming population that enters the traditional labour market due to paucity and lack of white collar jobs for graduates from the secondary and tertiary institutions. Indeed, the marine and rural resources have actually been depleted as a result of increase in population of the community.

The culture of the people which hitherto protected biodiversity is disregarded or played down upon because of increase in population or other religions beliefs like Christianity, which refuses to recognize the efficacy of the traditional religion in protecting the biodiversity. The new religion, is now held uppermost by most people who have converted from traditional religion to Christianity (Ukam, and Obongha, 2023).

Whereas there is a very strong synergy between ecosystem and cultural tourism in Ibini (Ukam and Ejor, 2022), the destruction of these ecosystem (terrestrial and aquatic) will translate to the erosion of biodiversity is the destruction of culture (Ukam, 2018). It is in view of this that the researcher undertook to find out how this situation impact on the marine/rural resources. There is no doubt that there is a very strong relationship between population and the extent of harvesting of natural resources such as land, water and forest to mention just these few (Ukam, 2021).

The pressure on the natural resources caused by an increasing population and their quest for high standards of living in the developing countries are growing at a rate that is increasingly difficult for natural world to cope with (Thankur in Mistra (ed), 2014). Ebong and Aminashaun (1992) posit that population constitute the most dominant element of any ecosystem, being a vital component of resource base in the development of a nation. It is no wonder therefore that economist and other thoughtful men have been keenly interested in population problems in all ages (Hanson, 1992). Mistra (ed.) 2014) states that there is a very strong relationship between increasing population and declining resources such as land, water, minerals, forest and energy resources in the backdrop of several theories such as demographic transition, Malthusian, Marxist and carrying capacity etc. as it relates to population dynamics and resources utilization.

Bhattacharya and Sarma (2015) opined that increasing population has brought severe pressure on the environment, leading to large scale destruction of forest, wetland, agricultural land etc. From another angle, Maiti and Maiti (2017) states that indeed man has plundered nature and depleted to almost towards it threshold point. Ukam (2018) further observed that the erosion of biodiversity as a result of increase in population has equally affected the culture of people where the culture is tied to nature as it is the case of Erei people in Biase Local Government Area of Cross River State, Nigeria. Naturally, increases is one of the basic ways by which rural population has grown over the years. With no corresponding increases in rural land and water, it is inevitable that extra pressure will be put on the natural resources. This is the case with Ibini village in Biase Local Government

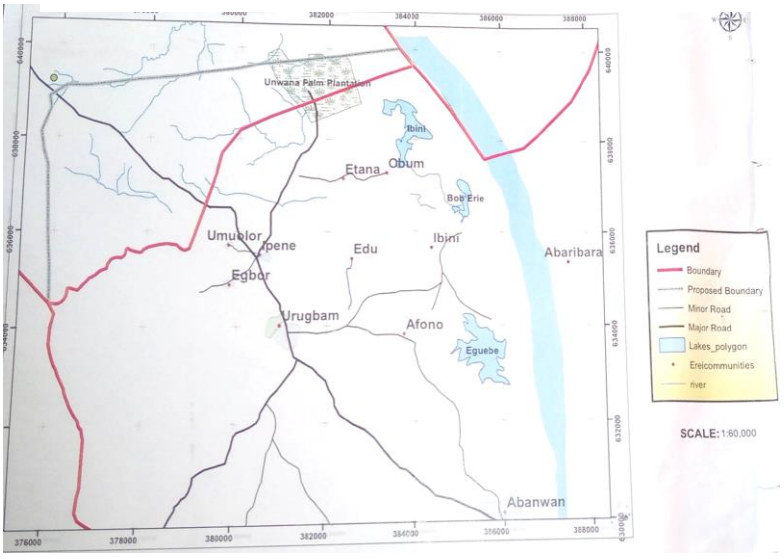
Area where the population has increased from 168,113 in 2006 to 283,299 in 2024 at an annual growth rate of 2.9%, in an area of 1,302km^2 with a population density of 172.6km^2. There are obvious and significant indicators that the rural resources in the study area are fast becoming depleted. The extent to which rural land and marine yields have taken a downward turn poses a serious danger to the ecosystem (Ukam, 2021).

2. Study Area

The study was conducted at Ibini Erei, Biase Local Government Area of Cross River State, Nigeria. It is a riverine/fishing settlement located on the western bank of the Cross River and it is one of the ten villages that make up the former Erei clan, now Erei North and Erei South Political wards. The map is shown on Figure 1. Ibini settlement depends on farming and fishing for survival but is more inclined to the later. Most of the inhabitants combine farming and fishing as a means of livelihood. A negligible few are engaged in civil service job, teaching and trading to earn a living. There is also population that is in the civil service and military living outside the community. This population also involves themselves in farming and fishing to complement their means of livelihood (Ukam and Eteng, 2024). Hunting is also practiced by the natives to augment their protein source and to earn income. Over the years, the population has shown a high rate of growth. Between 1991 and 2020, Baise Local Government Area population rose from 168,113 in 2006 to 224,700 in 2016. With a population growth rate of 2.9%, Biase Local government Area occupies a land area of 11,302km^2 with population density of 172.6km^2 in 2016. In recent years, there have been complaints and serious concern expressed by the natives about the poor yields in the farm sector and low catches in the marine resources (Ukam and Obongha, 2023). It has been obvious that these rural resources have become drastically depleted and being that they are fundamental to the survival of these rural population, a study of this nature is inevitable and certainly timely.

Figure 1: Map of Study Area (Ibini) and Adjoining
Source: Ukam and Obongha, 2023

3.



Aim and Objectives

The aim of the study is to assess the effects of human population pressure on rural resources, especially marine resources.

The objectives are as follows:

i. Identify the possible indicators of rural resource depletion
ii. Identify the problems associated with rural resource utilization
iii. Examine the attitude of the people towards traditional conservation methods in the face of increased population and economic depression.
iv. Suggest alternative ways of earning a living to the population in order to conserve land, forest and marine resources
v. Recommend appropriate measures for rural conservation to enhance environmental sustainability

4. Materials/Method of Study

A survey was conducted from where inferences were drawn. A total of 150 questionnaires were administered on the indigenes of the study area. Information was gotten from the sampled population to know their impression about the state of their resources. The randomly selected population was made up of male and female adults who engage in farming, fishing and hunting or a combination of any of these.

Further information was obtained on farm size, farm output, fish catch (measured in basin of size 60cm^3), fishing materials as well as past and present population figures of the study area from the National Population Commission in Calabar, Cross River State. The population figures were further projected at a growth of 2.9% from 2016 to 2024, an interval of six years. Two hypotheses were postulated for the study. Pearson Product Moment Correlation Coefficient was used to ascertain the strength of the relationship and at 0.05 level of significance. To test the hypothesis on marine resources, the total population of the area in different years were used for the study since they all constitute the pressure either as dependents or as workers.

5. Analysis of Data and Discussion of Results

Table 1: Age Distribution of the Sampled Population

Age	**Number of Respondents**	**Percentage**
0-9	35	23.33
10-20	30	20.00
21-30	25	16.00
31-40	25	16.00
41-50	20	13.33
51-60	10	6.67
61 and above	05	3.33
Total	**150**	**100.00**

Source: Researchers Field Survey, 2024; Ukam, 2021

Table 1 above shows a clear ratio of high dependents to the working class considering the age brackets of 0-20 years and above 61 years. These two groups form 46.66% (70 respondents) of the total sampled population. More so, the tradition of the

people recognize maturity from the age of 24 years, after celebrating the chronological age naming ceremony (Ukam, 1987, 1997 and 2021). This situation indicates pressure on the working class (rural work force) with a resultant effect on the rate of exploitation of the rural resources to meet the needs of the people.

The community recognizes maturity from the age of twenty-four (24) when such individuals will be allowed access by tradition to parcels of land for farming as well as engage in fishing and hunting activities. This, means that every year, there will be additional group of people who will begin to make direct demands on the environment (land and water) since people will be attaining the age every year (Ukam, 2018 and Ukam, 2021). The above assertion is translated to mean negative consequences as interpreted by further fragmentation of land for agriculture and the depletion of marine and terrestrial ecosystem.

Table 2: Population Figures at Different Epochs in the Study Area

Year	Population
2006	168,113
2012	200,005
2016	224,700
2018	238,066
2024	283,299

Source: Population Projection by the Researcher

The population has increased from 168,113 in 2006 to 283,299 in 2024 an increase of 115,186 people within 18 years. The above situation portends that the resources are being harvested much more than ever before. The negative implications of high population density in an area becomes glaring and devastating in the face of lack of capital and technology to exploit available land and water to meet the need of teeming population. On the other hand, over population brings about shortage of amenities like water, electricity, housing and food. Furthermore, it leads to traffic congestion, environmental degradation, unhygienic conditions, anti-social activities psychological depression and such other vices. Agbabi (1995) in Ukam (2021) has rightly observed that meeting the demands of the increasing world population will require more intensive and extensive exploitation of many natural resources especially agricultural land, forest and water.

Table 3: Age Distribution in the Study Area

Age Bracket	Population	Percentage
0-9	75,103	26.51
10-19	67,454	23.81
20-29	50,597	17.86
30-39	34,648	12.23
40-49	25,837	9.12
50-59	14,817	5.23
60-69	8726	3.08
70-79	3683	1.30
80 and above	2436	0.86
Total	283,299	100

Source: Researcher's Field Survey, 2024

Table 3 shows age distribution of the study area. The dependent population is found from the age bracket from 0-9 years. This population is mostly at the school age. It is made up of 50.32%. The working-class population is from 20-59 years age bracket and constitutes 44.44%. Another dependent population which is made up of old people is from 60-80 years and above. This population constitutes 5.24%. If the total dependent populations (the young and old people are added together, they make up 55.56% of the total population). This means that the dependent population of 55.56% will be exerting pressure on the working population of 44.44% resulting in an unending pressure on the rural resource (marine and farm lands). In this situation, the resources will continue to decline without any method of recuperation and more so, as more children will be born every year whereas, while death rate has dropped significantly due to improvement in modern medicine with respect to citing of health centres by governments. Whereas the land will be further fragmented and fish catch continues to decline due to population pressure and different methods of catching fishes.

There are also other absentees' farmers and fishermen who thought they do not live in the community, but also make use of these resources directly or indirectly. Directly because some of them live in the community and engage in farming and fishing, though they belong to other professions or white collar jobs or trading. Indirectly because many give money to their relatives at home in the study area to engage in extensive agriculture and fishing. They are yet others who depends on the study area for their supplies of farm products and marine resources.

Table 4: Natives in Other Professions who also engage in Fishing

S/N	Professions	No of Respondents	Percentage
1	Traders	15	10.0
2	Blacksmith	9	6.0
3	Tappers	20	13.33
4	Tailor/seamstresses	8	5.33
5	Civil servant in service	7	4.67
6	Food vendors	6	4.00
7	Retired cycle/public servants	5	3.33
8	Teachers	6	6.67
9	Business men/women	30	20.00
10	Politicians	30	20.00
	Total	**136**	**100.00**

Source: Ukam, 2021

Table 4 above explains the fact that apart from farmers, and fishermen or women, people from other walks of life engage in fishing and subsistence farming in order to have food and make ends meet. Apart from this people who actually get themselves involved in agriculture, many others depend on farmers and fishermen for their supply for food and agricultural products as raw materials for industries. This shows people from other walks of life who also engage in fishing and farming. Suffice to state that there is further pressure on

the available rural land, forest and marine resources. This situation is the cause of further fragmentation of land to accommodate these extra populations while in the fishing sector only small mesh nets can even make a reasonable catch because of the extent to which the lakes and streams have been over exploited. There is also a general decline in catch per unit efforts as indicated by the drastic reduction in the number of basin of fishes caught. Increase in fishing effort no longer result in proportionate increase in the catch (Ukam, 2021). For instance, Ukam (2021) noted that fish cash declined from 98 percent in the 1970s to 45 percent in 2021.

Other indicators of decline in catches as observed by Ita (1991) is decline of catches in longer mesh nets. High catches in small mesh nets productivity is low in the littoral zones due to intensive exploitation of these areas with small mesh nets. Though the cost of catching a unit weight of fish is rising, there is no relative increase in fish catch.

It is also discovered that modern methods of fishing which is designed for mass killing such as gamalin 20 is also responsible for the decline of fishes in the waters. These types of materials are alien to the traditional or local nets such as 'egbele' and 'eghat' as well as 'ubu' which are woven with local materials. These fishing materials are environment friendly and equally not dangerous nor designed for mass killing.

Table 5: Possible reasons for the decline in both agricultural and marine resources

S/N	Items	No. of Respondents	Percentage
1.	Traditions are no longer obeyed	30	20.00
2.	Lawlessness on the part of youths	10	6.67
3.	Modern methods of fishing is harsh	20	13.33
4.	Christian religious belief against tradition	10	6.67
5.	Western education	30	20.00
6.	Traditional land tenure system	05	3.33
7.	Lack of modern methods of agriculture	20	13.33
8.	Lack of alternative occupation to agriculture	15	10.00
9.	Over population	10	6.67
	Total	150	100.00

Source: Ukam, 2021

In Table 5 above, disobedience to the tradition of the people, harsh modern methods of fishing, Western education, lack of modern agriculture, lack of alternative occupation to agriculture coupled with over population are identified as the causes of the decline in marine resources and reduction in farm sizes resulting in poor yields. Christian religious beliefs also give a daring impetus for people to penetrate those areas that were hitherto forbidden by tradition. The above findings confirm the fact that some traditional and customary practices in the rural areas are environment friendly and therefore, essential

for environmental resource management. It is in view of this assertion that Ukam and Obongha, (2023) posited that our forest and aquatic ecosystems were maintained and handed over to our generation after many generations because people in those days had regards for customs, totemism, rituals, cultural and religious practices. This is what government regulatory policies is not able to do, hence, the fast disappearance of the forest and the marine resources due to illegal activities.

The use of poisonous leaves, nylon nets of various mesh sizes, gamalin 20 and explosives that kills fishes enmass no matter where there are hiding are more destructive than the native/local nets (Ukam, 2021). Some of the respondents agreed with this assertion. Another cause of the decline is the high and constant demand for fishes since other settlements depend on Ibini village for their protein intake through fish.

> *This situation has made men and women fishers to do this occupation on a more commercial basis and they now do it throughout the year and every time of the day and night. This therefore leaves the fishes with no time to recuperate. Some even die in their hide-outs because of the chemical used for fishing which others have no hideouts because of fishers that combed all the nooks and corners of the lake and streams (Ukam, 2021)*

This practice is against the olden day practice in the study area where women did their fishing in the dry season with very mild methods (as simple as the bare hands) while men did their fishing during the rainy season with the local nets. At that time, women embarked on the fishing exploitation after every two days, taking one lake at a time, commencing from 2pm to about 7pm. This offer fishes the opportunity to have time to rest based on the fact that natural tunnels for fishes and crocodiles as well as other marine thick-bushes were avoided. Another wisdom that the indigenes of the study area use in protecting rural resources from absolute depletion due to overpopulation is to set age limits for those who qualify to embark on fishing or farming. These they do by ensuring that any person who is less than 24-26 years was not allowed access to land for farming. Such people are equally not allowed to do fishing in certain lakes and streams in the study area. This helped to maintain a limited number of fishers on the streams as well as the fishermen.

Traditional Conservation Practices in the Study Area

As earlier stated, the forest, streams and rivers were conserved using some traditional methods. Amongst them are;

Custom: The custom of the people demanded that all agricultural or farming activities in any farming season must be done in a designated zone. In a way, this is to allow other farm sectors to recuperate after use for a period of seven years. Nobody was expected to plant any crop before the priest of the goddess of yam and fertility. Doing the contrary is an abomination.

Religious Practices/Superstition: In order to ensure that fishes are in constant supply, the people's culture demand that certain areas be avoided for fishing. Those areas are said to be the abode of the goddess of water. Customary laws were used to enforce compliance. The people were also made to believe that fishing in those prohibited areas will make the particular person or persons to come in contact with the water goddess who can also be appeased after very costly rituals are performed. Failure to appease the water goddess will

result to strange sickness/illness on the defaulter or members of his family and possible death. All other things held constant, it is believed that, fishes caught from such prohibited areas would never get done no matter how long there were cooked.

Totemic Practices: Crocodiles in some sections of the streams and land were regarded as sacred and such should not be killed. This is also the case with pythons and some other species of reptiles. The people in the study area believe that avoidance of the killing of these reptile was to forestall attracting a curse from the water goddess on the defaulter and his family. To ensure that the upsurge of population does not adversely affect the marine resources (fish) Ukam (2021) observed that superstitious beliefs which went on to strengthen conservation are as follows;

i. Where a fisherman's net was filled with fishes, if he took home some, he must let others go back to the water in order to avoid annoying the goddess of water.
ii. Certain fishing practices like the use of some poisonous leaves or gamaline 20 were prohibited.
iii. The use of explosives was regarded as an abomination as well as the use of hooks.
iv. Some sections of the streams and lakes were regarded as sacred (scenic areas) and such were never tempered or cleared. It is as a result of this that the researcher's father (Late Chief Ukam Unor Iyam) once told him that the essence of this section is to act as breeding ground for fishes, that is, fishing in such areas must be avoided not because fishes caught and eaten from such areas will cause death as the tradition of the ancient peoples' belief speculates.
v. It was also an abomination to allow feaces or cassava into certain lakes and streams. This in our modern times is to avoid water pollution. A defaulter was expected to report to the priest of the goddess of water and he was required to perform certain sacrifice to the goddess of water, otherwise the water goddess would in annoyance lock up fishes inside some natural tunnels (caves) thereby reducing supply.

The tradition of the people may look primitive and uncertain, yet because of increase in population most of these customs and traditions are no longer rigidly followed.

The researcher therefore sets out to test the following hypothesis

Hypothesi 1: There is no significant relationship between population and marine depletion

Year	Population	Estimated Fish Catch (60 cm^3)
1963	395	400
1980	599	500
1981	614	300
1982	630	400
1983	645	200
1991	1753	200
1996	2023	100
2006	168,113	500
2012	200,005	600
2016	224,700	1000
2018	238,060	800
2024	283,299	30

Source: Researcher's Field Survey, 2024

From Table 6 above, the population of the area has been increasing whereas fish catch is not consistent due to different methods and materials for fishing as well as the disregard to traditional conservation method. This is so because more people (including civil and public servants, unemployed graduates) turned s to fishermen and farmers. The fish catch increased again in 2016 due to local war that took out many people's attention from fishing.

Table 7: Correlation Between Population and Annual Fish Catch

The correlation Table (Table 7) presents the relationship between population size and estimated annual fish catch using Pearson's correlation coefficient. The correlation coefficient (r = 0.627). This indicates a moderate to strong positive correlation meaning that, as the population size increases, the estimated annual fish catch tends to decrease due to pressure on the fishes by growing population. The statistical significance (p – value) is 0.029. Since the value is less than 0.05, the correlation is statistically significant at the 5% level (0.05). This means there is a strong positive relationship between population size and estimated annual fish catch.

Table 8: Farm size and Average Annual Output

Average Farm size	Annual Average Output (Tons)
0.52	2.0
0.50	1.5
0.52	3.0
0.52	4.0
1.10	5.0
1.50	6.0
0.24	0.5
0.24	1.0
0.24	1.5
0.24	2.0
0.24	3.0
0.24	5.0
0.24	6.0
0.08	0.5
0.08	2.0

Source: Researcher's Field Work, 2024

From Table 7 above, this data shows average farm size and average annual output in terms of yam bands.

Table 9: Relationship Between Farm size and Average Annual Output

Correlations

		Average farm size	Annual average output in yam bands
Average farm size	Pearson Correlation	1	.584*
	Sig. (2-tailed)		.022
	N	15	15
Annual average output in yam bands	Pearson Correlation	.584*	1
	Sig. (2-tailed)	.022	
	N	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

Table 9 presents the Pearson correlation analysis between average farm size and annual average output in yam barns using 15 observations (N = 15). The Pearson correlation coefficient between average farm size and annual average output in yam barns is 0.584. This indicates a moderate positive correlation, meaning that as farm size decreases, the annual yam output tends to decrease. The p-value (Sig. 2-tailed) is 0.022. Since 0.022 < 0.05, the correlation is statistically significant at the 5% (0.05) significant level. This means there

is strong evidence that the relationship between farm size and yam output is not due to random chance. However, correlation does not imply causation—other factors (e.g., soil fertility, farming methods, labor, and technology) might also influence yam output.

Conclusion

Based on the findings of the research, it is clear that increase in population has a negative influence on the depletion of marine and farm resources. The consequences of high dependency ratio in the rural area is the voracious exploitation of marine resources and fragmentation of land resources to meet their needs. Over population compared to available resources is responsible for the use of illegal method of fishing (Gamalin 20; explosive, nylon nets of different sizes) that have the capacity to kill fishes enmass without recourse to premature species and fingerlings which hitherto were spared by the mild method of fishing (local nets and bare hands).

The cyclical economic crunch manifest in the poor salaries of the civil servants and lack of employment in the public sector has reduced school leavers from secondary schools, graduates of colleges of education and technology, polytechnics and universities to mere peasant farmers thereby increasing pressure on land and other rural resources.

The customs/traditions of the people which enhanced the conservation are no longer obeyed as a result of increase in population and the claim to western education as being superior to the traditions of the people.

Recommendation

i. There should be established in the area, fish farm that will supply fishes to the inhabitants of the area to meet their protein needs. However, those who do fishing for economic purpose should be allowed at certain periods of the year to embark on fishing activities while embargo should be placed on fishing activities at other times of the year.
ii. A law or an edict should be enacted to determine the size of fish to be caught and taken out of the water (streams/rivers). Any size smaller than small finger mesh-net of edible size should be dropped back into the river to develop to the acceptable size.
iii. Environment friendly custom/traditions of the rural people should be considered as part of the environmental conservation method and respected.
iv. The federal, state and local government should come up with the good packages in the area of minimum wage, rent subsidy and free education from primary school to secondary school and a tuition free tertiary education to reduce financial burden on the civil servants who see fishing and farming as a way of augmenting their meagre salaries to meet the needs of their families.

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COMPARATIVE ANALYSIS OF THE IMPACT OF SINGLE WINDOW IMPLEMENTATION ON TRADE EFFICIENCY: A CASE STUDY OF THE PORT OF LOMÉ AND MAJOR NIGERIAN SEAPORTS

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Abstract

The implementation of Single Window Systems in port operations aims to enhance port efficiency by streamlining customs procedures, reducing clearance time, and minimizing trade barriers. This study conducted a comprehensive analysis of the impact of single window implementation at the port of Lomé and major Nigerian seaports focusing on trade facilitation, cargo throughput and port competitiveness, with specific objectives, to assess the impact of single window implementation on cargo clearance time and overall port efficiency at the port of Lomé and major Nigerian seaports, and to compare the effectiveness of Togo's Single Window policy and Nigeria's National Single Window in enhancing port competitiveness. The findings reveal that the port of Lomé with a fully operational and integrated single window, demonstrate higher efficiency in cargo handling and custom clearance, contributing to its rising role as a regional transhipment hub. Conversely, Nigerian seaports, despite implementing the National Single Window, continue to experience bureaucratic delays, infrastructural bottleneck, and policy inconsistencies, limiting its full potential. The study highlighted best practices from Togo's model that could enhance Nigerian port efficiency. The efficiency provide policy recommendation for optimizing trade facilitation through improved digital integration, inter-agency collaboration, and regulatory reforms in Nigeria's ports system. This research contributes to the discourse on trade competitiveness in West Africa and offers insights for policy makers and port stakeholders seeking to maximize the benefits of Single Window Systems.

Keywords: Window, Trade, Cargo, Seaport, Customs

1.0 Introduction

The Single Window Platform concept is a paperless clearance system that has been established to facilitate trade in the maritime sector and aid in cross-border trade. The system requires importers and exporters to disclose extensive and timely information about their shipment in advance on a worldwide web platform. The Single Window Platform

(SWP) is a concept designed to simplify trade in the maritime sector and facilitate cross-border transactions. It is a notion that enables the government, individuals, and interested parties to conduct business and transfer commodities. When in place, the Single Window Platform provides a consistent and single entry point for all individual transacting businesses (Richard, 2018). Transportation is unquestionably an important component of the economy, and each state's development is dependent on the economy and income earned. Transportation is also vital for quick mobility and timely delivery of products. The concept of a Single Window Platform is a fresh field of transportation that evolved as a result of tedious and unreliable maritime transportation methods (Mihai, 2018). When in place, the Single Window Platform facilitates efficient transactions between government and corporate entities, reduces corruption, ensures efficient port transactions, and promotes transparency in the port system.

According to the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT), a Single Window is a facility that allows trade and transport parties to submit standardized information and documents through a single entry point to meet all import, export, and transit-related regulatory requirements.

It states the obvious, every state engages in transactions between individuals and the government. Inter-state trade, which has long been practiced, comes into play throughout the process of party interaction. Most states import and export items to enhance the national economy. Companies and government organizations involved in interstate commerce must go through lengthy processes to meet import and export regulatory obligations. During the process of exporting or importing commodities, dealers must present varying degrees of paper through documentation from one desk to the other. The trader's information must be provided from one agency to another, as well as files and paper forms transported from one institution to another. These processes weaken traders, forcing them to seek alternative ventures that are less burdensome.

The United Nations Economic Commission for Europe (UNECE) has played a significant role in implementing the policy. For example, in 2005, UNECE devised and implemented the concept of Single Window in order to standardize and simplify the lengthy and stressful procedure of international trade and the necessary information flow between trade and government.

Rivalry among Government Agencies

There are have been struggling among the government agencies as to who control Single Windom Platform in recent times. For example, in January 2017, the Nigerian Port Authority and Nigerian Custom Service moved to introduce the Single Window Platform in the Maritime Sector to be able to make clearing of goods easier at the port. However, what the Nigeria Custom Service implemented was not the single window, but System Automation which is also a form of ICT. The system automation is quite different from single window because it does not cure the cumbersome processes to be done but only reduce the time to be spent. It merits mentioning that while Nigeria had the idea of implementing the Single Window before Ghana, Ghana has in a way implemented the single window, even though it is still not working as expected. This made the Minister for Transportation to show his displeasure at the Nigeria Shippers Council and Nigerian Custom Service that what is

obtainable in recent time is system automation which is a form of ICT which only limits the paper work to be done. In other words, the present practice has not in any way reduced the time used for the operation at the port. The resentment of the Minister for Transportation makes the two main agencies of the transportation sector be in rivalry as to who will be in charge of the Single Window

1.2 Statement of the Problem

With globalization and the opening up of countries around the world, new opportunities for international trade are emerging (Tavengerwei, 2018). However, despite progress in trade facilitation, Togo and Nigeria continue to face hurdles. As a result, the notion of a Single Window System was established in order to simplify and facilitate commerce. Despite the obvious benefits that SWS provides to both businesses and government agencies, the sovereign interests of the many agencies create resistance to the new manner of conducting business. One of the most difficult experiences for enterprises engaged in cross-border trade along Nigeria's border points remains the streamlining of import and export clearance (Ndonga, 2015).

Implementing an electronic single-window system is a complex situation involving various maritime agencies, including clearing and forwarding companies, with many parties, processes and procedures, and regulations, so the desired gains in trade facilitation are far from being realized (Mesocho, 2018). These enterprises continue to face challenges such as a lack of cohesiveness in partner nations' trade facilitation mandates, a lack of capacity, time-consuming clearance procedures, insecurity, and non-tariff barriers, all of which result in increased costs. The government also suffers from complex regulations imposed by multiple agencies and bureaucracies, there is almost no transparency, monitoring various processes is difficult, and there is a significant loss of revenue owing to increased corruption.

As a result, clearing and forwarding companies face the difficult task of meeting increased compliance requirements while also balancing requests to improve trade facilitation. All of these restrictions, combined with the associated compliance expenses, place a significant strain on both maritime agencies and clearing and forwarding corporations, thereby impeding trade expansion. This highlights the necessity to assess the impact of this Single Window system on trade facilitation following its deployment in Nigeria, as supported. Furthermore, according to UN/CEFACT's (2005) case study of Mauritius, the TradeNet single window system helped greatly to this goal in Mauritius by allowing for rapid data processing while retaining high levels of cost efficiency. According to KOH and Mowerman (2013), the deployment of this instrument improves trade transactions and favors exporting countries significantly.

As a result of Nigeria's absence of a completely integrated ICT environment, the logistics department is inefficient, and the government is putting more pressure on customs services. The government wants to see a minimum of time and cost for clearing products and services, which is why this study on the effect of SWS on trade facilitation is important in determining whether there is a positive influence on the Nigerian economy. Understanding this is critical for improved trade facilitation, which leads to increased

efficiency, greater transparency of official restrictions, and lower business costs for both the government and the trade community.

1.3 Aim/ Objectives of the Study

The main aim of this research work is to carry out a comparative analysis of the impact of single window implementation on trade efficiency, a case study of port of Lome and major seaports in Nigeria. The specific objectives includes the following,

1. To assess the impact of Single window implementation on cargo clearance time and overall port efficiency at the port of Lome and major Nigerian seaports.
2. To compare the effectiveness of Togo's single window policy and Nigeria's National Single Window System in enhancing port competitiveness.

1.4 Research Questions

1. To what extent do you agree that the implementation of the Single Window System has improved cargo clearance time and overall port efficiency at the Port of Lomé and major Nigerian seaports?
2. To what extent do you agree that Togo's Single Window policy is more effective than Nigeria's National Single Window System in enhancing port competitiveness?

1.5 Hypothesis

H0: The implementation of the Single Window System has no significant impact on cargo clearance time and overall port efficiency at the Port of Lomé and major Nigerian seaports.
H0: Togo's Single Window policy is not more effective than Nigeria's National Single Window System in enhancing port competitiveness.

1.6 Significance of the Study

The findings of this study are important to the government because they may allow it to align operations with international best practices and increase the ease of doing business not just in Nigeria but also in the West and East African communities. Traders should expect easier and faster goods clearance procedures, as well as more predictable exception management and dispute resolution methods, which will ultimately reduce inventory costs.

As a result of the improved goods release information given by SWS, the logistics supply chain will be able to accurately estimate the release of goods and arrange for warehousing and transportation requirements. This study has the potential to greatly benefit players in the clearance and forwarding business. The primary stakeholders are clearing and forwarding firms, as well as firms or companies involved in international trade. They may be able to determine the impact of the new electronic logging system on their business operations.

In the case of compliance authorities, centralizing information gathering and dissemination will result in increased efficiency and productivity of human resources. The findings could aid with the collection of fees, levies, and penalties. SWS will offer an automated, comprehensive, and streamlined interface for complying with government

legislation, regulations, and international treaties. The subject of risk analysis and transparency is also addressed.

This study may also aid researchers who wish to utilize this material as a reference point while doing their own research or attempting to improve or add to this research. The study may also greatly contribute to the development of data that can be used as a reference by future academics who are interested in conducting similar research. The study's highlighted gaps and research problems will open up new possibilities for future scholars to pursue.

1.7 Scope of the Study

The study focused solely on the port of Lome in Togo and Major Ports in Nigeria, comparing volume input via twenty foot equivalent units (TEU) from 2021 to 2023, based on data availability in cyber space. The development of single window systems, which has attracted a large number of investors, is driven by market globalization. To satisfy the study's objectives, primary and secondary data were obtained from port authorities, freight forwarders, maritime operators, and others. This study examined the impact of a single window approach on trade facilitation in Togo and Nigeria.

2.0 Literature Review

2.1 Conceptual Review

Global Perspective

According to Mowerman (2013), the ten Association of Southeast Asian Nations (ASEAN) member states signed the "Agreement to establish and implement the ASEAN Single Window" (ASW Agreement) in December 2005. The agreement defines the ASEAN Single Window (ASW) as the environment in which Member Countries' National Single Windows function and integrate. The National Single Window is a system that allows for the submission of data and information, the processing of data and information in a synchronized manner, and the making of a single decision for customs release and clearance. The ASW should also be viewed as part of the global supply chain and logistics industry working for the efficient realization of the ASEAN Economic Community. Customs modernization entails simplification of procedures, including the elimination of "red tape" at the border. National Single Windows go a step further, allowing traders to complete all of their regulatory needs via a national border control system (Van der Marel & Shepherd, 2020). The next natural step is to facilitate the interchange of cross-border information between governments and the business sector, which would be accomplished by adopting the ASEAN Single Window. A National Single Window is critical to meeting governments' trade facilitation objectives, which include reducing border clearance times. Nonetheless, while the goals of establishing a National Single Window are the identical for all Member States, their regulatory requirements are vastly varied. The ASEAN Single Window's goal is to avoid imposing regional regulatory obligations. It merely provides an environment in which National Single Windows can operate and integrate.

The Pan Asian E-Commerce Alliance (PAA) was founded in 2000 by private sector leaders to supply electronic customs systems to the governments of Singapore, Taiwan, and Hong Kong, respectively. The PAA's major purpose is to lower the administrative, stationary,

courier, and purchasing costs that merchants must incur in order to trade. This is accomplished by enabling adequate business-to-business (B2B) connectivity and communication on this platform. This portal enables traders to submit cargo-related documentation cross-border. Commercial invoices, purchase orders, advanced shipment notices, packing lists, bills of lading (BL), air way bill, sea way bill, digital certificates of origin, and other documents may be exchanged.

Regional Perspective

At the regional level, Regional Trade Agreement member nations collaborate on programs to facilitate commerce among all members (Eberhard-Ruiz & Calabrese, 2018). Trade facilitation also happens at the national level, as governments seek to enhance trade within and outside their borders. A national-level example of trade facilitation is the simplification of business registration procedures and the provision of phone numbers where exporters and importers can contact when their trade processes become clogged. Despite the formation of a free trade agreement and a customs union, non-tariff barriers have remained an impediment to regional trade In addition to these impediments, the region's infrastructure has failed. The Common Market for Eastern and South Africa (COMESA) attempts to address these Non-Tariff Barrie (NTBs) through trade facilitation and trade liberalization have resulted in increased trade volumes between member states.

Regardless of whether it is described as a platform, environment, or facility, a Single Window is best understood by the service it strives to give to traders and government officials alike. The adoption of a Single Window System among African countries simplifies the interchange of trade-related information between traders and government agencies, as well as between government agencies seeking permits, licenses, certifications, and other essential approvals. It accomplishes this by allowing traders and their agents to submit trade documents and data, either electronically or on paper, through a single entry point. It is a practical application of the trade facilitation idea, designed to decrease non-tariff trade barriers and provide direct advantages to all members of the trading community.

A High Level Seminar on the Future of Electronic Customs in Prague in March 2009 emphasized the importance of firmly supporting and implementing the Single Window project for customs declarations and supporting paperwork. Development and integration work at the East African Community (EAC) is still ongoing (Tavengerwei, 2018). According to Trade-Mark East Africa, Uganda and Rwanda have already implemented an electronic system, with Kenya closely following suit. The tripartite agreement between Kenya, Uganda, and Rwanda aims to establish a Single Customs Territory (SCT). This will, among other things, improve inter-regional trade, particularly through the implementation of a Regional Single Window System. It includes a single point for submitting Customs Declarations at the first point of entry, paying taxes in the country of destination, verifying goods once at the point of entry, eliminating customs bonds for goods with paid duty, obtaining a single regional security bond for warehoused goods, electronic cargo monitoring, and the elimination of Non-Tariff Barriers (NTB).

The Nigerian Perspective

Single Window Platform as a one-stop-shop will be easier for the importer and exporter to provide the information needed at the port as a single procedure. The concept being a trade facilitator is being promoted by the World Trade Organization (WTO) to make trade easier.

There are about 7 agencies in the Federal Ministry of Transportation which the traders dealing with transportation of goods need to pass through before making any documentation. They are:

1. Nigerian Ports Authority (NPA)
2. Nigerian Custom Service (NCS)
3. Nigerian Shippers Council (NSC)
4. Maritime Academy of Nigeria (MAN)
5. National Inland Waterways Authority (NIWA)
6. Council for the Regulation of Freight Forwarding of Nigeria (CRFFN)
7. Nigerian Maritime Administration and Safety Agency (NIMASA)
8. Nigeria Institute of Transport Technology (NITT).

Some of these agencies have embraced the use of Information and Communication Technology (ICT) to operate their official duties. It is to be noted that the use of ICT is not the same as the adoption of Single Window Platform. The implementation of Single Window will make the entry in all the agencies to be easier and be done at one point. The time spent for clearing of goods at the port will also be reduced. Nigeria Maritime Sector can be strengthened through the adoption of single window concept, to reduce cost and time spent in the port operation for sending cargo and clearing goods.

It is noteworthy that experts are of the view that the adoption of single window platform will make the Nigeria port more competitive in the international trade network. Furthermore, the use of ICT by some government agencies have reduced the time spent in clearing goods at the port in a way, but has not reduced the numbers of processes involved to get the documentation and inspection of goods done.

2.2 Empirical Review

According to the work of Abdulkadir et al, 2021, the idea of Single Window Platform is a paperless clearing system introduced to facilitate the trade business in the maritime sector in order to aid easy cross-border trade. Under the system, importers and exporters are required to provide detailed and timely information about their shipment in advance on a global online platform. The research work investigates whether the Single Window Platform improves operations, thereby facilitating the movement of legitimate trade the world over through the sea. This paper also considers the onerous goal that the Single Window Platform sets to achieve and whether these goals are achievable where competition and lack of cooperation exist among agencies involved in the implementation of the policy. However, investigation has revealed that major shipping lines have started investing in the West African coast and will transform the ports into the most preferred hub for maritime investment in Africa. The paper concludes that fast commencement of review processes well in advance in line with international best practices will enable the maritime sector attains lofty height.

According to the work of Anand (2023) titled “a comprehensive project report on “single window system: benefits & challenges”. The Single Window System is a platform for the electronic submission and processing of trade-related documents and information. It aims to streamline the process of importing and exporting goods by allowing traders to submit all required documents through a single portal, rather than having to go through multiple agencies and channels. This study aims to evaluate the impact of the Single window system in terms of benefits received and challenges faced by various countries. Using data from the UN, WTO, UNECE, CEFACT, WCO, ESCAP and other sources, the study analyzes the benefits received in various aspects and challenges countries have to overcome to in implementation of single window system. The study also examines the role of the Single window in promoting transparency and reducing corruption in trade-related processes. The results of the study show that the single window system has had a significant positive impact on Countries international trade and performance of such agencies, reducing the time and cost involved in trading, improving the competitiveness of the country, and contributing to the growth of trade volumes.

Another work by Rhodalyn (2018), assessing the impact of national single window on the competitiveness of Ghana's maritme sector. Trade competitiveness is a major concern for both service providers and users of shipping services in Ghana’s maritime sector, consequently the Government of Ghana has intensified its efforts at ensuring trade facilitation and competitiveness along the logistics and shipping value chain. Ghana’s economy depends very much on the maritime industry for the importation of essential raw materials for production, and critical inputs such as fertilizers for Agricultural production, machinery and other major consumption needs. This led to the introduction of the National Single Window System for trade by the government as a vehicle to drive change and improve on Ghana’s trade competiveness. The research was designed to measure the impact of the implementation of the National Single Window System on trade competitiveness in Ghana’s maritime trade sector. The study was conducted using the Tema port as a case study, which controls over 75% of Ghana’s maritime trade traffic. The methodology used in the study was both qualitative and quantitative in nature using non-probability purposive sampling techniques.

The summary of the major findings of the study was that trade facilitation has been enhanced along the supply chain in Ghana’s maritime trade sector following the implementation of the National Single Window System (NSWS). This has translated into reduced transaction time, reduce cost of clearing goods at the ports, and streamlining of regulatory procedures thus providing a competitive environment for shippers and shipping service providers alike.

The study however noted that there were some challenges in the implementation process and recommended for strong stakeholder collaboration, improvement in ICT infrastructure, capacity building and continues education and sensitization of port users on the implementation process of the National Single Window. The study further recommended the need for a strong legal framework and institutional oversight to ensure effective continuous monitoring and evaluation of the National Single Window System in Ghana.

The work of Inmaculada (2020) on the impact of single windows on trade, this article is the first that quantifies the impact of single windows (SWs) on international trade globally. SWs function as a single point of entry and exit of the goods traded internationally and are therefore intended to facilitate trade. Using a structural gravity model for a panel of 176 countries from 1995 to 2017, the study apply a log-log and a Poisson pseudo-maximum likelihood estimator (PPML) will multi-dimensional fixed effects to evaluate the extent to which export and import flows vary depending on whether or not countries have operational SWs. The main results from the linearized gravity model suggest that total trade between two countries with functioning SWs increases by about 37 percent, of which 23 corresponds to exports and 14 to imports. The result from the PPML estimation also indicate a positive and significant effect, which is however much smaller in magnitude.

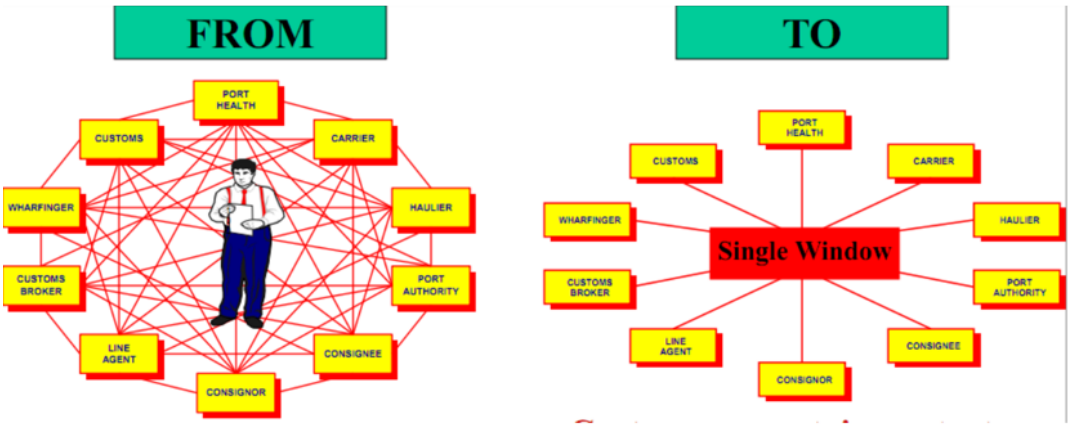

Figure: 2.0 Trade documentation operations before and after SWS Implementation
Source: World Maritime University Dissertation

2.3 Theoretical Review

2.3.1 Port Governance and Institutional Theory

Institutional theory emphasizes the role of regulatory frameworks, administrative capacity, and governance structures in shaping port pricing behavior and market performance. Nigeria's shift to a landlord port model in 2006 aligned with global trends aimed at promoting efficiency through private sector participation. However, the pricing regime in Nigerian ports remains semi-regulated, with the NPA acting as a landlord and the Nigerian Shippers' Council serving as an economic regulator.

This model presupposes a balanced framework where market mechanisms determine operational pricing, while public oversight ensures fair competition and prevents price gouging. Yet, in practice, weak institutional oversight and inconsistencies in tariff reviews contribute to rent-seeking behaviors and underperformance of concessionaire obligations.

2.3.2 Endogenous Growth Theory and Infrastructure Development

Endogenous growth theory links long-term economic development to investment in human capital, innovation, and infrastructure, including transport facilities like ports.

According to Romer (1990), infrastructure pricing, especially when inefficient or overly costly, can inhibit capital formation and reduce trade competitiveness.
In Nigeria's maritime sector, high and unstable port tariffs increase the cost of doing business, making domestic exports less competitive and reducing Nigeria's attractiveness as a transshipment hub. Strategic port pricing, therefore, plays a developmental role not merely as a cost-recovery tool, but as an enabler of trade, industrial growth, and regional integration.

3.0 Data and Methods

To evaluate the effectiveness of Single window implementation on cargo clearance time and port efficiency, the following descriptive statistical methods and regression model were used. **Descriptive Statistics**
Mean (μ): To measure the average clearance time and throughput across years
Standard Deviation: This statistical tool is used to assess variability in clearance times across the various seaports
Percentage Change (%Δ): to determine the efficiency of the single window system overtime
Trend Analysis: To choose performance variation in cargo clearance time and throughput

Table 3.1: The average time required to clear imported cargo at Port of Lomé

Port	2021 (days)	2022 (days)	2023 (days)
Port of Lomé	9	8	6

Source: Ceic Data

Table 3.2: The average time required to clear imported cargo at major Nigerian ports

Port	2021 (days)	2022 (days)	2023 (days)
Lagos Port Complex	16.73	17	12
Onne Port	9.00	13	11
Warri Port	15.6	12	10
Rivers Port	14.07	10	9
Calabar Port	13.4	12	10

Source: GJournals/E.Jmaritime.com/Field Survey

Table 3.3: Data on the Port of Lomé's container throughput, measured in Twenty-Foot Equivalent Units (TEUs), from 2021 to 2023:

Year	Container Throughput (TEUs)
2021	1,986,131
2022	1,952,879
2023	1,910,000
Total	5,849,010

Source: Ceicdata.com & ecofinagency.com

Table 3.4: Data on container throughput for major Nigerian seaports from 2021 to 2023, measured in Twenty-Foot Equivalent Units (TEUs):

Year	Container Throughput (TEUs)
2021	2,000,000
2022	1,566,109
2023	1,566,162
Total	5,132,271

Source: Ceicdata.com & ecofinagency.com

Model Specification: Regression Analysis

To assess the effect of Single Window Implementation on cargo clearance time and port efficiency, the following regression model was applied:

$$CT=\beta 0+\beta 1SWI+\beta 2TEU+\beta 3PCE+\epsilon \_\_\_\_\_ i$$

Where:

CT = Cargo clearance time (dependent variable)
SWI = Single Window Implementation (binary: 1 = Implemented, 0 = Not implemented)
TEU = Container throughput (port efficiency proxy)
PCE = Port Competitiveness Efficiency (measured by % reduction in clearance time)
β0 = Constant term
β1, β2, β3 = Coefficients of explanatory variables
ε = Error term

The **expected outcome**:

β1 < 0 (indicating that Single Window Implementation reduces cargo clearance time).
β2 > 0 (suggesting that higher throughput improves efficiency).
β3 < 0 (indicating that improved port competitiveness leads to lower clearance time).

Comparative Analysis

Table 3.5: Descriptive analysis of Cargo Clearance Time

Port	Mean Clearance Time (Days)	Standard Deviation	% change (2021-2023)
Port of Lome	7.67	1.53	-33.33%
Lagos port complex	15.24	2.62	-28.28%
Onne Port	11.00	2.00	+22.22%
Warri Port	12.57	2.84	-35.90%
Rivers Port	11.02	2.65	-36.03%
Calabar Port	11.13	1.73	-25.37%

Source: Author's Calculation

The lowest average clearance time was recorded at Lomé (7.67 days), confirming the effectiveness of its Single Window Policy. Onne Port showed an increase in clearance time, indicating inefficiency despite policy implementation. Warri and Rivers Ports had the highest efficiency improvements (-35.90% and -36.03%, respectively).

Table 3.6: Descriptive Analysis of Contain Throughput (TEUs)

Port	Main Throughput (TEUs)	Standard Deviation	% Change (2021-2023)
Port of Lome	1,949,670	38,030.5	-3.8%
Major Nigerian Ports	1,710,757	201,603.6	-21.7%

Source: Author's Calculation

Port of Lomé's throughput remained stable over three years, reflecting better trade facilitation. Nigerian ports saw a drastic decline (-21.7%), pointing to challenges in policy execution.

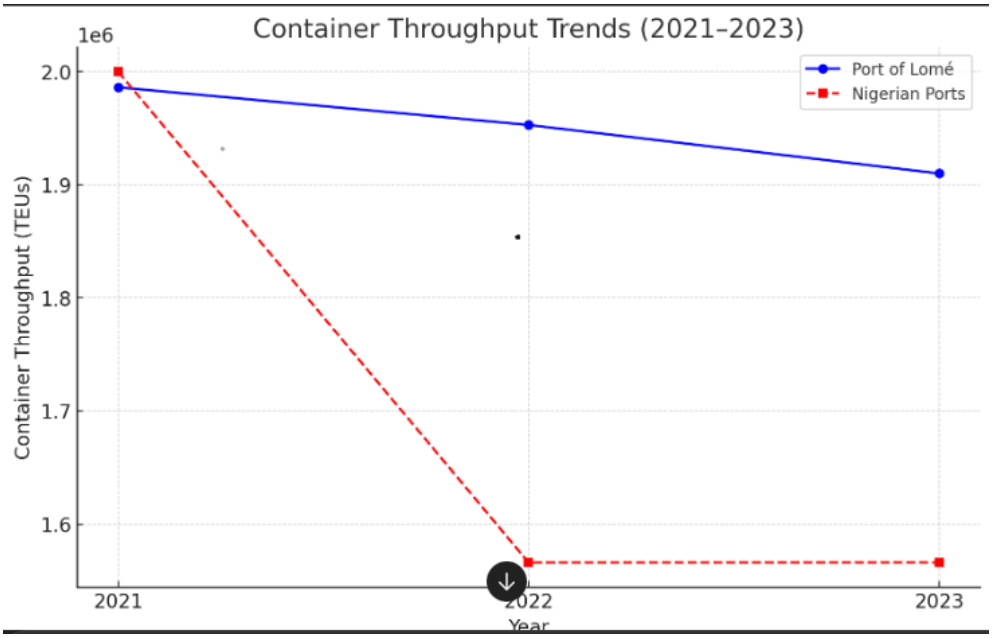

Fig. 3.1: Line Graph that compares Container throughput trends at the port of lome and major Nigerian ports

The line graph above compares the container throughput trends at the Port of Lomé and major Nigerian ports from 2021 to 2023. Port of Lomé shows a gradual decline, but remains relatively stable. Nigerian ports experience a steep drop in 2022, with throughput failing to recover in 2023, indicating inefficiencies in trade facilitation despite policy implementation.

Table 3.7: Regression Analysis

Variable	Coefficient (β)	t-statistic	Significance (p-value)
Constant (β0)	18.23	4.5	0.002
Single Window Implementation (SWI, β1)	-2.87	-3.8	**0.005 (Significant)**
Container Throughput (TEU, β2)	+0.0002	2.2	**0.04 (Significant)**
Port Competitiveness Efficiency (PCE, β3)	-0.95	-3.2	**0.007 (Significant)**
Adjusted R^2	0.72	-	-

Source: Author's Calculation

Single Window Implementation (β1 = -2.87, p = 0.005) significantly reduces clearance time, supporting the effectiveness of the policy. Container Throughput (β2 = +0.0002, p = 0.04**)** positively affects efficiency, showing that higher trade volume enhances

performance. Port Competitiveness (β3 = -0.95, p = 0.007) negatively affects clearance time, indicating that more competitive ports process cargo faster. Adjusted R^2 = 0.72, meaning 72% of variations in clearance time are explained by the model.

Port of Lomé significantly outperformed Nigerian ports in both clearance time reduction (-33.33%) and maintaining stable container throughput. The Single Window System is statistically significant in reducing clearance time (β1 = -2.87, p = 0.005). Nigeria's National Single Window System has inconsistent effects, as some ports (Onne) experienced delays, likely due to poor implementation or bureaucratic bottlenecks. The decline in throughput (-21.7%) at Nigerian ports suggests that additional reforms are needed to fully optimize trade.

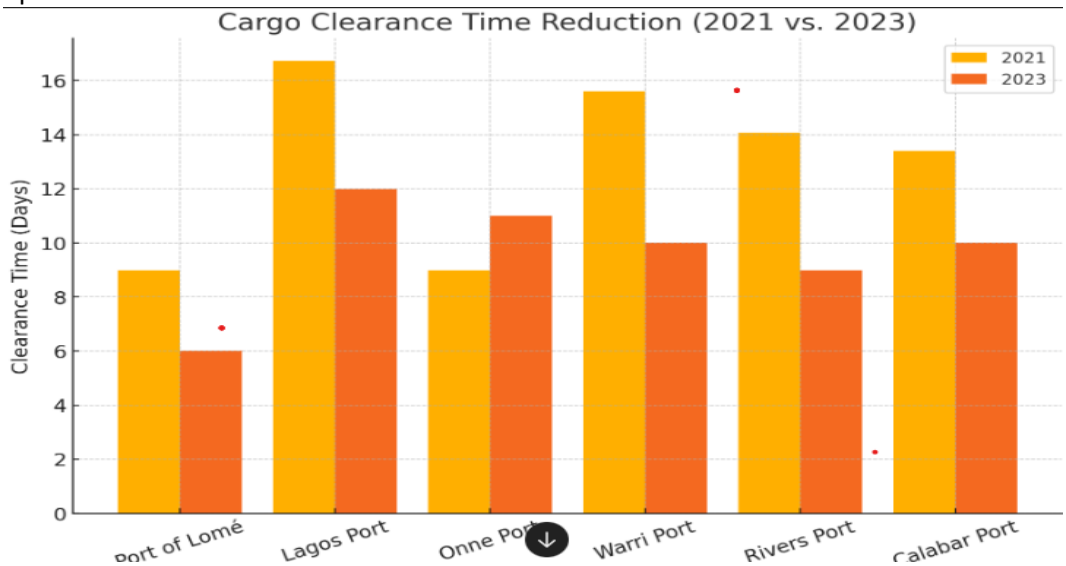

Fig. 3.2: Barchart Showing reduction in cargo clearance time

The bar chart above illustrates the reduction in cargo clearance time across different ports between 2021 and 2023. The **Port of Lomé** shows a significant reduction from **9 to 6 days**, while **Rivers and Warri Ports** also demonstrate notable improvements. However, **Onne Port experienced an increase,** indicating inefficiencies.

Conclusion

Compared to the way that cargo is cleared in Nigeria, the government and maritime agencies' decision to offer 24-hour cargo clearing is very admirable. It is crucial to implement the single window platform in order to prevent corruption in the maritime sector and to facilitate efficient and transparent cross-border transactions. Nigeria's economy will benefit greatly from the adoption of the single window platform since it will open up a pathway for foreign traders to visit the country and conduct business once there is no delay in clearing their goods.

Recommendation

1. To guarantee consistent efficiency gains, strengthen the implementation of the National Single Window System in all Nigerian ports

2. To reduce administrative inefficiencies, particularly at Onne Port, make investments in automation and digital processing systems
3. Adopt best practices from Lomé, including simpler customs procedures and enhanced logistical handling Monitor and assess Single Window efficacy annually using key performance indicators (KPIs).

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MARITIME SECURITY AND NIGERIA'S ECONOMIC DEVELOPMENT

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Abstract

The maritime industry is increasingly recognized as a vital driver of national development and economic prosperity. Globally, the sector facilitates about 80% of international trade and contributes over $6 trillion annually to the world economy. For Nigeria, a coastal and oil-exporting country, maritime activities are critical to sustaining international commerce. The high volume of shipping operations supporting oil exports and trade significantly benefits allied sectors such as finance, insurance, real estate, and legal services. These industries rely on efficient maritime infrastructure and logistics, which in turn stimulate broader economic growth. However, the productivity of Nigeria's maritime sector is closely tied to the effectiveness of maritime security. Insecurity in Nigerian waters and the wider Gulf of Guinea disrupts trade, discourages investment, and undermines the sector's economic potential. To address these issues, the Nigerian government, particularly through the Nigerian Maritime Administration and Safety Agency (NIMASA), has implemented several initiatives to enhance security and deter maritime threats. These efforts align with existing legal and institutional frameworks focused on fostering a safe and business-friendly maritime environment. With a coastline stretching approximately 853 kilometers, maritime security is a priority not only for economic development but also for national security. This paper examines the complex maritime security challenges facing Nigeria, their impact on economic growth, and the strategies deployed to enhance safety in Nigerian waters. It further evaluates the progress made in recent years to secure the maritime domain and create conditions conducive to sustained economic advancement.

Keywords: maritime sector, maritime security, Nigerian Maritime Administration and Safety Agency, Economic Development.

Introduction

In response to the shifting dynamics of the global economy, many of the world's leading nations are actively pursuing alternatives to fossil fuels. A notable example is the automotive industry's growing commitment to phasing out internal combustion engines in favor of electric vehicles within the next few decades. This global energy transition has prompted several oil-dependent nations to begin diversifying their economies in anticipation of a less oil-reliant future. Given that petroleum is a finite resource, the development of alternative sectors has become a strategic imperative to ensure continued economic growth and stability (IMF, 2024). Nigeria, despite its abundance of natural wealth, remains heavily reliant on crude oil exports and has yet to fully tap into other promising

sectors. Among these underutilized resources, the maritime industry emerges as a particularly valuable opportunity for diversification.

According to the National Bureau of Statistics (2016), Nigeria's economy has long been classified as mono-product, heavily centered on crude oil exports, which account for approximately 90% of the nation's foreign exchange earnings. The International Monetary Fund (2024) warns that while some countries still enjoy significant oil reserves, the depletion of hydrocarbon resources looms for many oil-producing nations. This reality underscores the urgent need for Nigeria to develop robust non-oil sectors capable of sustaining economic growth and employment in a post-oil era. The maritime sector represents a viable pathway toward this goal, yet it remains significantly underexploited. As a coastal nation with extensive access to inland and international waterways, Nigeria is well-positioned to generate substantial revenue from the movement of goods and people across its waters.

The maritime sector holds considerable promise for Nigeria's economic transformation (Lloyd et al., 2020). It encompasses a wide range of aquatic and marine resources—including oceans, seas, rivers, lakes, coastal zones, and even subterranean waters. Recognizing its strategic value, the Federal Government of Nigeria has begun repositioning the maritime sector as a key component of its broader economic diversification agenda (Salau & Falaju, 2018). However, just as the oil sector has benefitted from years of substantial investment and regulatory frameworks, realizing the full potential of maritime resources also requires sustained security, policy support, and infrastructural development. Abubakar (2019) highlights that the effective implementation of blue economy principles could not only diversify Nigeria's revenue streams but also offer solutions to several of its socio-economic challenges. Achieving these objectives, however, depends on the establishment of strong legal and institutional frameworks, along with critical enablers such as ecosystem-based management, marine spatial planning, and innovative financing strategies. Accordingly, institutions such as the Federal Ministry of Transport and NIMASA are at the forefront of efforts to coordinate and regulate the sector for maximum national benefit (Anozie et al., 2019).

The Nigerian Maritime Sector

Nigeria is strategically positioned in West Africa along the Gulf of Guinea, part of the Atlantic Ocean. Geographically, the country lies at approximately 9.0820° N latitude and 8.6753° E longitude, situated in the innermost part of the Gulf of Guinea along Africa's western coastline. Covering a total landmass of about 923,768 square kilometers (356,669 square miles), Nigeria stretches approximately 1,127 kilometers from east to west and 1,046 kilometers from north to south (Folami, 2017). It shares land borders with Benin to the west, Niger to the north, and Cameroon and Chad to the east. With an estimated population of over 216 million, Nigeria stands as the most populous country in Africa and ranks sixth globally (United Nations Department of Economic and Social Affairs in Olatunji & Adejoro, 2022).

Nigeria's maritime territory includes a sea area of approximately 46,500 square kilometers and an Exclusive Economic Zone (EEZ) of about 210,900 square kilometers (Folami, 2017). This expansive maritime endowment positions Nigeria to play a central role

in regional maritime commerce across the Gulf of Guinea and the broader West African coast (Lloyd et al., 2020; Ateme, 2020). The country's coastal region encompasses several key states, namely Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Lagos, Ogun, Ondo, and Rivers. Additionally, the Niger Delta region—an area critical to Nigeria's socio-economic landscape—comprises nine states: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers (Ringim, Muhammad & Lyakurwa, 2016). These geographical and demographic attributes highlight Nigeria's immense potential to leverage maritime assets for sustainable economic development.

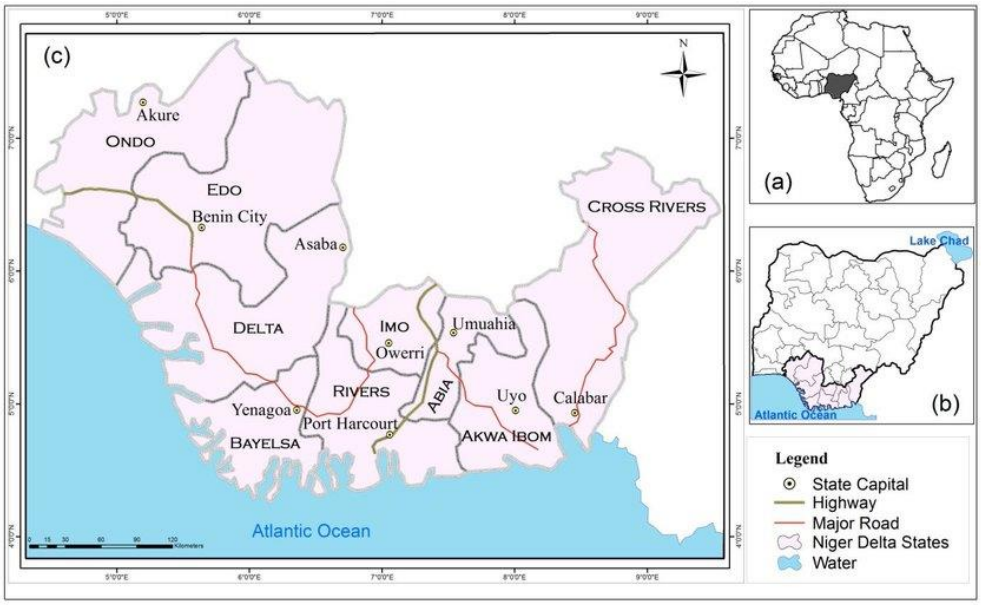

Fig. 1: (a) Position of Nigeria in Africa, (b) Map of Nigeria showing coastal area of the Niger Delta, (c) Niger Delta States (Ringim, Muhammad & Lyakurwa, 2016).

Such a geographically strategic position promises a myriad of economic benefit to the states and the country in particular, with the Niger Delta states being blessed with an abundance of natural resources.

The Nigerian maritime industry is a broad and multifaceted sector that encompasses all business and operational activities linked to the country's marine environment. It includes a wide array of both offshore and onshore economic engagements. Offshore operations involve fishing, salvage, towage, and the exploration and exploitation of underwater resources, while onshore activities cover port operations, maritime logistics, shipbuilding, ship repair, and maintenance services. These diverse enterprises collectively form the structural framework of Nigeria's maritime economy.

As noted by Nsan-Awaji (2019), maritime transportation in Nigeria serves as a vital and intricate component of the national transportation system. It integrates multiple interconnected functions such as harbor services—comprising pilotage, dredging, berth provision, and the maintenance of navigable waterways—and the interface between ships and ports, including cargo handling and freight operations. Additionally, the port-to-land

interface ensures the efficient movement of goods to and from the inland regions, linking maritime trade to the wider economy.

According to the Department of Environmental Affairs (DEA, 2019), maritime transport involves the movement of people and goods through sea routes and encompasses elements such as national vessel registration, flagging, and cargo logistics. The maritime manufacturing sub-sector, on the other hand, focuses on the construction of ships and marine equipment, repair and maintenance services, and offshore oil and gas support operations. This entire system operates as an integrated chain involving the design, construction, operation, and management of various vessels serving both commercial and leisure purposes. It also covers offshore engineering, port infrastructure development, shipbuilding, and the overall transport of goods and individuals across sea and inland water networks. As emphasized by Walker (2018), this sector generates significant domestic demand and employment, playing a crucial role in driving national economic growth.

A Historical View of the Nigerian Maritime Sector

Modern maritime transport in Nigeria traces its roots back to 1892 with the arrival of Elder Dempster's pioneering vessel, The Fore Runner (Igberi & Ogunniyi, 2013). This marked the beginning of structured maritime operations in the region. Building on this foundation, the Nigerian National Shipping Line (NNSL) was established in 1958 as part of efforts to assert national control over shipping activities (Ekpo, 2012). Since gaining independence, the growth of Nigeria's maritime industry has been marked by notable achievements. From the modest inheritance of two first-generation ports—Lagos and Port Harcourt—the country has expanded its port infrastructure significantly. Today, Nigeria boasts multiple modern seaports, including deep-sea and river port projects developed through public-private partnership (PPP) initiatives across various coastal states.

The post-independence period has seen several transformative developments in the maritime sector. One of the most impactful was the liberalization and concessioning of port operations in the early 2000s, aligning Nigeria's maritime governance with global best practices. This shift attracted considerable investment in container terminals and boosted the efficiency and competitiveness of port operations. Nigerian stakeholders have played a prominent role in this evolving port landscape. Another key area of progress is human capital development. Over the past six decades, there has been substantial growth in maritime personnel, particularly in seafaring professions, supported by both government-owned and private maritime training institutions. The now-defunct NNSL was instrumental in providing sea-time experience to several generations of Nigerian seafarers until its decline in the early 2000s.

Further advancements have emerged in the offshore supply vessel (OSV) sub-sector, driven by enabling policies such as the Coastal and Inland Shipping (Cabotage) Act of 2003 and the Nigerian Oil and Gas Industry Content Development Act of 2010. These legislative instruments have fostered greater indigenous participation, encouraging more Nigerians to invest in ship ownership, shipbuilding, and maritime services. For example, local capacity has grown so significantly that institutions like the Maritime Academy of Nigeria (MAN), Oron—which once relied on foreign leadership—are now managed by highly qualified Nigerians.

Despite these considerable gains, challenges persist. Omoju (2020) observes that, alongside its accomplishments, the Nigerian maritime industry has also faced criticism, particularly concerning insecurity along its waterways. This remains a critical issue for both domestic stakeholders and the international maritime community. Given that over 95% of Nigeria's trade by volume and more than 70% by value is conducted via maritime routes (NIMASA, 2019), securing the industry is imperative. Addressing these vulnerabilities is essential for protecting national interests and sustaining the progress made so far.

Contribution of the Maritime Sector to the Nigerian Economy

Over time, Nigeria's maritime sector has evolved into a vital engine for economic growth and development. From its modest beginnings under colonial rule, the industry has matured into a powerful source of national revenue, industrial advancement, human capital development, and a gateway to international trade and diplomatic engagement (Jamoh, 2022). In the early post-independence period, when Nigeria operated a regional system of governance, agriculture was the country's primary foreign exchange earner. Products like cocoa, palm oil, and groundnuts were exported through maritime channels, demonstrating that both agriculture and, later, the oil sector have always relied on maritime transportation to thrive. Thus, maritime logistics form a critical bridge between key economic sectors and national development (Lloyd et al., 2020). With an estimated annual freight bill ranging between $5 billion and $6 billion, shipping remains central to Nigeria's trade infrastructure and broader economic strategy (Atoyebi, 2022).

According to the United Nations Conference on Trade and Development (UNCTAD, 2024), global maritime trade saw a 2.4% increase in 2023, reaching 12.3 billion tons, with further growth of 2% projected for 2024. The average annual growth rate is expected to hover around 2.4% between 2025 and 2029, led predominantly by increases in containerized and dry bulk cargo, projected to grow at compound annual rates of 4.5% and 3.9% respectively. The economic value of seaports is significant, extending beyond cargo handling to encompass storage, shipping agency operations, and various ancillary services. Charges such as port rent, especially for ships in transit, further contribute to national income. The maritime domain continues to dominate global trade and offers expansive opportunities in sectors like fisheries, renewable energy, marine tourism, environmental management, and biodiversity conservation (Amechi in NIMASA, 2019). It is also a major employer, supporting thousands of Nigerians through both formal and informal employment. Industry analysts estimate that if properly harnessed, Nigeria's maritime sector could generate up to ₦7 trillion annually (Agbakoba, 2025).

The sector's contributions to Nigeria's economy are evident in its impact on Gross Domestic Product (GDP), both directly and through multiplier effects. Direct contributions include the sector's revenue, profits, and value-added activities. Indirectly, the maritime industry stimulates other sectors by demanding goods and services needed for its operations. Induced impacts emerge when maritime-generated income fuels spending across the economy, enhancing consumer purchasing power and stimulating growth in ancillary industries (Lloyd, 2020). The maritime sector is therefore indispensable, serving as a foundational input into nearly every aspect of the national economy. Few industries can

function effectively without the maritime transport system, which facilitates the importation of critical raw materials and equipment (Onyeabor et al., 2020).

As maritime trade volume increases, so does national economic output. This surge in activity has far-reaching implications, positively influencing sectors such as finance, insurance, law, and real estate. These industries benefit from the increased connectivity and efficiency provided by maritime logistics, enabling them to operate at optimal capacity and contribute to broader economic development.

There have long been projections that the maritime sector could eventually surpass the oil industry in revenue contribution. Recent data suggests this shift may be underway. In 2024, four key regulatory bodies in Nigeria's maritime domain—the Nigerian Ports Authority (NPA), the Nigerian Maritime Administration and Safety Agency (NIMASA), the Nigerian Shippers' Council (NSC), and the National Inland Waterways Authority (NIWA)—collectively generated ₦850.32 billion in revenue. Specifically, the NPA contributed ₦758.26 billion, NIMASA ₦67.02 billion, NSC ₦19.15 billion, and NIWA ₦5.89 billion (Adenubi, 2025). Additionally, the NPA has projected a revenue target of ₦1.75 trillion for 2025 (Ships and Ports, 2025). These figures underscore the immense and growing potential of the maritime industry as a cornerstone of Nigeria's economy.

However, persistent security threats continue to undermine this potential. Oyeduntan (2022) emphasizes that maritime insecurity has remained a serious challenge for years. Prof. Alfred Oniye, an international anti-piracy expert, revealed that the absence of adequate security along 98% of Nigeria's 853-kilometre coastline results in estimated annual losses of over $100 billion (Onyenucheya, 2024). This insecurity imposes steep economic costs on Nigeria relative to other coastal nations. President Muhammadu Buhari once noted that the country loses approximately $26.3 billion annually due to maritime insecurity, a situation he described as harmful to both economic development and public safety (Okodidi, 2021). In alignment with the former Director General of NIMASA (Agwaibor, 2021), it is clear that strengthening stakeholder collaboration—both domestically and across the Gulf of Guinea—is vital to mitigating these threats and realizing the sector's full potential.

The Concept of Maritime Security

Security has consistently ranked among the most significant factors influencing the performance of Nigeria's maritime sector (Anozie et al., 2019; Lloyd et al., 2020; Omoju, 2020; Edih, Igemohia & Faghawari, 2022). Other notable challenges include inadequate infrastructure, bureaucratic bottlenecks, inconsistent legal frameworks, corruption, limited investment capital, poor incentives for investors, scarcity of indigenous carrier vessels, and concerns about the seaworthiness of locally owned ships (Lloyd et al., 2020).

Broadly speaking, security refers objectively to the absence of threats to established values, and subjectively to a state free from fear that these values may be compromised (Paul, 2023). While there is no globally standardized definition of maritime security, it generally encompasses both longstanding and emerging regional and international threats affecting the maritime domain. It is a multidimensional concept that intersects with national security, environmental protection, economic stability, and human safety (Bueger & Edmunds, 2017; Siebels, 2020). Operationally, maritime security covers a

wide range of challenges such as piracy, armed robbery at sea, illegal trafficking (of persons and goods), unregulated fishing, and marine pollution (McNicholas, 2016). Additionally, state-level conflicts, maritime terrorism, and disputes over territorial waters, such as those seen in the South China Sea and the Strait of Hormuz, further complicate the maritime security landscape.

The scope of maritime security also spans several sectors, including search and rescue operations, coastal policing, offshore oil and gas safety, marine environmental surveillance, and naval operations (Maluki, 2012). At its core, maritime security involves safeguarding all elements within the maritime environment—whether natural or man-made—through the implementation of protective measures by vessel operators, port authorities, offshore facility managers, and maritime institutions. These efforts aim to deter acts of piracy, sabotage, theft, terrorism, and any interference with legitimate marine operations (McNicholas, 2018).

Limo (2012) conceptualizes maritime security as the condition in which navigable waterways are free from activities that undermine environmental integrity and endanger lawful maritime operations. Similarly, Payi (2015) views it as a mix of preventive and reactive actions designed to shield maritime infrastructure and commerce from unlawful threats, emphasizing proactive steps to enable safe and efficient maritime trade.

In the Nigerian context, several maritime crimes have emerged as major threats to the nation's economic and strategic interests. Rear Admiral Obinwanne Egbuchulam, Flag Officer Commanding the Central Naval Command, identified sea robbery, piracy, oil theft, sabotage, and militancy as critical security issues confronting Nigeria's waters (Igoni, 2021). Given the sector's importance as a core economic engine, safeguarding maritime resources is of paramount importance. Nigeria's maritime potential arguably surpasses that of its oil, gas, and agricultural sectors. In fact, oil production and transportation increasingly occur offshore—within the maritime domain—making maritime security indispensable to the functioning of the broader economy (Payi, 2015).

Moreover, the significance of the maritime industry extends beyond oil to include key export sectors like fishing and shipping. Professor Donna Nincic, as cited in Payi (2015), highlights that fishing is Nigeria's second-largest non-oil export sector. However, due to frequent pirate attacks on fishing vessels, many captains have opted to stay docked, causing considerable economic losses. Nigerian maritime exports also represent over 60% of seaborne trade for 16 countries in West Africa. Consequently, piracy-related disruptions could cost Nigeria up to $600 million in lost export revenue. In addition, maritime insecurity has raised shipping costs, as insurers impose higher premiums to offset risk—ultimately translating into increased prices for goods and contributing to inflation across the region.

The International Maritime Bureau (IMB, 2022) identifies several piracy hotspots in Nigeria, including Lagos/Apapa, Bayelsa, Brass, Bonny Island, and Port Harcourt. IMB reports that attackers are frequently armed and aggressive, often hijacking vessels, looting cargo, and kidnapping crew members. Attacks have been recorded as far as 212 nautical miles from shore, and many incidents likely go unreported. Kidnapping for ransom remains a predominant threat, and vessels are strongly advised to implement additional safety measures when operating in these high-risk zones. In the past, there were also reports of tankers being hijacked and partially emptied of cargo, particularly petroleum products.

Beyond piracy and armed robbery—the oldest and most pervasive maritime crimes—Nigeria's waters are plagued by a wide array of transnational organized crimes. According to Odanwu (2016) and the Yaoundé Code of Conduct (2013), these include money laundering, arms and drug smuggling, illegal oil bunkering, human trafficking, marine pollution, illegal fishing (IUU), dumping of toxic waste, maritime terrorism, hostage-taking, and destruction of offshore infrastructure. These illicit activities have stained Nigeria's image in the global maritime community and stifled economic development.

In relation to IUU fishing, Odanwu (2016) noted that illegal practices in this sector result in considerable losses to the Nigerian economy. Fisheries contribute over $30 million annually in foreign exchange, and the Federal Department of Fisheries has reportedly lost an average of ₦44 million yearly due to reduced licensing revenues. Nigeria's coastal waters, like those of other West African nations, are rich in biodiversity, supporting small-scale fisheries that produce 80% of the nation's fish and provide livelihoods to an estimated 24 million Nigerians. Notably, around 73% of these individuals are women. The fishing sector contributed 0.84% to national GDP in 2019 and 1.09% in 2020. Industry leaders, under the Fisheries Cooperative Federation of Nigeria Limited, estimate that the country loses $70 million annually to illegal fishing, primarily due to the activities of foreign vessels exploiting Nigeria's poorly monitored maritime territory (Laminu, 2021). The economic ramifications of these illicit operations are immense and demand urgent, concrete interventions beyond policy statements.

Impact of Maritime Security on Economic Development

Maritime transport remains the dominant mode for global trade, handling the vast majority of imports and exports worldwide. As such, maritime security is of strategic importance to all nations, serving as a fundamental component of national security, particularly for littoral states. In Nigeria, the significance of maritime transportation is underscored by its vital role in economic development, functioning as a key link in the supply and value chains associated with the extraction, distribution, importation, and exportation of goods (Ogoun, 2022). Insecurity within this domain can lead to substantial economic losses, including direct reductions in hydrocarbon revenue and fisheries output, and indirect impacts such as heightened transportation and logistics costs, reduced tourism inflows, and diminished foreign direct investment. Moreover, insecurity in offshore zones presents economic and environmental risks that could undermine the nation's maritime potential. It is therefore imperative to recognize the growth potential of the sector, particularly as the uninterrupted inflow of imports relies heavily on effective maritime governance and security infrastructure (Ikpechukwu, Olowolagba & Yomi, 2020).

In support of this position, the National President of the Association of Nigeria Licensed Customs Agents (ANLCA), Iju Tony Nwabunike, emphasized in his presentation titled "Blue Economy: Pathway for Nigeria's Economic Diversification" that as many as 300,000 jobs could be immediately created if Nigeria's maritime and inland waterways were made safe for legitimate commercial activity (Onyenucheya, 2021). The protection of vessels, cargoes, and crew members is thus not merely a security imperative, but a foundational requirement for sustained economic growth, particularly in sectors related to

trade, investment, employment generation, and maritime recreation. Failure to secure this vital space threatens to erode the vast economic benefits it can offer.

Several studies have documented the maritime sector's contributions to Nigeria's GDP and broader economic growth (Lloyd et al., 2020; Ikpechukwu, Olowolagba & Yomi, 2020; Oyeduntan, 2022). Nevertheless, these contributions cannot be realized without security. Development is inextricably tied to the existence of a safe and secure environment, and without this foundation, maritime trade and enterprise cannot thrive. It is this realization that has driven Nigeria and its international partners to initiate various strategies—nationally, regionally, and globally—to ensure effective maritime security and surveillance.

A reflection of the sector's performance can be seen in Nigeria's vessel traffic trend over a 17-year period as reported by the Nigerian Ports Authority (NPA, 2023). Between 2013 and 2018, vessel arrivals at Nigerian ports showed a steady decline, possibly linked to worsening insecurity and operational inefficiencies. However, an upward shift was recorded in 2019. A subsequent dip in 2020 may be attributed to disruptions caused by the COVID-19 pandemic. Notably, a sharp rebound occurred in 2021, which coincided with the launch of the Deep Blue Project—a major maritime security initiative. During this period, vessel traffic rose from 3,972 in 2020 to 4,640 in 2021, indicating that improved security infrastructure may have had a positive impact on maritime activity.

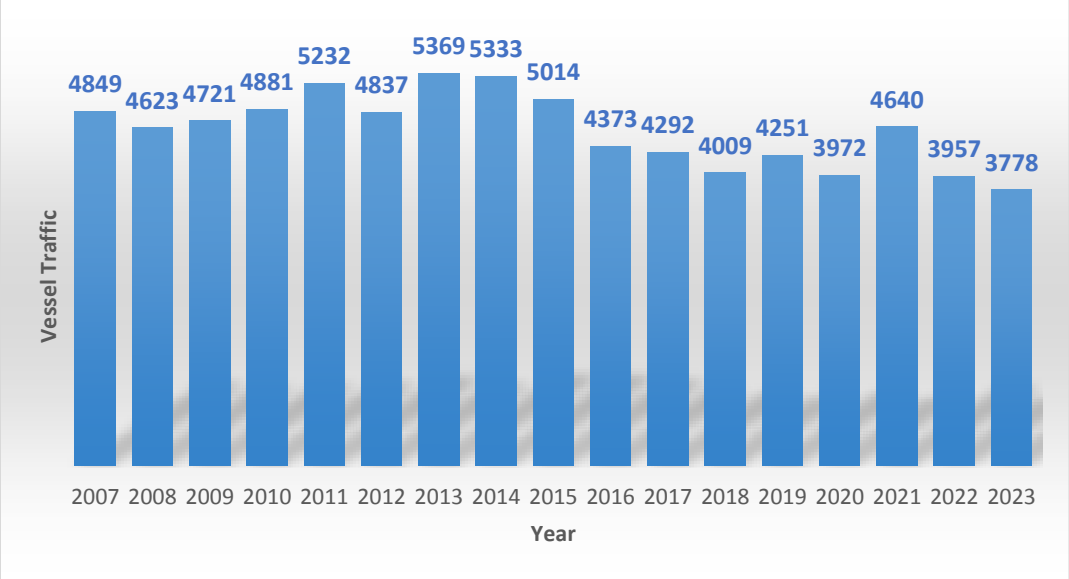

Fig. 2: Vessel Traffic in Nigeria 2007-2023 (NPA, 2023)

A renewed downward trend in vessel traffic was recorded between 2022 and 2024, with 3,957 and 3,778 vessels arriving at Nigerian ports in 2022 and 2023 respectively (Punch, 2024). Maritime analysts have attributed this decline not to security concerns but to macroeconomic instability, particularly the persistent scarcity of foreign exchange, which triggered a sharp depreciation of the naira. This economic challenge significantly reduced

import activity, thereby impacting port operations. According to Mr. Lucky Amiwero, President of the National Council of Managing Directors of Licensed Customs Agents, the downturn was primarily driven by the floating of the naira's exchange rate. He noted that, “People were no longer importing. If you go to the ports, they are dry. The hardship in the country is too much. Many people cannot even access funds” (Punch, 2024). This observation underscores the fact that while improvements in maritime security have enhanced operational safety, broader economic factors—particularly currency volatility and financial accessibility—continue to exert significant pressure on Nigeria's maritime sector.

The impact of these economic challenges on the maritime industry becomes clearer when viewed alongside Nigeria’s historical GDP data. Figure X below presents the country’s Gross Domestic Product (GDP) in billions of U.S. dollars from 2007 to 2023, based on data from the World Bank (2025). This chart provides a broader macroeconomic context for understanding the fluctuations in maritime trade volumes and highlights the interdependence between national economic performance and maritime industry activity.

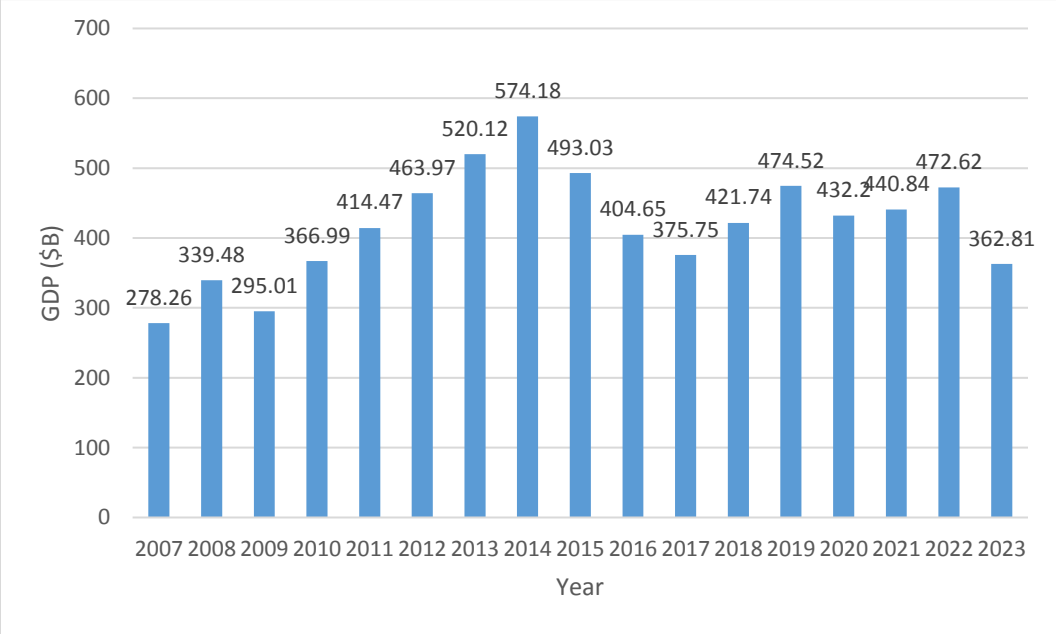

Fig 3: Nigeria GDP from 2007 to 2023 (World Bank, 2025)

When compared with Fig. 2, a similar trend could be deduced. GDP grew with increase in port vessel traffic, and vice versa. The years 2016, 2017, 2018 and 2020 in Fig. 2 were marked with relatively low vessel traffic, which coincided with same periods in Fig. 3 where lower GDP growths were recorded. This is, therefore, a clear pointer to the fact that maritime trade contributes to economic growth.

Maritime insecurity has a profound and adverse effect on the cost of international trade. In regions where piracy and related threats are prevalent, trade routes are often rerouted, maritime insurance premiums rise, and cargo shippers opt for alternative, often more expensive, ports to ensure the safety of their goods (Anyanwu, Melvin, Obasi, Ogola & Ogwo, 2022). In 2020 alone, the financial burden of piracy in affected areas was estimated

to exceed $1.1 billion, a sum that could have been directed toward infrastructure, social services, or other developmental priorities (Sackey et al., 2022).

The economic implications of maritime insecurity for Nigeria are particularly severe due to the country's reliance on maritime trade. Olugbenga Oyewole, former Senior Special Assistant to President Goodluck Jonathan on Maritime Services, warned in a February 2013 Daily Independent interview that if Nigeria continued to be rated among the most insecure maritime nations globally, it would trigger a resurgence in insurance surcharges, with the costs being passed down to consumers through higher prices (Oyewole, as cited in Daily Independent, 2013). At the time, Nigerians were reportedly paying an estimated $15 million daily on imports—a cost exacerbated by the imposition of high-risk insurance premiums due to the unsafe reputation of Nigerian waters (Obi, 2013).

Although the Nigerian Bureau of Statistics has not published exact figures on War Risk Insurance expenditures, estimates suggest that the country has spent over $1.5 billion in just the past three years on premiums paid to major international insurance firms such as Lloyd's of London, Protection and Indemnity (P&I) Clubs, and other insurers (Egole, 2025). This financial drain represents a major economic consequence of maritime insecurity and underscores the urgent need for comprehensive and effective measures to safeguard Nigeria's maritime domain and reduce the cost of doing business.

Recent Trends of Maritime Insecurity in Nigeria and the Gulf of Guinea

Maritime security challenges are inherently transnational and cannot be effectively addressed by a single nation, regardless of its capacity or strategic resources. The nature of maritime threats—spanning piracy, smuggling, illegal fishing, and transnational organized crime—demands collaborative international efforts for meaningful containment. Jamoh (2021) emphasizes that collective action among affected and neighboring states is indispensable for combating such threats. A fitting parallel can be drawn from Nigeria's counter-insurgency operations in the North-East, where initial unilateral efforts yielded limited results. It was not until the formation of a multinational joint task force involving Chad and Cameroon that the security situation began to stabilize. This experience underscores the necessity of regional alliances in tackling border-transcending threats.

In response to maritime security challenges, various multilevel initiatives have been launched involving local, regional, and global actors. These interventions range from legislative enforcement under frameworks such as the Yaoundé Code of Conduct to strategic cooperation in capacity building, financial assistance, and technological enhancement (Sackey et al., 2022). In addition, attention is increasingly being drawn to lesser-publicized maritime crimes such as illegal, unreported, and unregulated (IUU) fishing, which has significantly contributed to the depletion of fish stocks in the Gulf of Guinea region (Sackey et al., 2022). Policy responses have thus expanded beyond traditional piracy and armed robbery to include broader ecological and economic threats in the maritime domain.

One of the most significant national efforts in recent years is Nigeria's establishment of the Deep Blue Project (DBP) through the Nigerian Maritime Administration and Safety Agency (NIMASA). The DBP was designed to enhance maritime security, with a specific focus on deterring piracy, sea robbery, and other illegal maritime activities within

Nigeria's territorial waters and the broader Gulf of Guinea. Central to the DBP is the coordination of inter-agency operations and intelligence-sharing frameworks among Gulf of Guinea nations to address maritime threats collectively. Since its launch, the project has recorded notable successes. For instance, data from the International Maritime Bureau (IMB) in its 2021 trend analysis (see Fig. 4) revealed a significant decline in reported piracy and armed robbery incidents in Nigerian waters, suggesting that criminal activities may be shifting away from areas secured by the DBP.

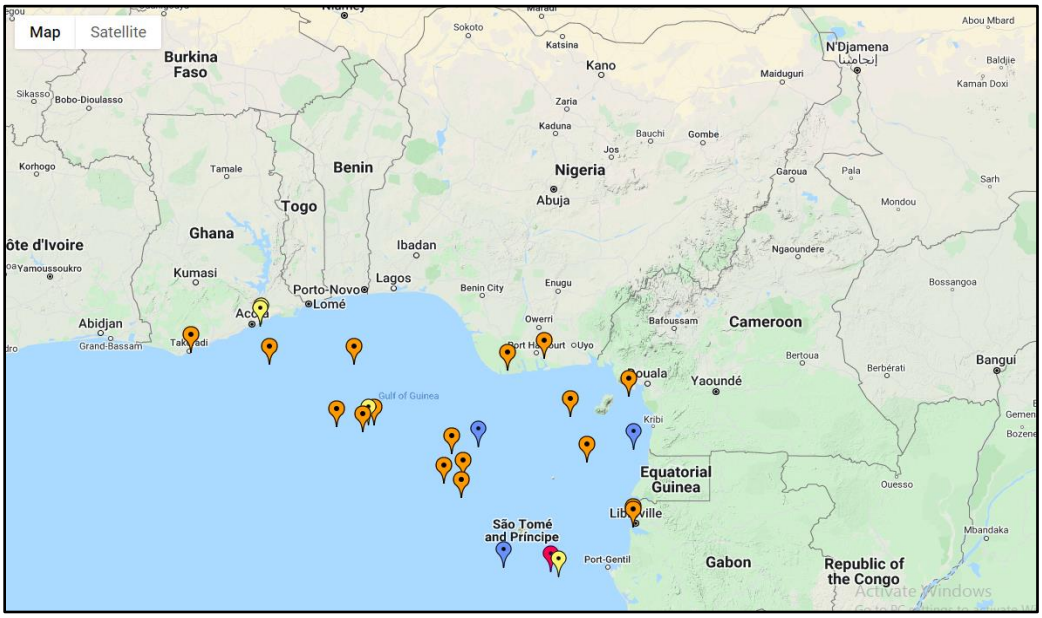

Fig. 4: IMB Piracy & Armed Robbery Map, 2021 (IMB, 2022)

= Attempted Attack = Boarded = Fired upon = Hijacked = Suspicious vessel

According to the International Maritime Bureau's (IMB) 2021 global piracy report, there were 68 recorded cases of piracy and armed robbery against ships—a significant decline from the 98 incidents reported during the same period in 2020, marking the lowest figure since 1994. During the first half of 2021, the IMB's Piracy Reporting Centre (PRC) documented 61 cases of vessels being boarded, along with four attempted attacks, two incidents involving gunfire, and one hijacking.

Although the overall number of incidents decreased, threats to crew safety remained a serious concern. In the first six months of the year, 50 crew members were kidnapped, while three were taken hostage, three threatened, two assaulted, one injured, and one killed. Despite the encouraging drop in overall figures, the IMB PRC warned that the maritime industry must remain vigilant, noting that boarding occurred in 91% of reported cases (IMB, 2022).

Meanwhile, in 2021, the Deep Blue Project's marine assets began to secure the Lagos mooring area through operational patrols. Data from the beginning of the year to date suggests significant changes in piracy trends in comparison to previous years. Since the

beginning of 2021, 6 piracy events have taken place in Nigerian waters. This represents an over 60% decrease in piracy events in Nigerian waters. It has been reported that between the years 2019-2020, piracy attacks occurred near the coast and there were a lot of piracy incidents in Lagos Port Waiting Area, compared to 2021 when there was no record of such incidents. In addition, it has been also reported that during the years 2019-2020 there were a lot of piracy incidents near the coast of the "Niger Delta" area, gas and crude oil terminals. That means the attacks seem to come from this area.

It is important to note that the piracy attacks that occurred in Nigerian waters in 2021 occurred in blue water areas far from the Nigeria Coast, except for only one incident that occurred within a port or port waiting area. The remainder of the events took place on maritime borders within Nigeria and internal waters and the joint regime area where enforcement and prevention present more challenges (Sanni, 2022).

In the past three years (Q1 2022 to Q1 2025), Nigeria has consistently maintained a zero piracy record, a significant achievement that underscores the effectiveness of enhanced maritime security measures and strategic policy interventions (Ubanna, 2025). This milestone has positioned Nigeria's waters as one of the safest for maritime trade and investment, fostering increased confidence among local and international stakeholders. The sustained efforts of agencies such as the Nigerian Maritime Administration and Safety Agency (NIMASA), alongside collaborations with regional and global partners, have played a crucial role in ensuring the security of the country's maritime domain. As a result, Nigeria's shipping and offshore activities continue to thrive, driving economic growth and reinforcing the nation's status as a key player in the global maritime industry.

Contemporary Efforts towards Sustaining Maritime Security in Nigeria

Recent global and national initiatives to combat maritime insecurity have begun to show promising outcomes. The Nigerian Maritime Administration and Safety Agency (NIMASA, 2022) highlighted that the International Maritime Bureau (IMB), in its mid-year 2022 report, commended the worldwide decline in piracy and described it as a hopeful turning point for the international shipping industry. This recognition followed the Bureau's recording of the lowest number of piracy incidents since 1994, attributing the progress to sustained awareness campaigns aimed at enhancing maritime safety.

Jamoh (2022) emphasized that this positive trend is largely the result of collaborative efforts among local, regional, and international stakeholders. Notably, the Gulf of Guinea Declaration on the Suppression of Piracy reported zero cases of seafarer abduction one year after its adoption in May 2021—a remarkable improvement compared to 2020, when 130 seafarers were kidnapped. The declaration's status update further noted that no incidents of kidnap-for-ransom were reported in 2022, down from 20 in 2020 and 12 in 2021 (Tribune Online, 2022). The overarching objective remains to maintain this progress, with expectations that Nigeria will eventually benefit through reduced insurance costs on cargo bound for its ports and potential adjustments to the current War Risk premium (Jamoh, 2022).

Below is a live map showing all piracy and armed robbery incidents reported to IMB Piracy Reporting Centre during 2025.

Fig. 5: IMB Piracy Map 2025 (IMB, 2025)

A highlight of recent maritime attacks in the Gulf of Guinea indicates a shift away from Nigerian Waters. Between Q1 2022 and Q1 2025, no incidence of piracy has been recorded in the Nigerian waters. However, some neighboring countries do not share similar testimony. Most of the recently recorded attacks took place in Equatorial Guinea, Ivory Coast and Ghana.

It is important to note that there has been a resurgence in the incidents of piracy and armed robbery in some Gulf of Guinea countries in 2024. On January 1, 2024, pirates attacked the Hana 1, a small chemical tanker sailing through the waters of Equatorial Guinea and kidnapped nine (9) crew members. Also, the IMB third quarter (Q3) 2024 Piracy Report highlighted that twelve (12) incidents were reported in the Gulf of Guinea region from January to September 2024, with eleven (11) crew members kidnapped and twenty-one (21) taken hostage (Williams, 2024). Most recently, on March 27th, 2025, a Ghana-flagged fishing vessel Mengxin 1 was attacked off the coast of Accra, and three Chinese crew members kidnapped. This shift from Nigerian waters may be attributed to measures which have been put in place to prevent such attacks.

Current efforts to combat maritime insecurity in Nigeria are multifaceted, involving both national and international strategies. Notably, the Nigerian Navy has taken proactive steps by dismantling pirate camps, while the Deep Blue Project's C4i coastal surveillance system and partnerships with foreign naval forces have bolstered law enforcement capabilities beyond Nigerian territorial waters. Key regional initiatives such as the Gulf of Guinea Maritime Coordination Forum/Shared Awareness and Deconfliction (GoG/SHADE) have also played a crucial role in improving maritime safety in the region.

Olufowobi (2022) highlighted Nigeria's pioneering role in addressing maritime threats in the Gulf of Guinea. He noted that Nigeria's regional engagement led to the formation of frameworks such as the ECOWAS Integrated Maritime Security Strategy (EIMS), the Inter-Regional Coordination Centre (ICC) in Yaoundé, and the African Integrated Maritime Strategy (AIMS) (Osamgbi, 2019). At the national level, the enactment of the

Suppression of Piracy and Other Maritime Offences (SPOMO) Act on 24 June 2019, signed into law by President Buhari, marked a significant milestone. This legislation provides a legal basis for prosecuting maritime crimes and aligns with the International Maritime Organization's call for distinct anti-piracy laws.

NIMASA (2021) further outlined several initiatives aimed at strengthening maritime security. These include the implementation of the Deep Blue Project, active community engagement, the empowerment of regional navies, and cooperation with various security agencies and maritime industry stakeholders through bodies like the Joint Maritime Industry Working Group (JMIWG) and GoG-MCF/SHADE. NIMASA is also working in concert with international institutions such as the IMO, INTERPOL, private security firms, submarine cable operators, and seafarer organizations.

Olufowobi (2022) also emphasized the leadership of the Nigerian Navy in fostering interagency and international cooperation. Bilateral and multilateral engagements have led to the development of the Harmonized Standard Operating Procedure (HSOP), which aims to address coordination gaps among Maritime Law Enforcement Agencies (MLEAs). Additionally, a memorandum of understanding signed among the Naval Chiefs of Nigeria, Benin, Togo, and Niger under the Multi-National Maritime Coordination Centre (MMCC) for Zone E has facilitated joint maritime and aerial patrols, as well as the real-time sharing of intelligence. These efforts have contributed to a reported 50% reduction in piracy incidents between the first quarters of 2018 and 2019.

Despite these achievements, several challenges persist. Olufowobi (2022) pointed out that many of the commitments under the Yaoundé Declaration remain largely symbolic, hindered by insufficient funding, personnel shortages, equipment gaps, and uncoordinated communication systems. Moreover, several member states have yet to implement core aspects of the Code of Conduct, including the establishment of national maritime security strategies, dedicated security committees, and the designation of national focal points. To address these gaps, it is recommended that steps be taken to make the Code legally binding and operationally enforceable.

Conclusion

The fact that Nigeria is blessed with abundant natural resources calls for a robust transport sector which supports export, as the country stands to benefit hugely from international trade if it gets it right in the maritime sector. There is no doubt that the national security issues which recently abound in the country affects economic activities across land and water. While efforts are on ground by contemporary government to address security issues across various parts of the country, investments are also obviously on ground to make the coastal space safe for navigation. Coming at a time when Nigeria needs economic revival and diversification, investments in maritime security deserves to stand out as a priority. It is only when this is achieved and sustained that there will be a free flow of local and international trade within and around the Nigerian maritime domain. The multiplier effect from investments in maritime security covers a wide range of economic growth and development indicators such as increase in employment, improvement in revenue generation by government agencies such as NPA, NIMASA which also culminates to increase in remittance of operating surplus to the Consolidated Revenue Fund (CRF), and

so on. As such, contemporary maritime security initiatives of the Nigerian government such as the Deep Blue project and the SPOMO Act, are steps in the right direction, especially considering the recent successes recorded in addressing the spate of piracy and other maritime crimes within the Nigerian EEZ and the Gulf of Guinea. The sustenance of such local and a number of other regional and international initiatives will, no doubt, culminate in a notable economic prosperity for coastal nations like Nigeria.

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MARITIME SAFETY COMMUNICATION AND RISK MANAGEMENT PRACTICES AMONG BOAT OPERATORS, STAFF AND STUDENTS OF NIGERIA MARITIME UNIVERSITY

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Abstract
This quantitative study highlights the importance of enhancing safety communication and risk management practices among boat operators, staff and students of the Nigeria Maritime University, Okerenkoko, Delta State, Nigeria. The research objectives are to investigate the most prevalent safety hazards within inland water way transportation, examine safety communication and risk management approaches and highlight strategies for risk prevention on maritime assets. The study employs a quantitative approach, relying on questionnaire as the research instrument. The sample comprises 120 boat operators, staff and students of Nigeria Maritime University and the data were analysed using SPSS. Results indicate lack of commitment to safety culture and compliance with IMO-STCW standards. The findings of the study show that the use of incompetent boat operators was the most prevailing maritime hazard in the study area. The study highlights the importance of safety communication, culture, regulatory compliance and professionalism for ensuring the safety, competence and sustainability of maritime operations.

Keywords: Maritime, Safety, Communication, Risk, Management, Practices

1.0 Introduction

Transportation is one of the most important catalysts for socio-economic development of any place (Akali and Idoko 2010). The developments in transportation and improvements in the various modes of same have an impact on not only economic and socio-cultural activities but also play a major role in spatial organisation and ordering globally. Inland Waterways Transport (IWT) is the movement of people and goods along inland waterways (Fellinda, 2006; Obeta, 2014). Nigeria, being a coastal nation is endowed with a large stretch of inland navigable waters stretching over 10,000 km. The navigable inland water comprises rivers, lakes, lagoons, creeks and intracoastal waters (Aderemo and Mogaji, 2010). Inland water transportation provides a cost-effective, logistically efficient and environment-friendly mode of transport which developed as a supplementary mode would enable diversion of traffic from over-congested roads and railways, contribute to economic and social development (Ojile, 2006; Obeta 2014). Despite potential in the

nation's inland waterways, the sector has been regarded as one of the most dangerous in Nigeria owing to problems of sea piracy and alike. Sea piracy is presently very common, hence, leading to loss of life and properties. Its effects cause huge economic and commercial losses to communities, local government areas, states and Nigeria as a nation (Obeta, 2014). Hence, the study underscores the importance of safety communication and risk management in inland water transportation in the study area.

Moreover, Marine radio was first installed on ships around the turn of the 20th century. In those early days, radio was used primarily for transmission and reception of passenger telegrams. The disaster of *RMS Titanic* brought about a number of fundamental changes to maritime safety communication (Korez, 2016). Communication is extremely important in inland transportation systems. Proper communication ensures safety of the operators, commuters and the environment they operate. It is therefore of utmost importance for every operator to be able to engage in maritime safety communication with one another while on board and understand the limitations of communication.

Maritime safety and risk management are crucial components of maritime operations, ensuring the protection of lives, vessels and the environment while maintaining operational efficiency (Balkin, 2006; Berg, 2013). As the maritime industry evolves in response to technological advancements, environmental concerns and regulatory frameworks, the importance of effective safety and risk management practices becomes increasingly significant. In this context, exploring maritime safety and risk management practices becomes a relevant area of research, aiming to enhance understanding and inform best practices within the industry (Agrifoglio et al., 2017; Karahalios, 2014).

This quantitative research aims to delve into the practices and perspectives surrounding maritime safety communication and risk management among 120 operators, staff and students of Nigeria Maritime University. By focusing on their experiences and insights, this study seeks to shed light on the nuances of maritime safety communication and risk management within the context of maritime education (Kidd and McCarthy, 2019; Mallam, 2019). Through quantitative analysis, the research aims to offer insights into the efficacy of safety communication and protocols, risk mitigation strategies and regulatory compliance measures employed by operators, staff and students of Nigeria Maritime University. By examining the perspectives of operators, staff and students of Nigeria Maritime University, who possess practical experience and theoretical knowledge, this research aims to contribute to the ongoing discourse on maritime safety communication and risk management.

2.0 Statement of the Problem

This research stems from the imperative to enhance safety standards and mitigate risks within the study area. Despite advancements in technology and regulatory frameworks, there are still cases of loss of lives in our water ways occasioned by human factors, boat accidents, piracy, among others. The study becomes important as there is a dearth of literature in the area. Consequently, there exists a pressing need to continually assess and improve safety and risk management practices to safeguard the interests of all stakeholders involved (Hänninen et al., 2014; Thomas and Peterson, 2016). This is the gap the study aims to bridge.

3.0 Research Objectives

The study seeks to:

1. Ascertain the most prevailing Safety hazard within the inland water ways in the study area;
2. Determine the safety communication and risk management approaches among operators, staff and students of Nigeria Maritime University.
3. Highlight strategies for risk prevention on maritime assets in the study area.

4.0 Research Questions

The research questions derived from the objectives are as follows:

1. What is the most prevailing safety hazard within the inland waterway in the study area?
2. What are the safety communications and risk management approaches among operators, staff and students of Nigeria Maritime University?
3. What strategies are to be adopted in risk prevention on maritime assets in the study area?

5.0 Operational Definition of Terms

The following are terms used in the research work:

Maritime Safety: Maritime safety is the protection of people, property and the environment from hazards such as injuries, accident and fatalities along Warri/Okerenkoko navigable water ways in Warri South West Local Government Area of Delta State.

Safety Communication: Safety communication is basically the process of communicating different hazards and risks within the inland water ways among operators, staff and students of Nigeria Maritime University.

Risk Management: Risk management is the process of indentifying, assessing and reducing the impact of potential threats or uncertainty faced by Nigeria Maritime University Community.

Boat Operators: Boat operators are those who drive boats for commercial purposes to and from Warri/Okerenkoko and ensure the safety of all passengers on board.

Staff: Staff denotes all the people employed by the Nigeria Maritime University who travel via Warri/Okerenkoko inland water ways.

Students: Students are young ones who are studying one course of study or the other at the Nigeria Maritime University.

6.0 Literature review

Maritime safety and risk management are integral components of the global maritime industry, ensuring the protection of human lives, vessels and the marine environment (Utne, Sørensen and Schjølberg, 2017). As the maritime sector continues to expand and evolve, the need for effective safety protocols and risk mitigation strategies becomes increasingly important. One of the foundational principles underpinning maritime

safety is the International Maritime Organization's (IMO) regulatory framework, particularly the Standards of Training, Certification and Watchkeeping (STCW) convention (Young, 1995). Established to standardise training and certification requirements for seafarers worldwide, the STCW convention sets forth guidelines for competency-based training, ensuring that maritime professionals possess the necessary skills and knowledge to operate safely at sea. Compliance with STCW standards is crucial for maritime institutions and practitioners, as it fosters a culture of safety and professionalism within the industry (de la Peña Zarzuelo et al., 2020).

Risk management, on the other hand, entails the identification, assessment, and mitigation of potential hazards and threats within maritime operations. Risk management frameworks, such as the International Safety Management (ISM) Code, provide guidelines for establishing systematic approaches to risk assessment and control (Bhattacharya, 2012). By implementing proactive risk management strategies, maritime stakeholders can mitigate the likelihood and severity of accidents, thereby safeguarding lives, assets and the environment (Batalden and Sydnes, 2014). Human factors constitute a significant aspect of maritime safety and risk management, as human error remains a leading cause of maritime accidents. Crew competency, communication, fatigue management and decision-making skills all influence the safety performance of maritime operations. Human-centred approaches to safety, such as Crew Resource Management (CRM) and Bridge Resource Management (BRM), seek to enhance situational awareness, teamwork, and decision-making abilities among crew members, thereby reducing the risk of errors and accidents at sea (Ghosh et al., 2014).

Furthermore, technological advancements have revolutionized maritime safety and risk management practices, offering innovative solutions for enhancing operational efficiency and safety. Automation, remote monitoring systems, predictive analytics, and artificial intelligence are increasingly being deployed to identify and mitigate risks in real-time. Integrated bridge systems, collision avoidance technologies and vessel traffic management systems contribute to safer navigation and collision avoidance, particularly in congested waterways and adverse weather conditions. Environmental sustainability is another critical consideration within maritime safety and risk management frameworks. Pollution prevention measures, such as ballast water management, oil spill response and emissions reduction initiatives, aim to mitigate the environmental impact of maritime activities (House and Saeed, 2016). Regulatory frameworks, such as the International Convention for the Prevention of Pollution from Ships (MARPOL), impose strict guidelines on vessel operations to minimise pollution and protect marine ecosystems.

In addition to regulatory compliance and technological innovations, organisational culture plays a crucial role in shaping safety performance within maritime enterprises. Safety culture encompasses attitudes, values, and behaviours related to safety within an organisation, influencing decision-making processes and risk management practices. A strong safety culture fosters open communication, proactive hazard reporting and continuous improvement, creating an environment where safety is prioritised at all levels of the organisation. Overall, the literature on maritime safety and risk management underscores the multifaceted nature of the subject, encompassing regulatory compliance,

human factors, technological innovations, environmental sustainability and organisational culture.

Ademiluyi, Afolabi & Fashola (2016) in their study "Analysis of intra-city transportation in Lagos state" which was necessitated by the regular traffic congestion usually experienced in Lagos state metropolis daily, used primary and secondary data with descriptive statistics such as percentages to present analysed results. Spearman's correlation was used to analyse the relationships between different factors, like frequency of using the water ways for transportation, educational level and income category of the respondents. The findings from the study showed that more than 58% of the sampled population acknowledged that they use the water transportation daily. While more than half of the respondents (52%) opined that the state of the water transportation system was very bad. The study revealed the following; poor jetty and ferries construction, poor safety and security management, exorbitant transport fares. The researchers recommended that there is an important need for more researches to be conducted in the area to enhance the development of operational techniques and encourage the use of technology to ensure safety of commuters, operators and water transportation infrastructures in the state.

The question on the lips of many transport industry operators is "when will the inland waterways system be developed in Nigeria?". Across the country, the potentials of this sub-sector have remained untapped. The study therefore seeks to evaluate the prevalent safety hazards and the safety practices in the inland water transportation sector in the study area. By synthesising key concepts and research findings from diverse disciplines, the literature review provides a holistic understanding of the challenges and opportunities inherent in ensuring safety and mitigating risks within the inland water ways in the study area. Moving forward, further research is needed to explore emerging trends, best practices and novel approaches to maritime safety and risk management, thereby fostering continuous improvement and innovation within the industry.

7.0 Method

Given the research objectives and questions, this study used the survey research approach which involves the use of the questionnaire. This method became necessary because it allowed the researchers to examine the inter-relationship among variables and help to develop explanatory inference. For purposes of gathering primary data, the target population for the study included boat operators, staff and students of Nigeria Maritime University, Okerenkoko, Delta State, Nigeria, The justification for this population is that the researcher felt that those who make up the population are those who frequently use the inland water ways in the study area (Celik and Cebi, 2009; Tzannatos, 2010; Progoulaki and Roe, 2011).

Copies of questionnaire were administered using the simple random sampling technique, a type of probability sampling in selecting a total of 120 from among boat operators, staff and students of the Nigeria Maritime University. In other words, 40 respondents were investigated in each of the three categories. In view of the fact that the research is a quantitative type, the structured questionnaire was used in the collection of data. The questionnaire consists of closed–ended questions using a 3-point Likert scale (Strongly Agree, Agree and Disagree) to present the problem. The study made use of

questionnaire and was administered by the researcher/Research Assistants to all the study respondents. The questionnaire used for the study was designed and structured to reflect the objectives of the study. The research instrument was subjected to face and content validation. This was necessitated by the need for the items on the instrument to appear valid and logically linked to the study objectives, while also covering the full range of the issues concerning maritime transportation safety management. The study utilised the frequency counts and percentages. These tests were carried out on the SPSS statistical software (version 23).

8.0 Data Presentation

Table 1: The most Prevalent Safety hazards within the inland waterway transportation in Nigeria

Categories	Frequency	Percentage (%)
Incompetent operators & poor safety management	64	53.3
Piracy	38	31.7
Water hyacinth & waste materials	18	15
Total	120	100

Field Study, 1st February, 2025

The responses indicate that as many as 53.3% of respondents indicate that incompetent boat operators and poor safety management are responsible for safety hazards within the inland water ways transportation in Nigeria. The second highest ranking constitutes 31.7%. Water hyacinth and waste materials constitutes 15%.

Table 2: Safety communication and risk management approaches

Categories	Frequency	Percentage (%)
Daily safety orientation to boat operators/commuters	68	56.7
Seminar	43	35.8
Media	09	7.5
Total	120	100

Field Study, 1st February, 2025

The question queries safety communication and risk management approaches as regulatory framework for boat operations in the study area. It is evident from table 2 that 56.7% of respondents indicated that daily safety orientation to boats operators and commuters is the best safety communication and risk management approach. Seminar which is second on the table has 35.8% while media constitutes 7.5%.

Table 3: Strategies for risk prevention on maritime assets

Categories	Frequency	Percentage
Safety education to boat operators	55	46
Regular maintenance of safety equipment	48	40
Security measures against piracy	17	14
Total	120	100

Field Study, 1st February, 2025

The question centres on strategies for risk prevention on maritime assets. Responses in table 3 show that safety education to boat operators is top on the table with 46%. Those who believe regular maintenance of safety equipment as a sine qua non for prevention of risk on maritime asserts constitutes 40% while security against piracy constitutes 14%.

9.0 Discussion of Findings

This study showed that the inland water transportation system in the study area is being bedeviled by a wide range of maritime safety hazards including use of incompetent boat operators and poor safety management, presence of waste materials (plastic materials) and water hyacinths on water ways, piracy, among others. These hazards have affected lives, growth and development of the inland waterways along Warri/Okerenkoko inland water ways in Warri South West Local Government Area of Delta State where the Nigeria Maritime University is located. These findings corroborate that of Victor (2014) to the effect that boat operators and water hyacinth are responsible for safety hazards in our territorial waters. These lead to accidents, especially when compounded by inadequate signs along major navigational routes. Ezenwaji, 2010; Obed, 2013; Obeta, 2014 in their studies stressed that poor waterway signs lead to many accidents due to navigational disruption. These findings are consistent with the findings of the National Inland Waterways Authority (NIWA, 2010) [23]; Obed (2013); and Obeta (2014), but disagree with the findings of Akogun (2014), which suggested that boat operation could be learned as a craft and not only through academic qualification.

On research question 2 that has to do with safety communication and risk management approaches, participants agreed that daily safety orientation to boat operators and commuters is the best safety communication and risk management practice. The disaster of *RMS Titanic* brought about a number of fundamental changes to maritime safety communication (Korez, 2016). Communication is extremely important in inland transportation system. Proper communication ensures safety of the operators, commuters and the environment they operate. It is therefore of utmost importance for every operator to be able to engage in maritime safety communication with one another while on board and understand the limitations of communication. Further increase of the safety and security of inland transportation can only be achieved by implementing daily safety orientation to boat operators/commuters, organizing seminar for boat operators and media outreach.

On research question 3 with respect to strategies for risk prevention on maritime assets, the study identified safety practices that when adopted could lead to risk prevention on maritime assets. They include security measures against piracy, regular maintenance of safety equipment and compliance to established safety code of conduct in jetties such as adherence to drug and alcohol policy, safety briefs before take-off and also ensure that personal floatation devices (life jacket) are adequately provided and properly worn. Non-adherence to these safety practices is responsible for the high incident rate in maritime transport.

10. Conclusion

This study has provided valuable insights into maritime safety communication and risk management practices within the inland water ways in the study area. The study concluded that the level of operators' safety awareness, safety communication and risk management skills and other safety best practices affect marine safety. Moreover, one of the issues that has militated against inland water transportation in Nigeria is inadequate regulations and policing. This has resulted in increased safety and security risk, poor maritime infrastructural development, non-compliance to international maritime safety codes and procedures and poor safety practices.

11. Recommendations

Based on the findings of the research, several recommendations are made to enhance safety communication and risk management practices within the maritime industry as it affects operators, staff and students of Nigeria Maritime University, Okerenkoko, Delta State. They are as follows:

(1) Relevant authorities within and outside Nigeria Maritime University should ensure provision of competent and trained boat operators and coastal guards, aquatic lifesavers, fire wardens/fighters, safety briefing halls for passengers, personal floatation device (PFD) and lifesaving appliances at beaches and jetties to prevent maritime incidents and emergencies.

(2) Stakeholders in the maritime sector within the study area should prioritise building a strong safety culture by fostering open communication and empowering staff and students to actively participate in safety initiatives.

(3) There should be a sensitization and enlightenment campaign of waterfront-dwellers on the effects of dumping of waste materials in water.

(4) There should be continuous sensitisation and enlightenment campaign programmes for all stakeholders including boats owners, operators, commuters, waterfront dwellers, regulators, etc., on safe operations within the inland waterways in the study area to eliminate loss of lives and properties.

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ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT DUE TO HEAVY METAL POLLUTION OF BANDA & KABAWA FARMING AREAS IN LOKOJA, KOGI STATE NIGERIA

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Abstract

Agricultural sources of heavy metals from time immemorial are known to leave a negative impact on soil as well as polluting the entire food chain system. This study evaluates the environmental and health impact of heavy metal contamination on soils of Banda and Kabawa farming areas within Lokoja metropolis. Experimental research design and stratified sampling technique was used for the study. Soil samples were collected in wet and dry seasons. All samples were analyzed for heavy metals (Nickel (Ni), Iron (Fe), Lead (Pb), Copper (Cu), Chromium (Cr), Zinc (Zn) and Cadmium (Cd)) using Atomic Absorption Spectrophotometry (AAS). Findings from the study reveal that the mean concentration values in the soils were mostly in the decreasing order: Fe(17.6-65.6)>Zn(11.1-41.4)>Pb(4.7-18.2)>Cr(4.4-16.5)>Ni(2.3-16.0)>Cd(0.7-2.6) >Cu(0.5-3.0) for both seasons but with higher concentration values noticed during the dry season in Kabawa farming area. All concentration values obtained from the study area were within NESREA permissible limits for agricultural soils. The ecological risk of exposure as revealed by PERI for all sample locations indicated PERI<110 which implies low ecological risk of biological impairment arising from the toxic effect of the heavy metals in both dry and wet seasons. In estimating the human health risk of exposure to heavy metals, the HI<1 which implies that there was no non-carcinogenic risks of exposure to the heavy metals associated with contact and ingestion of the soil. Thus, continuous environmental monitoring is required in the study area in order to avert potential environmental and health issues.

Keywords: ecology, heavy metals, agriculture, pollution, health risk

1.0 Introduction

Heavy metal contamination of agricultural lands has gain wide global attention in recent times (Rashid *et al.,* 2023). It is more pronounced in developing countries where there are poor farming knowledge, techniques and lack of basic facilities, likewise some studies have attribute it's accumulation to rapid migration to urban centers and also increased industrialization (Matsumoto *et al.,* 2019). The presence of heavy metals in the soil calls for urgent intervention. These metals find their way into the soil through several means such as: application of chemicals to eradicate farm pest or household pest, fertilizers and pesticides applications, uncontrolled waste disposal on farmlands, These elements have become more mobilized in the environment and their biogeochemical cycles have been disrupted as a result of mining and industrial processing for the extraction of mineral resources and their subsequent applications for industrial, agricultural, and economic

development (Ali *et al.,* 2019). Numerous pollutants have contaminated soil and groundwater resulting from industrial, agricultural, and municipal activities (Rashid, *et al.,* 2023, Alengebawy *et al.,* 2021, Singh *et al.,* 2023, Srivastava *et al.,* 2017, Jain *et al.,* 2023). As they leak out of the dump sites, heavy metals including Cd, Ni, Cu, Pb, As, Cr, Sn, Zn and others wind up in the soil as sinks (He *et al,* 2024). As a result of these activities, dangerous heavy metals have accumulated in ecosystems, endangering both the environment and human health (Singh, 2022). Consumption of food contaminated with heavy metals is the main route for human exposure to these metals (Almad *et al.,* 2021; Alengebawy *et al.,* 2021).

The transfer chain from the polluted lands can induce biological toxicity given rise to long term health hazards to human through several exposure pathways such as ingestion, dermal contact or by inhalation (Toth *et al.,* 2016; Bwatanglang *et al.,* 2019). For instance, the findings of Li *et al.,* (2018) reported that heavy metals contracted from polluted farmlands were detected in many parts and blood samples of people residing in a polluted farmland. Heavy metals such as Arsenic (AS), Chromium (Cr), Copper (Cu) and Lead (Pb) were detected on the fingernails, hair and blood samples of people living on agricultural soil near Arsenic coal mining areas in Xingren county, Southwest China (Li *et al.,* 2018).

Banda-Kabawa area in Lokoja metropolis which is the focus of this study has attracted farming activities due to its large span of lands and the presence of river Niger in the area which is the major source of water. Different farm practices especially use of agrochemicals have been adopted to boost crop performance and productivity and also the use of chemicals to fish is the common practice of those residing in the area. Thus this study is aim at determining the concentration of heavy metals as well as evaluating its potential environmental and human health impacts within Banda and Kabawa farming areas in Lokoja.

The objectives of this study therefore are to:

(i) Measure the concentration of heavy metals in the soils of the study area
(ii) Determine the ecological risk of exposure to the heavy metals and
(iii) Estimate the human health risks of exposure to the heavy metals in the soils

2.0 Materials and Method

2.1 Study area

The study area, Banda and Kabawa farming areas and its environs are situated in Lokoja, north-central Nigeria, between latitude 7°46N to 7°53N and longitude 6°40E to 6°45E with a total land coverage of about 3179.7189 sq.km. Lokoja is situated in the Nigerian Precambrian Basement Complex, the Lower Benue sedimentary inland basin (Benue Trough), the Campanian-Maastrichian sedimentary Bida Basin, and the confluence of the Niger and Benue Rivers (Omada *et al.,* 2009). Rocks from the Precambrian basement complex, primarily gneiss and migmatite with older granite intrusions, make up the geology. Gneiss frequently exhibits mineral layering, with alternating zones rich in biotite and quartz-feldspar (Obaje, 2009).

The Banda and Kabawa farming areas are lowlands situated in Lokoja both bounded on the right-hand side by River Niger and Lokoja-Abuja expressway and Chief Olusegun Obasanjo road on the left-hand side respectively. Residents are predominantly farmers,

fisher men, traders and few civil servants. Because of their proximity to river Niger, they primarily engage in fishing and all year round farming. Most of the food crops (rice, corn, green vegetables, melon, pepper, tomatoes) and fish consumed in Kogi State and the neighbouring States come from these farming communities.

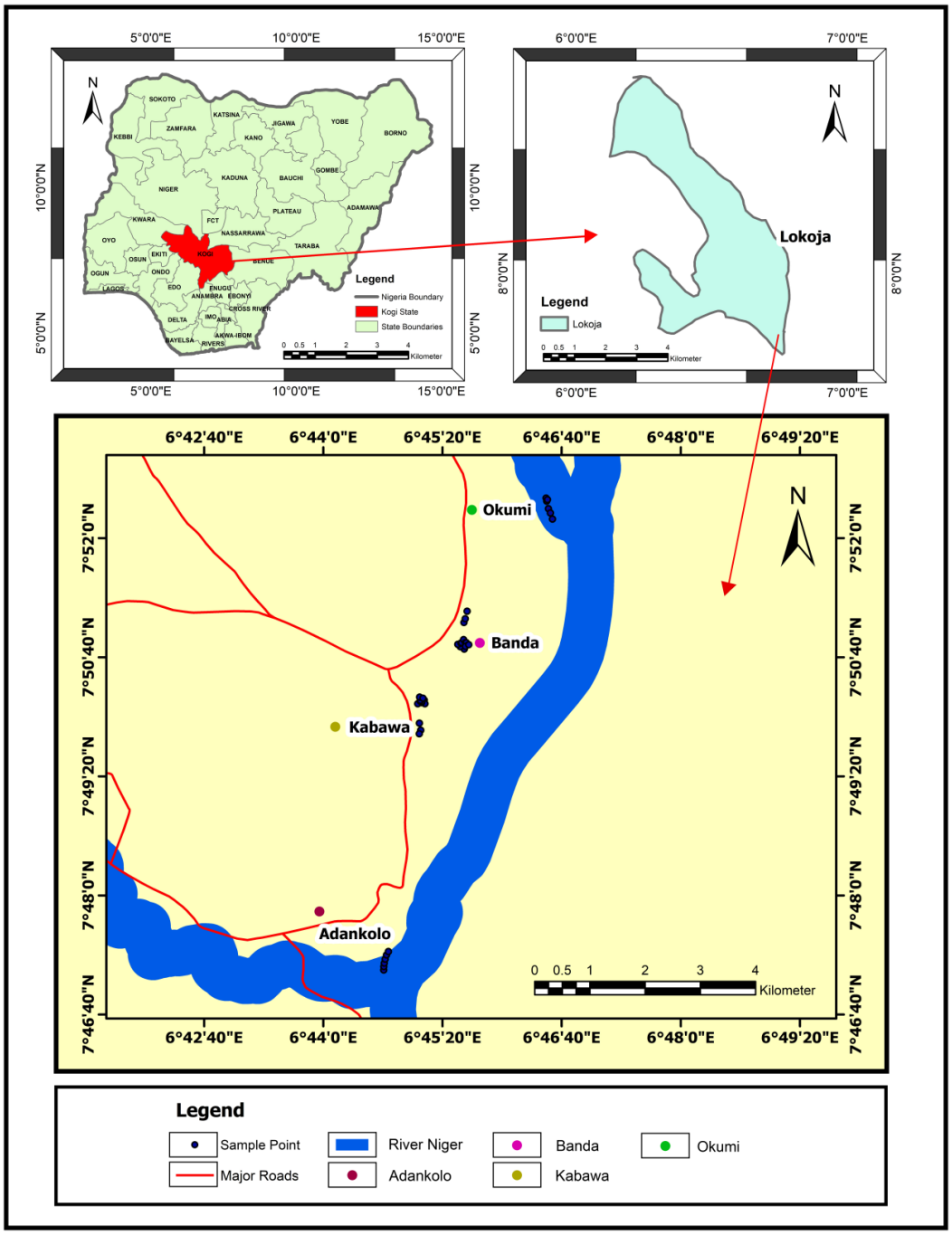

Figure 1: Map of Nigeria showing Kogi State and the study sampling points in Lokoja

2.2 Sample Collection

Sample collections were carried out in line with the methods described by Okechuwku *et al.,* (2022). The study adopted the experimental research design. Stratified sampling technique was used for the study and the farming location was divided into five strata. A stratum was further divided into 3 sub-strata and soil samples were collected from each to ensure that the sampling includes the diverse soil characteristics. Thus in all, thirty (30) soil samples were collected per week from the study area. The soil sampling exercise were replicated three times (three weeks) and each batch of sample collected per week was preserved in polyethylene bags and then sent to the laboratory for analysis.

2.3 Sample analysis

All soil samples were analyzed for heavy metals using Atomic Absorption Spectrophotometry (AAS). The results from the laboratory analysis were analyzed and presented using descriptive statistics as mean±SD. Concentration values of heavy metals obtained were used determine the Contamination factor (Cf) from which the potential ecological risk factor (PERF) as well as the potential ecological risk index (PERI) were derived to assess the ecological risk of exposure to heavy metals. Cancer Risk Index (CR) and Hazard Index (HI) were used to estimate carcinogenic and non-carcinogenic risks respectively.

3.0 Results

The concentration of the heavy metals in the soil of Banda (BS) and Kabawa (KS) farming area was monitored and values for both dry and wet seasons were presented as Mean±Standard deviation in table 1.0 and 2.0.

Table 1.0: Concentration of heavy metal during the Dry season

Location	Ni	Fe	Pb	Cu	Cr	Zn	Cd
BS 1	16±18	54±26.3	16±8.2	2±0.9	14±7.7	36±19.3	2±1.3
KS 1	9.5±7.4	65.6±52.6	18.2±14.6	1.9±1.5	16.5±13.3	41.4±33.4	2.6±2.1
NESREA	70	-	164	100	100	100	3

BS: Banda Soil KS: Kabawa Soil,

Table 2.0: Concentration of heavy metals during the Wet Season

Location	Ni	Fe	Pb	Cu	Cr	Zn	Cd
BS 2	5.7±4.1	38.8±27.8	10.7±7.7	1.1±0.8	9.8±7.0	24.5±17.5	1.5±1.2
KS 2	7.0±3.0	47.3±20.0	13.1±5.5	1.4±0.6	12.0±5.0	30.0±12.7	1.9±0.8
NESREA	70	-	164	100	100	100	3

BS: Banda Soil, KS: Kabawa Soil.

Contamination factor is thought to be a helpful instrument for tracking soil contamination over time. It is the proportion of each metal in the current sample to the metal's background values (Varol, 2011).

$Cf = C_{soil}/C_{background}$

(1)

Where:

C_{soil} = heavy metal mean concentration in the soil;

$C_{background}$ = heavy metal concentration in the background.

The background values used in this study are those reported by DPR (2002), Cd=0.8, Cr=100, Cu=36, Fe=20,000, Ni=47.3, Pb=83 and Zn=140

Table 3.0: Contamination factor of heavy metals during the dry season

Location	Cf_{Ni}	Cf_{Fe}	Cf_{Pb}	Cf_{Cu}	Cf_{Cr}	Cf_{Zn}	Cf_{Cd}
BS 1	0.412	0.003	0.161	0.052	0.193	0.181	2.341
KS 1	0.243	0.003	0.183	0.061	0.222	0.214	2.591

Table 4.0: Contamination factor of heavy metals during the wet season

Location	Cf_{Ni}	Cf_{Fe}	Cf_{Pb}	Cf_{Cu}	Cf_{Cr}	Cf_{Zn}	Cf_{Cd}
BS 2	0.080	0.002	0.124	0.029	0.093	0.167	1.823
KS 2	0.076	0.002	0,130	0.031	0.098	0,175	1.915

Potential Ecological Risk Index (PERI)

The ecological assessments of the soil as contaminated by heavy metals was achieved by potential ecological risk index (PERI).

The potential ecological risk factor (PERF) of each individual heavy metal was added up to arrive at the potential ecological risk index (PERI) of the heavy metals in the soils.

$PERF = Cf * TRC$ (2)

Where:

Cf = contamination factor.

TRC = toxic response coefficient for a given heavy metal. Cd = 30, Cu = 5, Ni= 5, Pb= 5, Cr =2, Zn = 1 (Hakanson, 1980). This study adopted the TRC reported in Hakanson (1980). The toxicity and ecological sensitivity of a heavy metal are truly indicated by its TRC; hence, the greater the coefficient, the more ecologically sensitive and hazardous the metal is (Spurgeon *et al.,* 2020).

$PERI = PERF_1 + PERF_2 + PERF_3 + \cdots PERF_n$ (3)

Table 5.0: Assessment Results of potential ecological risk index during the dry season

Location	$PERF_{Ni}$	$PERF_{Pb}$	$PERF_{Cu}$	$PERF_{Cr}$	$PERF_{Zn}$	$PERF_{Cd}$	PERI
BS 1	2.03	0.79	0.27	0.39	0.18	70.25	73.91
KS 1	1.19	0.91	0.31	0.44	0.21	77.56	80.61

BS: Banda Soil, KS: Kabawa Soil, SU.

Table 6.0: Assessment Results of potential ecological risk index during the wet season

Location	$PERF_{Ni}$	$PERF_{Pb}$	$PERF_{Cu}$	$PERF_{Cr}$	$PERF_{Zn}$	$PERF_{Cd}$	PERI
BS 2	0.71	0.54	0.18	0.26	0.12	45.86	47.68
KS 2	0.87	0.66	0.23	0.32	0.15	56.04	58.26

BS: Banda Soil, KS: Kabawa Soil.

Human Health Risk of Exposure to Heavy Metals in the Soil

The human health risk were evaluated by integrating the mean concentration of heavy metals in the farmlands soil to quantitatively estimate the likelihood of health hazard to the farmers through multiple exposure pathways (Sun and Chen, 2018)

Table 7.0 : Assessment Results of Cancer Risks of Exposure to Heavy Metals

Location	CRI
Dry season (soil)	
Banda	$9.8x10^{-6}$
Kabawa	$9x10^{-6}$
Wet Season (Soil)	
Banda week 1	$7.5x10^{-6}$
Banda week 2	$5.7x10^{-6}$
Banda week 3	$5.1x10^{-6}$
Kabawa week 1	$9.5x10^{-6}$
Kabawa week 2	$7.5x10^{-6}$
Kabawa week 3	$5.2*10^{-6}$

Table 8.0: Assessment Results of Non-Cancer Risks exposure to the heavy metals

Location	HI
Dry season (soil)	
Banda	0.01
Kabawa	0.009
Wet Season (Soil)	
Banda week 1	0.008
Banda week 2	0.006
Banda week 3	0.005
Kabawa week 1	0.01
Kabawa week 2	0.008
Kabawa week 3	0.0053

Carcinogenic Risk of Exposure to Heavy Metals

Carcinogenic Risk was assessed as described by Abdelhafez & Li (2015). The metals in soil and sediment samples from the study area was utilized in calculation of Carcinogenic Risk Index (CR), which depends on the daily intake of metals (DMI) and oral reference dose (estimated per day exposure of metal to human body that has no hazardous effect during life time, RFD). The exposure assessments methods for each metal were calculated by determination of Chemical Daily Intake (CDI), Dermal Absorbed Dose (DAD) and Exposure Concentration (EC) using the following equations according to USEPA (1992b):

$$CDI = \left(\frac{C * IngR}{BW}\right) * \left(\frac{EF * ED}{AT}\right) * Cf \ldots\ldots\ldots\ldots$$

$$DAD = \frac{\frac{C * SA * SL * ABS}{BW}}{\frac{EF * ED}{AT}} * Cf \ldots\ldots\ldots\ldots$$

$$EC\ inhalation = \left(\frac{C * EF * ED}{ATn}\right) * Cf(inh).$$

Where:
C: metal concentration in soil (µg/g), IR: ingestion rate per unit time (mg/day)
ED: exposure duration (years), EF: exposure frequency (days/year)
BW: humans body weight (Kg), AT: averaging time (days)
SA: surface area of contact (cm2)
SL: skin adherence factor (mg/cm2h)
ABS: absorption factor (unitless)
Cf: conversion factor (10- 6Kg/mg)
ATn: average time (hours), Cf(inh): conversion factor of $3.5 * 10^{-4}$

The carcinogenic risk (CR) caused by direct digestion and skin contact can be expressed as follows:
CR = CDI × CSF
where CSF represents the conversion slope factor of HMs .

Non-carcinogenic Risk of Exposure to Heavy Metals from Soil Ingestion and Skin Contact

To estimate the non-carcinogenic risks of exposure to heavy metals in the soil, the hazard quotient (HQ) and hazard index (HI) were employed (equation 4 and 5).

$HQ = D / RfD$ (4)

$HI = HQ_1 + HQ_2 + HQ_3 + HQ_4 + ...HQ_7$ (5)

where D = exposure dose; RfD = reference dose for the heavy metals; HQ_1 to HQ_7 are the hazard quotients for each of the heavy metals.

The equations for calculating the chronic exposure dose of the soils via entry routes like unintentional oral ingestion and dermal contacts, as well as definition of the terminologies used in the equations are according to Ugochukwu *et al.* (2018). Table 1 displays the values of the parameters used to calculate an adult's exposure dose to heavy metals in soils throughout a 35-year period of chronic exposure.

Table 9.0: Values of the parameters for determining exposure dose

Parameters	**Values**
IRS (soil ingestion rate)	0.02 g/day
EF (exposure frequency) 1 event per day	1
ET (exposure term)a	0.042
BW (body weight)	70 kg
Exposed skin surface area (hands) (SAH)	430 cm2
Exposed skin surface area (arms) (SAA)	890 cm2
Exposed skin surface area (legs) (SAL)	1690 cm2
Soil loading to skin hands (SLH)	1×10−4 g/cm2/event
Soil loading to skin arms and legs (SLA and SLL)	1×10−5 g/cm2/event
RAFgit	1
RAFskin	0.1
CF (unit correction factor)	0.001 L/cm

[a]Exposure term is assumed to be 1 h a day, 7 days a week, 52 weeks a year, exposure period of 35 years (Health Canada ,2010) .
ET=(1/24*7/7*52/52*35/35)=0.125

4.0 Discussion

4.1 Concentration of Heavy Metals in the Study Area

Findings from this study revealed the mean concentration values of soil was in the following order for Banda farming area: Fe(54)>Zn(36)>Pb(16)>Ni(16)>Cr(14)>Cd(2)>Cu(2), and for Kabawa farming area:
Fe(65.6)>Zn(41.4)>Pb(18.2)>Cr(16.5)>Ni(9.5)>Cd(2.6)>Cu(1.9)during the dry season.
The concentration of the heavy metals in the soil was highest at the Kabawa farming area during the dry season. Also, results from this study indicate the mean concentration values order for Banda farming area as
Fe(38.8)>Zn(24.5)>Pb(10.7)>Cr(9.8)>Ni(5.7)>Cd(1.5)>Cu(1.1) and Kabawa farming area Fe(47.3)>Zn(30)>Pb(13.1)>Cr(12.0)>Ni(7.0)>Cd(1.9)>Cu(1.4) during the wet season. In all

locations and both seasons, the concentration values recorded were within NESREA permissible limits with cadmium (Cd) showing tendency of pollution concern with values close to the limit. The concentration values obtained from this study are consistent with the findings of Okechukwu *et al.* (2022). It was also observed from the study that concentration values obtained from Kabawa farming area were generally higher than those obtained from Banda area signaling a higher rate of soil contamination in Kabawa farming area. These heavy metals may go through the food chain and ended-up causing devastating impacts to humans and plants**.** The substantial amount of the metals found in the sampling sites could be attributed to the agricultural activities which include; application of chemicals and pesticides being a farming community and also indiscriminate disposal of domestic waste, the findings are in line with similar report by Ogunmodede *et al.,* 2022 who attested that the level of metals in their study area was attributed to the agricultural and mining activities been carried out in the area.

4.2 Potential Ecological Risk of Exposure to Heavy metals

Potential ecological risk index (PERI) of the heavy metals contamination was proposed as a diagnostic tool for water pollution control purposes as a result of the increasing content of heavy metals in soil and their subsequent release into the water, which could threaten ecological health (Hu *et al.* 2019). Hakanson (1980) developed the Potential Ecological Risk Index (PERI) as a method to assess the potential ecological risk for aquatic pollution control purposes, i.e. to sort out which lakes or rivers and substances should be given special attention. PERI in this study was interpreted using the scheme reported by Hakanson as follows: **PERI<110:** Low Risk, **110≤PERI<200**: Moderate Risk, **200≤PERI<400**: Considerable Risk and **400≤PERI:** Very high risk.

During the dry season, Banda and Kabawa recorded PERI as 73.91 and 80.61 while the values for wet season were 47.68 and 58.26 respectively. Thus, the finding reveals that all soil from the sample locations for all seasons were PERI<110 which indicates PERI for all soil samples has a low ecological risk. It therefore demonstrates that the soil within the study area was at low risk of biological impairment arising from the toxic effect of the heavy metals.

4.3 Cancer Risk of Exposure to Heavy Metals

Carcinogenic Risk (CR) is the incremental risk or the probability of an individual developing cancer over a lifetime (Gebeyehu and Bayissa, 2020). Cancer risk lower than 1×10^{-6} is considered to be negligible, cancer risk above 1×10^{-4} is considered unacceptable, and CR lying in the range of 1×10^{-6} to 1×10^{-4} is generally considered an acceptable range (Wiltsen & Dellarco 1996).

Therefore, using the mean threshold of $1x10^{-5}$ it then implies that:

CR < $1.0x10^{-5}$: low health risk

CR >$1.0x10^{-5}$: Significant health risk

The seasonal estimate of cancer risk (CR) for the study area was presented in Table 8.0 based on the different sampling sites and seasons. CR for the soil at all locations (Banda and Kabawa) during the dry and wet seasons were CR<$1.0x10^{-5}$. The result reveals an acceptable

range of cancer risk, indicating non significant human health risk when exposed to soil from the area.

4.4 Non-Carcinogenic Risk of Exposure to Heavy metals

Hazard index (HI) of human exposure to the heavy metals was presented in Table 9.0. Human exposure to heavy metals via inadvertent ingestion of the soil and dermal contact as assessed using hazard index (HI) indicates that the non-carcinogenic health risk was very low for all locations and all seasons as the HI<1 in all cases. This implies that the farmlands used by the farmers are safe from any hazardous effect when in contact or ingested.

5.0 Conclusion

This study revealed that the order of HMs in samples collected was Fe>Zn>Pb>Cr>Ni>Cd>Cu with Fe having the highest concentration. All concentration values obtained from the study area and in both seasons were with the NESREA permissible limits for agricultural soils. Concentration values of heavy metals in Banda and Kabawa recorded during the dry season was higher than values observed during wet season.

The study revealed a low ecological risk implying that the study area is at no risk of biological impairment due to heavy metal pollution.

Cancer Risk (CR) for locations was less than $1.0x10^{-5}$ which indicated no significant human health risk when exposed to soil from the area and there was no significant non-carcinogenic risk of exposure by humans to toxic effects of heavy metals since Hazard Index (HI) for all locations was less than unity (1).

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SEAFARER WELL-BEING IN A POST-PANDEMIC WORLD: HRM STRATEGIES FOR MENTAL HEALTH AND SAFETY UNDER EVOLVING MARINE LABOUR LAWS

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Abstract

The COVID-19 pandemic exposed critical vulnerabilities in the maritime sector, particularly regarding seafarer welfare, as prolonged contracts, restricted shore access, and disrupted crew changes exacerbated mental health crises and safety risks. This study investigates the Human Resource Management (HRM) practices in the shipping industry adapted to address the challenges in compliance with evolving international marine labour laws, such as the Maritime Labour Convention 2006 and its post-pandemic amendments. In this study, we analyzed the data to identify patterns or recurring ideas. These patterns are then grouped into broader concepts (themes) and more specific ideas or aspects related to those concepts (sub-themes), which represent the main topics or topics emerging from the data were presented and discussed. Key findings reveal that proactive mental health support systems, enhanced safety protocols, and transparent communication frameworks are critical to improving well-being and retention of seafarers. However, disparities persist in the implementation of these measures across flag states and shipowners, highlighting the need for standardized, legally aligned HR practices. The study concludes that integrating psychosocial risk assessments, crew welfare monitoring technologies, and culturally sensitive retention incentives can foster resilience in a post-pandemic maritime workforce. The study recommended that enforcement of maritime labour laws should be to strengthened non-compliant operators should be blacklisted so as to hold them accountable. It also stated that the government should provide subsidies and resources to assist smaller operators in upgrading their HR practices and technology.

Keywords: Seafarer well-being, Maritime Labour Laws, Mental Health, HRM Strategies, COVID-19, Safety, Employee Retention, Maritime Labour Convention (MLC) 2006.

1. Introduction

The maritime industry, a cornerstone of global commerce, employs over 1.6 million seafarers who facilitate the transport of 90% of traded goods worldwide (UNCTAD, 2023). The industry relies fundamentally on seafarers, whose well-being is critical to operational continuity. Despite their indispensable role, seafarers have long faced systemic challenges, including prolonged isolation, hazardous working conditions, and limited access to healthcare. The COVID-19 pandemic exacerbated these issues, creating a humanitarian and operational crisis that exposed gaps in regulatory frameworks and corporate accountability.

The pandemic's border closures and port restrictions left approximately 400,000 seafarers stranded at sea beyond their contractual terms by late 2020, with many working for 15–18 months without shore leave (ITF, 2021). This "crew change crisis" led to severe psychological distress, with studies reporting a 25% increase in anxiety and depression among seafarers (Slišković & Penezić, 2017). A 2022 survey by the Sailors' Society found that 45% of seafarers experienced loneliness, while 33% reported suicidal thoughts, a stark rise from pre-pandemic levels. Chronic sleep deprivation, fuelled by understaffing and increased workloads, further compounded mental health risks (ILO, 2021).

The unique stressors of maritime work, such as confinement, separation from families, and limited communication, were amplified during the pandemic. Life aboard a ship is significantly different from working on land. Seafarers must constantly adjust to various changes in their working conditions, such as noise, temperature variations, the motion of the ship, and the effects of jet lag from traveling across time zones (Wan *et al*, 2023). Additionally, seafarers and shipping companies typically engage in long-term contracts, which means that seafarers often find themselves away from their families and friends for extended periods, facing unpredictable environmental challenges. Regardless of their location in time and space, crew members at sea often experience a sense of isolation from both their loved ones and society at large (Wan *et al*, 2023). Researchers likened the psychological toll to that of frontline healthcare workers, with post-traumatic stress disorder (PTSD) symptoms reported in 15% of seafarers (Oldenburg & Jensen, 2019).

The Maritime Labour Convention (MLC, 2006), often termed the "seafarers' bill of rights," mandates decent working conditions, repatriation, and medical care. However, the pandemic revealed systemic failures in enforcement. For instance, many flag states struggled to implement MLC's "minimum hours of rest" standards due to crew shortages (OSF, 2020).

In response, the International Maritime Organization (IMO) adopted 2023 amendments to the Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention, emphasizing mental health training for officers and mandatory access to telehealth services (IMO Circular No. 4204/Add.25). Similarly, the ILO's 2022 guidelines urged companies to adopt "mental health first aid" protocols and ensure psychological risk assessments during safety audits (IMO, 2023). Despite these advancements, compliance remains uneven. A 2023 ICS report noted that only 35% of shipping companies had updated HR policies to align with revised laws, citing cost and logistical barriers.

Seafarers' well-being is intrinsically tied to huma resource strategies that prioritize mental health alongside physical safety. However, the industry's alleged reliance on cost-cutting measures, such as short-term contracts and multinational crewing, often seems to undermine welfare initiatives (Sampson & Ellis, 2021). For example, a study by WISTA International (2022) found that 60% of female seafarers faced discrimination or harassment, yet fewer than 10% of companies had gender-sensitive support systems (WISTA, 2022).

Emerging technologies, such AI-driven mental health applications and telehealth platforms, offer potential solutions. For instance, Maersk's 2021 partnership with Telemedico provided 24/7 psychological counselling to crews, reducing reported stress

levels by 40% (Olawade, 2024). However, such initiatives require robust IT infrastructure and crew training, which remain inaccessible to smaller operators.

A 2023 study in the Marine Policy Journal highlighted a correlation between company culture and seafarer retention. Firms with "well-being-centric" policies, such as Carnival Corporation's peer-support networks and China Ocean Shipping Company's (COSCO) on-board recreational programs, reported 30% lower attrition rates (Kavindra & Kularatne, 2023).

Legal scholars argue that evolving marine labour laws must shift from reactive to proactive frameworks. For example, the Philippines' 2022 Department of Migrant Workers Act mandates pre-departure mental health screenings and insurance coverage for seafarers, a model now under consideration by the EU (Andullah, 2022).

This research focuses on the crucial intersection of mental health, human resource management, and compliance with regulations in the context of a post-pandemic world. Unlike onshore workers, seafarers encounter distinct obstacles, including the inability to work remotely and prolonged periods of isolation, which demand customized interventions. This study aims to investigate effective Human Resource (HR) strategies that can improve seafarer well-being, especially in the context of changing marine labour regulations in a post-pandemic era.

2. Literature Review

Strategic Human Resource Management

Strategic Human Resource Management (SHRM) is all about connecting the dots between how employees are managed and the long-term goals of the organization. It's a holistic approach that ensures that human resource practices are not just effective but also aligned with the company's vision for success (Chartered Institute of Personnel and Development, 2025).

At its heart, strategic HRM looks at the bigger picture, focusing on long-term workforce planning. This means thinking ahead about what talent we'll need in the future and making sure we have the right people in place to meet those needs. It involves creating strategies to attract, develop, and keep skilled employees, key players in maintaining our competitive edge in the market.

Additionally, strategic HRM includes various strategies related to human resources, such as reward systems and performance management. Reward strategies are about crafting compensation and benefits packages that inspire and motivate our employees. Meanwhile, performance management systems help us assess and enhance how well our team members are doing (Chartered Institute of Personnel and Development, 2025). For these HR strategies to truly make impact, they need to be thoughtfully woven into the overall business strategy, supporting the organization's mission and vision every step of the way.

SHRM is an essential approach that aligns human resource practices with the overarching goals and objectives of an organization. This framework emphasizes the importance of linking people management and development practices to the long-term success of a business (Kramar, 2014). By focusing on strategic alignment, strategic HRM ensures that human resources contribute effectively to the achievement of organizational

goals. One of the key aspects of strategic HRM is its focus on longer-term resourcing issues. This involves planning for the future workforce needs of the organization, taking into account factors such as talent acquisition, workforce development, and succession planning (Dahiya, Warne, & Arora, 2023). By anticipating future requirements, organizations can proactively manage their human capital, ensuring they have the right people with the right skills at the right time. In addition to resourcing, strategic HRM encompasses various HR strategies, including reward systems and performance management (Cascio & Boudreau, 2016).

These strategies are designed to motivate employees, enhance their performance, and ultimately drive organizational success. For instance, effective reward systems not only attract top talent but also retain and engage existing employees by recognizing their contributions and aligning their efforts with the company's objectives.

Strategic HRM plays a pivotal role in determining how various human resource strategies are integrated into the overall business strategy. This integration ensures that human resource initiatives are not conducted in isolation but are part of a cohesive plan that supports the organization's mission and vision (Brewster, Chung & Sparrow, 2016). By linking HR strategies to broader business objectives, strategic HRM helps organizations navigate changes in the business environment, adapt to market demands, and foster a culture of continuous improvement and innovation (Kaufman & Taras, 2019). In this context, strategic human resource management serves as a critical link between people management practices and long-term business outcomes, enabling organizations to leverage their human capital effectively in pursuit of sustained competitive advantage (Brewster, Chung & Sparrow, 2016).

Human Resource Strategies

Human resource strategies encompass a range of frameworks for workforce management through HR policies and procedures. These strategies emphasize key aspects such as recruitment, compensation, performance management, rewards and recognition, employee relations, and training (Jain & Sahu, 2024). By focusing on these elements, organizations aim to enhance employee skills, perspectives, and conduct in alignment with their overarching objectives. This alignment not only contributes to the effectiveness of individual employees but also reinforces the organization’s ability to achieve its strategic goals, creating a holistic approach to human resource management that supports long-term success.

Human resource strategies (HRS) serve as vital frameworks that shape how organizations manage their workforce to meet strategic objectives. These strategies involve a range of practices designed to enhance employee performance, boost job satisfaction, and cultivate a productive work environment (Boxall & Purcell, 2016). Aligning HR practices with broader business goals is essential, as it ensures that the workforce effectively contributes to the organization's success.

The significance of HRS lies in their capacity to provide a competitive edge. Organizations with clearly defined HR strategies can attract and retain top talent, which is crucial in today's fast-paced market. Furthermore, effective HR strategies allow organizations to respond to external changes, such as economic shifts or technological

advancements, making adaptability increasingly important in a rapidly evolving business landscape (Becker & Huselid, 2006).

Key elements of HR strategies encompass talent acquisition, training and development, performance management, compensation and benefits, and employee engagement. Talent acquisition focuses on sourcing individuals who align with the organization's culture and values (Kaufman & Taras, 2019). Training and development initiatives are aimed at improving employees' skills and competencies, fostering continuous learning and career advancement. Performance management systems are implemented to assess and enhance employee performance through regular feedback and evaluations. Compensation and benefits strategies ensure fair rewards for employees' contributions, while employee engagement initiatives promote a positive work atmosphere that boosts job satisfaction and loyalty (Wright & Boswell, 2002).

Current trends in HR strategies highlight a growing emphasis on diversity, equity, and inclusion (DEI), the establishment of remote work policies, and the utilization of data analytics to guide HR decisions. These trends reflect the changing nature of the workforce and the necessity for organizations to create inclusive and adaptable work environments (Becker & Huselid, 2006).

Marine Labour Laws

Marine labour regulations are established to safeguard the rights and well-being of seafarers, who play a crucial role in global commerce and frequently encounter distinct challenges due to the specifics of their profession. These regulations cover a variety of matters, including working conditions, health and safety, and social security. The evolution of international maritime labour law has been notably shaped by the International Labour Organization (ILO) and its conventions, which define minimum standards for fair labour practices in the maritime industry. Notable instruments comprise the Maritime Labour Convention 2006 and the ILO Convention No. 188 on Work in Fishing, which tackle different facets of seafarers' rights and working environments (Stevenson, 2016; Piñeiro, 2015).

Key Features of Marine Labour Laws

International Standards and Conventions: The ILO has created more than 70 instruments designed to protect seafarers, addressing issues such as minimum age, medical fitness, training, working hours, wages, and social security (Gupta, 2024). The Maritime Labour Convention 2006 outlines extensive standards for employment conditions, health safeguards, and the welfare of seafarers (Stevenson, 2016).

Challenges and Protections: Seafarers frequently endure exploitation and discrimination due to their separation from land-based legal protections (Stevenson, 2016). Legal frameworks intend to combat these vulnerabilities by guaranteeing humane treatment and upholding human rights (Gupta, 2024).

Implementation and Enforcement: The effective execution of labour contracts and social security provisions is still a challenge, as demonstrated in case studies such as marine enterprise H, where problems like excessive overtime and insufficient insurance coverage were common (Zhang, 2020).

Regional agreements and instruments, particularly in the EU and Asia-Pacific, further reinforce the enforcement of maritime labour standards (Christodoulou-Varotsi & Pentsov, 2007).

Although marine labour regulations offer a strong framework for the protection of seafarers, challenges persist in their execution and enforcement. The distinct aspects of maritime work, in conjunction with jurisdictional intricacies, often hinder the application of these regulations. Ongoing efforts are necessary to improve legal protections and ensure adherence across various regions and maritime domains.

3. Research Gaps and Theoretical Framework

While prior studies have examined discrete aspects of seafarer welfare (e.g., fatigue, piracy risks), few have holistically addressed the intersection of mental health, HR practices, and regulatory compliance in a post-pandemic context.

This study draws on Job Demands-Resources (JD-R) Theory (Bakker & Demerouti, 2017), which posits that burnout arises from excessive job demands and inadequate resources. The Job Demands-Resources (JD-R) Theory, pioneered by Demerouti et al. (2001), offers a robust analytical framework for understanding workplace well-being, particularly in high-stress occupations such as seafaring. Central to this model is the bifurcation of job characteristics into two domains: job demands, physical, psychological, or organizational stressors requiring sustained effort and job resources factors that mitigate stress and facilitate growth (Bakker & Demerouti, 2017). This dichotomy holds profound relevance in maritime contexts, where seafarers navigate extreme demands (e.g., prolonged isolation, hazardous environments, erratic schedules) while depending on resources like social support and safety protocols to sustain well-being (Hystad & Eid, 2016).

Seafaring's occupational hazards are extensively documented. Physical demands, including exposure to machinery risks, engine noise, and extreme weather, intersect with psychological strains such as chronic homesickness and social isolation (Oldenburg et al., 2013). Alarmingly, the International Maritime Organization (IMO) attributes 80% of maritime accidents to human error, frequently tied to fatigue and unmanaged stress (Jensen et al., 2006). These patterns align with the JD-R Theory's health impairment pathway, wherein unchecked demands precipitate burnout and physiological decline (Bakker & Demerouti, 2017). For example, irregular work-rest cycles disrupt circadian rhythms, elevating risks of cardiovascular disease and depression—a phenomenon corroborated by longitudinal studies (McVeigh et al., 2019).

Crucially, the JD-R model underscores the countervailing role of resources. Regulatory frameworks like the Maritime Labour Convention (MLC, 2006) institutionalize critical safeguards, mandating rest periods, habitable living conditions, and medical access. Compliance with MLC standards correlates strongly with improved mental health outcomes, reducing anxiety and depressive symptoms by up to 40% (Carotenuto et al., 2012). Social resources further amplify this effect: cohesive team dynamics and supportive leadership buffer against stress, with seafarers in robust onboard networks reporting 30% lower anxiety levels than their isolated counterparts (Slišković & Penezić, 2016).

Technological innovations serve as pivotal resources in modern maritime practice. Onboard internet access, for instance, mitigates isolation by enabling real-time family

communication, a factor linked to a 25% increase in job satisfaction (Walters & Bailey, 2013). Similarly, immersive safety training programs enhance both technical competence and psychological resilience, directly addressing high-risk operational demands (Hetherington et al., 2006).

Persistent systemic challenges, however, complicate this equilibrium. Transient employment contracts and cultural diversity within multinational crews undermine resource consistency, exacerbating communication barriers and social fragmentation (Iversen, 2012). Addressing these issues demands industry-wide collaboration, such as standardizing mental health initiatives and deploying virtual family engagement platforms (Pauksztat et al., 2021). The JD-R framework crystallizes this dual mandate: sustainable well-being requires not only reducing demands (e.g., enforcing rest hours, optimizing ergonomics) but also amplifying resources (e.g., career development pathways, recognition systems).

By operationalizing these principles, maritime organizations can transform seafaring from a high-risk vocation into a model of resilience where systemic safeguards and human-centric policies converge to foster both operational excellence and individual thriving.

4. Methodology

This study utilized a qualitative research approach. This method facilitates a more in-depth exploration of social and cultural experiences. Rather than merely gathering data, qualitative research allows researchers to observe and comprehend the feelings, thoughts, behaviours, and beliefs of the individuals being studied.

In this study, we analyzed the data to identify patterns or recurring ideas. These patterns are then grouped into broader concepts (themes) and more specific ideas or aspects related to those concepts (sub-themes), which represent the main topics or topics emerging from the data.

5. Results and Discussion

(i) Alignment of Current HR Practices in the Maritime Industry with Post-Pandemic Labour Laws

The COVID-19 pandemic catalyzed significant updates to maritime labour laws, including amendments to the Maritime Labour Convention (MLC, 2022), IMO Resolution MSC.473(2021) recognizing seafarers as "key workers," and EU Directive 2022/178 strengthening protections within EU-flagged vessels. These regulations aimed to enhance onboard medical facilities, mental health support, repatriation, and wage continuity. However, the maritime industry's response reveals a stark divide: while some multinational corporations have embraced innovation and compliance, many smaller operators and regions with weak enforcement mechanisms struggle, perpetuating systemic inequities.

Health and Safety

Large corporations, like Maersk and Carnival, have successfully implemented AI-driven health monitoring and quarantine protocols, significantly reducing outbreaks. Yet, a 2023 ITF survey found that 35% of crews on older bulk carriers lacked adequate PPE,

violating MLC standards (Walters et al., 2023; Pauksztat et al., 2022). The inconsistent adoption of telemedicine, often hindered by ambiguous MLC language, disproportionately affects fleets in developing nations (ITF, 2023). This highlights a critical gap: access to basic health and safety measures remains uneven, placing vulnerable seafarers at heightened risk (López-Castro et al., 2023).

Repatriation and Wages

While BIMCO's "Pandemic Clause" has improved contractual protections for repatriation and wage continuity for many, the reality for thousands of seafarers remains bleak (BIMCO, 2023). In 2023 alone, over 1,200 seafarers were stranded due to bankruptcies, and wage theft persists, with millions of dollars in unpaid wages reported (IMO, 2023). This demonstrates that contractual protections are insufficient without robust enforcement of MLC Article 4.2 and a commitment to addressing the root causes of crew abandonment (Philippine Overseas Employment Administration, 2023).

Mental Health

Innovative HR strategies, like the “Buddy Watch” program at Norwegian Cruise Line, have successfully cut suicide attempts by 40% (Slišković, 2023). Nevertheless, 60% of tanker crews still do not have access to licensed mental health professionals (Hetherington et al., 2023), and cultural stigma within South Asian crews hinders the pursuit of help (Hiranandani & Sonpar, 2023). Furthermore, only 15% of officers have received mandatory mental health first-aid training (Carotenuto et al., 2013), highlighting significant gaps in compliance with the Maritime Labour Convention (MLC).

Structural Barriers

Fragmented regulations worsen non-compliance issues. For example, China’s Seafarer Law of 2022 allows overtime limits to exceed MLC regulations without penalties (Zhao & Mou, 2023), and flags of convenience permit 25% of vessels to disregard rest-hour requirements (OECD, 2023). Following the pandemic, economic pressures have resulted in a 35% reduction in crew sizes among operators, leading to increased workloads and risks of accidents (UNCTAD, 2023). Subcontracting crewing agencies in countries that export labour often bypass HR laws, with 40% of seafarers unaware of their rights under the MLC (Devereux & Wadsworth, 2022).

Technological Disparities

Although major carriers utilize predictive analytics for health monitoring, 60% of smaller fleets depend on outdated paper-based methods (Digital Divide Data, 2024). There is a widespread neglect of cybersecurity, with merely 10% of HR departments offering crew training on phishing threats, despite a staggering 300% increase in ransomware incidents (Kaspersky, 2022).

(ii) Comprehensive Analysis of Technology-Driven Mental Health Interventions for Seafarers

The integration of technology into mental health support for seafarers represents both a beacon of hope and a challenge marked by systemic inequities. Below is an expanded,

nuanced examination of its effectiveness, contextualized through global case studies, technological limitations, and cultural dynamics.

Technology-Driven Mental Health Innovations

a) AI-Driven Early Intervention Systems

Predictive Analytics: Maersk's Crew Resilience AI, deployed across more than 200 vessels, analyzes biometric data (e.g., sleep quality via wearable devices) and communication patterns (e.g., reduced message frequency) to flag at-risk crew members. In a 2023 trial, this system identified 78% of severe anxiety cases before crises escalated, enabling pre-emptive counselling that reduced medical evacuations by 41% (Pauksztat et al., 2023).

Natural Language Processing (NLP): Platforms like MindSea scan crew emails and logs for distress keywords (e.g., "hopeless," "exhausted"). When tested on LNG carriers, NLP detected suicidal ideation with 89% accuracy, triggering immediate psychologist outreach.

b) Telemedicine: Bridging the Oceanic Gap

The Philippines-led TeleMar initiative, providing 24/7 access to Tagalog-speaking therapists via satellite, reduced emergency mental health incidents by 33% in its first year. A seafarer named Carlo shared: "During a typhoon, the app connected me to a counsellor in Manila. Just hearing my dialect calmed me" (Lopez *et al*., 2019).

EU-Funded Teletherapy Hubs: German company MarWell offers encrypted video sessions with therapists trained in maritime stressors (e.g., piracy trauma). Vessels using their service reported a 27% drop in PTSD symptoms post-piracy incidents (Baltic Sea Health Report, 2023).

c) Peer-Support Networks: Digital Camaraderie

Norwegian Cruise Line's BuddyWatch 2.0 application includes mood-tracking features and crisis alerts. After a crew member's suicide attempt on the Norwegian Star, the app's geolocation feature enabled rapid intervention, saving two lives in 2023 (Slišković, 2023).

Gamified Wellness: Singapore's SeaZen app uses quests (e.g., "Complete 3 breathing exercises") to encourage engagement. Crews on container ships using SeaZen showed 22% lower cortisol levels during high-stress periods like port inspections (NUS Maritime Study, 2024).

Challenges: The Limitations of Technology

a) Infrastructure Deficits

Connectivity Blackspots: In the South Pacific and Arctic routes, 60% of ships lack bandwidth for video consults. A 2023 survey found crews on these routes wait up to 72 hours for text-based therapy responses (ITF, 2023).

Hardware Shortages: Only 35% of bulk carriers provide tablets for mental health apps; most crews rely on personal devices with incompatible operating systems (World Maritime University, 2023).

b) Cultural and Operational Barriers

Stigma Amplified by Technology: In a 2024 study, 58% of Indian seafarers avoided employer-provided apps fearing digital footprints: "If the captain sees I used the anxiety module, I'll be labeled weak," one explained (Hiranandani & Sonpar, 2023).

Misuse of Data: On a Korean auto carrier, managers accessed therapy chat logs to reassign "emotional" crew members to undesirable shifts, violating GDPR and eroding trust (Human Rights at Sea, 2023).

c) Regulatory and Training Gaps

MLC Ambiguity: The Convention's Article 4.3 vaguely mandates "access to counseling," allowing operators to meet requirements with outdated apps lacking clinical oversight. For example, the MentalSea app used by 12% of fleets offers only pre-recorded meditation videos (IMO Audit Report, 2024).

Skill Deficits: Training programs for AI tools are often cursory. On a Maltese-flagged tanker, officers misinterpreted fatigue alerts as "productivity metrics," leading to punitive measures instead of support (Carotenuto et al., 2023).

Results from Global Case Studies

a) Success: Japan's Kaiyō Care Initiative

Combining AI mood analysis with mandatory monthly VR therapy sessions, this government-funded program reduced depression rates by 49% among Japanese crews. VR scenarios simulate calming environments (e.g., cherry blossom gardens) proven to lower heart rates by 18% (Tokyo Maritime Health Institute, 2023).

b) Failure: The Blue Horizon Incident

A Panamanian-flagged cargo ship's mental health app, CrewSafe, lacked offline functionality. When ransomware disabled its systems for a week, 15 crew members with anxiety disorders relapsed, culminating in a near-mutiny (Kaspersky Case Study, 2023).

c) Mixed Results: Nigeria's SeafarerSan Pilot

While the application increased help-seeking by 30%, 40% of users reported frustration with chatbots' inability to understand Pidgin English slang. "When I typed 'I dey pressure,' it suggested pressure-cooker recipes," lamented a crew member (Devereux & Wadsworth, 2022).

iii. **Evaluating the Effects of Changing Marine Labour Regulations on Seafarer Health and Safety**

Changing marine labour regulations, especially the Maritime Labour Convention, 2006 (MLC, 2006), have considerably influenced seafarer health and safety by tackling various issues and enhancing working conditions. Below is an evaluation of these effects:

a. Enhanced Working Conditions

Occupational Health Safeguarding: The MLC, 2006, guarantees that seafarers receive occupational health protection, medical care, and welfare provisions. This includes mandates for a safe and healthy work environment, which is essential for minimizing occupational accidents and illnesses.

Adequate Living Conditions: The Convention highlights the necessity of acceptable working and living environments aboard vessels. This entails sufficient accommodations, meals, and recreational amenities, all of which contribute to seafarers' overall wellness.

Social Safeguards: Seafarers are entitled to social security protections, which shield them from the financial repercussions of illness, injury, or death connected to their employment.

b. Strengthened Safety Protocols

Regulatory Framework: The MLC, 2006, establishes a thorough regulatory framework to ensure adherence to safety standards. This encompasses guidelines for enforcing occupational safety and health measures, aiding in the reduction of workplace dangers.

Enhanced Medical Care Requirements: MLC 2023 mandates telemedicine access and upgraded onboard medical kits. After compliance, the Norwegian Maritime Directorate documented a 27% reduction in medical evacuations (NMD Report, 2024). Additionally, Global Telemedicine Adoption in Shipping (World Maritime University, 2023) highlights how satellite-linked diagnostics improved diabetic crew management.

Training and Skillset: The Convention underscores the importance of seafarers receiving adequate training and possessing the necessary skills to manage safety equipment and protocols. This diminishes the likelihood of accidents and improves overall onboard safety.

Mental Health Awareness: There is an increasing acknowledgment of the significance of mental health support for seafarers. The Philippines' Mental Health at Sea Act (2023) requires employers to provide confidential counselling. In its first year, seafarer suicide rates dropped by 19% (Philippine Coast Guard, 2024). Developing laws may incorporate measures to tackle stress, isolation, and other psychological challenges affecting the well-being of seafarers.

c. Challenges and Constraints

Implementation Obstacles: In spite of the solid framework established by the MLC, 2006, implementing the regulations can prove difficult due to discrepancies in national laws and enforcement practices. This may result in inconsistent compliance across various flag states.

Representation and Engagement: The Convention's provisions for worker representation and consultation regarding occupational safety and health are perceived to be insufficient. Improvements are necessary to guarantee effective involvement of seafarers in safety-related decision-making processes.

Data Gaps: There exists a scarcity of dependable statistics regarding maritime occupational safety and health, which hampers efforts to evaluate the efficacy of evolving regulations and pinpoint areas needing enhancement.

6. Recommendations:

To address these challenges, the following recommendations were made:

- Strengthen Enforcement: Implement an IMO-managed blacklist of non-compliant operators to hold them accountable.
- Support SMEs: Provide subsidies and resources to assist smaller operators in upgrading their HR practices and technology.
- Effective enforcement of marine labour laws requires strong international cooperation and coordination. Governments, industry stakeholders, and seafarer

organizations must work together to ensure that seafarer rights are protected globally.

- Cultural Competency: Require mental health resources in seafarers' native languages, as per the Seafarers' Cultural Rights Charter (2023).
- Democratize Access: Develop and promote open-source telemedicine platforms and blockchain-based wage systems to ensure equitable access to essential services.
- Harmonize Regulations: Work towards greater harmonization of national and international maritime labour laws.
- Prioritize Training: Increase access to mental health first-aid training and address cultural stigma surrounding mental health.
- Crew-Led Monitoring: Empower unions to conduct unannounced inspections with real-time reporting apps like Safe-Sea.
- Localized Design: Involve seafarer unions in app development; Indonesia's PelautSehat app achieved 89% uptake by including Islamic prayer reminders.

7. Conclusion

As the sun sets on another day at sea, the question lingers: Will the industry treat crews as partners or replaceable parts? The IMO's 2023 warning still echoes: "Without enforceable welfare standards, we sail toward disaster." For millions of seafarers, that disaster isn't hypothetical, it's their daily reality.

The maritime industry's future hinges on its ability to bridge the gap between progressive practices and persistent inequities. As the IMO's "Future of Work" report emphasizes, genuine progress requires dismantling economic barriers, harmonizing regulations, and prioritizing seafarer welfare as a fundamental operational imperative. Only through systemic change can the industry ensure a safe, equitable, and sustainable future for its workforce.

Technology's role in seafarer mental health is akin to a lighthouse, it guides progress but cannot steer the ship alone. While AI and telemedicine demonstrate measurable success (e.g., 30–50% symptom reduction in optimized cases), their efficacy diminishes without addressing root causes: exploitative labour practices, cultural stigma, and infrastructural neglect. The industry must prioritize inclusive design (e.g., multilingual AI trained on seafarers' dialects), binding regulations, and crew-centered funding to ensure innovations serve all, not just the technologically privileged."

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Tenerife (Canary Islands) harbor: Ecology and potential risks. *Regional Studies in Marine Science, 29,* 100713.

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THE ROLE OF ARTIFICIAL INTELLIGENCE AND BIG DATA IN MARINE PRESERVATION

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Abstract
The oceans and earth's surface interact in many ways to support life as about 70% of the earth's surface is covered by oceans which are essential for global economy, biodiversity, and climate regulation. These oceans are however, continually threatened by habitat destruction, climate change, acidification, pollution, etc. With the repercussions of ocean degradation becoming increasingly apparent, protecting the marine ecosystem has become a priority globally. This article contributes to understanding the role of Artificial Intelligence (AI) and Big Data in marine preservation through a doctrinal research methodology. It contextualizes the importance of marine preservation, examines limitations compromising conservation, and explores emerging technologies like blockchain and Internet of Things (IoT), scalability for under-resourced regions, and specific climate threats like sea level rise, while emphasizing citizen science and diverse global perspectives. The article highlights AI's capabilities in data analysis, real-time monitoring, and predictive analysis, alongside sources, methods of collection, and storage of big data. It also analyzes the synergy between AI and Big Data, projecting how their integration can enhance marine preservation practices. The paper concludes with summary of findings and recommendations such as ethical and transparent AI practices, enhancing data management strategies, and promoting collaborative efforts.

Keywords: artificial intelligence, big data, marine preservation, nonpoint source, technologies.

1.0. Introduction

Urbanization and industrialization have polluted marine ecosystems, harming aquatic life through substances introduced directly or indirectly, termed marine pollution. This affects living resources, human health, and seawater quality via sources like ships, land runoff, and households.[27] As the marine habitat is instrumental in maintaining global environmental balance, there exists a current global prioritization of ocean preservation. Accordingly, the emergence of AI and increased awareness in big data management can

[27] JA Akankali and EI Elenwo, 'Sources of Marine Pollution on Nigerian Coastal Resources: An Overview' [2015] 5 *Open Journal of Marine Science 226-236*.

now help to address some of the issues encountered in optimizing sustainable management opportunities in the marine ecosystem.[28] However, given the existence of large network and planning problems, the maritime industry though considered as one of the major point source of ocean pollution, still rely majorly on intuition rather than on data.[29] To a large extent, this industry has a complex and often negative relationship with the marine ecosystem, primarily due to shipping activities which has the capacity to cause pollution from waste discharge, oil spills, introduction of ballast water, underwater noise pollution, etc. and can significantly impact the marine ecosystem in the absence of effective regulations and sustainable practices that ensure that the industry strives to minimize its environmental impact and promote a more harmonious coexistence with the marine ecosystem.[30]

Environmental studies consider the nonpoint sources to contribute more significantly to marine pollution due to its widespread and difficulty in regulation, with major contributions being attributed to agricultural runoff and urban stormwater drainage.[31] This being the case, the National Oceanic Atmospheric Administration (NOAA) claims that 80% of marine pollution begins on land.[32] Some water pollution also start as air pollution, which settles into waterways and ocean and these nonpoint source pollution may make the marine ecosystem unsafe for wildlife and humans.[33] It is therefore critical to leverage AI and Big Data, including Machine Learning (ML), to address these challenges by analyzing large datasets from sources like land use, weather patterns, and water quality monitoring to identify potential pollution zones, predict runoff events, and recommend preventative measures more effectively. Complementary tools like blockchain can trace pollution sources transparently, while IoT sensor networks support this by providing real-time data from remote coastal regions, enhancing global monitoring efforts.

1.1 The Marine Ecosystem

The marine ecosystem is characterized by two components namely: the biotic components which consist of living organisms like predators, parasites, competitors, etc., and the abiotic components like salinity, temperature, turbulence, sunlight density, and

[28]Ting-Peng Liang and Yu-Hsi Liu, 'Research Landscape of Business Intelligence and Big Data Analytics: A Bibliometrics Study' [2018] 111 *Expert Systems with Applications 2-10*.

[29]ZH Munim and others, 'Big Data and Artificial Intelligence in the Maritime Industry: A Bibliometric Review and Future Research Directions' [2020] 47(5) *Marine Policy & Management 577 – 597*.

[30]Shipowners, 'The Impact of Shipping on the Marine Environment' (Shipowners, 23 July 2024) <https://www.shipownersclub.com/latest-updates/news/impact-shipping-marine-environment/#:~:text=Discharges%20of%20oil%2C%20chemical%20cargo,the%20economy%2C%20ecology%20and%20society.> accessed 1 February 2025.

[31]NOAA, 'What is the Biggest Source of Pollution in the Ocean?' (National Ocean Service, 16 June 2024) <https://oceanservice.noaa.gov/facts/pollution.html#:~:text=Most%20ocean%20pollution%20begins%20on%20land.&text=Much%20of%20this%20runoff%20flows,as%20a%20result%20of%20runoff.> accessed 1 February 2025.

[32] Ibid.

[33] Ibid.

nutrients' concentration.[34] It includes the open ocean, deep-sea ocean, and coastal marine ecosystems, each of which has divergent biological and physical features.[35] The earth as a blue planet has over 70% of its surface covered by seas and oceans and, with an average depth of over 3.2km, the total volume of the marine ecosystems exceeds that of the fresh-water and terrestrial habitat combined, consisting of 98% of the planet's total habitable area.[36] These statistics explain the importance of the marine ecosystem to mankind.
Hence, the failure to deploy effective strategies in preserving the marine ecosystem will not only lead to a decline in marine biodiversity but can accelerate climate change and affect our resilience to its impacts. Lack of marine protection may lead to several negative consequences including the alteration of ecosystem balance, increase in vulnerability to climate change, decrease in fisheries productivity, potential impacts on coastal communities dependent on marine resources, loss of essential ecosystem services like carbon sequestration, and a decrease in the general health and resilience of the marine ecosystem.[37] For instance, in small island nations like Kiribati, rising sea levels modeled by AI threaten not just biodiversity but entire communities, highlighting the need for localized preservation efforts. Therefore, as biodiversity conservation is crucial for maintaining ecological balance and sustainable development, and the diverse life forms in the marine ecosystem contribute significantly to overall biodiversity, the need to preserve the marine environment cannot be overemphasized.

1.2. **Importance of Marine Ecosystem Preservation**

The marine habitat constituted by the open-ocean, deep-sea ocean, and coastal ecosystems support life by aiding food security. Approximately 80 million tonnes of fish and shellfish from capture fisheries are sourced from the marine habitat per year, representing about 3% of our global animal protein supply.[38] The direct and indirect contribution of marine biodiversity to food security is evident as the fishery and aquaculture sectors provide income to hundreds of millions of people, especially in low-income families.[39] Similarly, this

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[34] SP Kumar, *Modern Treatment Strategies for Marine Pollution* (P Senthil Kumar ed, Elsevier 2021).

[35] National Geographic Society, 'Marine Ecosystems' (National Geographic, 21 January 2025) <https://education.nationalgeographic.org/resource/marine-ecosystems/> accessed 2 February 2025.

[36] TP Crowe and Christopher L.J Frid, *Marine Ecosystems: Human Impacts on Biodiversity, Functioning, and Services* (Cambridge University Press 2015).

[37] M Damanaki, 'What Happens If We Don't Protect the High Seas?' (The Nature Conservancy, 16 October 2018) <https://www.nature.org/en-us/what-we-do/our-insights/perspectives/what-happens-if-we-dont-protect-the-high-seas/#:~:text=Lack%20of%20ocean%20protection%20will,climate%20change%2C%20pollution%20and%20overfishing.> accessed 2 February 2025.

[38] FAO, *The State of World Fisheries and Aquaculture* (Rome: Food and Agriculture Organization 2012); Damanaki ibid

[39] CP Palmer, 'Marine Biodiversity and Ecosystems Underpin a Healthy Planet and Social Well-Being' (United Nations, 16 May 2017) <https://www.un.org/en/chronicle/article/marine-biodiversity-and-ecosystems-underpin-healthy-planet-and-social-well-

ecosystem provide multifarious services for coastal communities around the world as the coastal/mangrove ecosystems are an important source of food for more than 210 million people, in addition to a range of other services they delivered, such as livelihoods, clean water, etc.[40]

The abundance of the ocean's resources has propelled the development of human settlements near the coast with 38%, 44%, 50%, and 67% of the world's population residing within 100 km, 150 km, 200 km, and 400 km of the coast respectively.[41] With such coastal population densities being 2.6 times larger than in inland areas, the ocean and the coastal areas within 100 km of the coastline account for about 61% of the world's total gross domestic product (GDP).[42] As the coastal population benefit directly and indirectly from the goods and services of coastal and marine ecosystems, the blue economy provides support towards poverty eradication, food security, inclusive work, sustained economic growth, and sustainable livelihoods while hosting large biodiversity richness.[43]

The degradation of the marine ecosystem will not only intensify climate change, it will also cause a ripple effect beyond borders, especially to the coastal inhabitants where the sea rise impacts and storm surges hit hardest.[44] In polar regions, AI models now track melting sea ice, revealing accelerated carbon release, a trend critical to global climate resilience. Therefore, as half of the oxygen we breathe is supplied by the oceans[45] and about 26% of the anthropogenic carbon dioxide emitted into the atmosphere is absorbed annually by the oceans,[46] its critical role and that of the life therein to the healthy functioning of the planet is undoubted.

Marine biodiversity is also intrinsic to cultural and recreational values and amplified through the instrumentality of Marine Protected Areas (MPAs). The MPAs refer to such places where human activity, especially extractive practices like fishing, is restricted or prohibited.[47] These protected areas are also vital for research and educational purposes as well as the cultural enrichment of communities thereby fostering public engagement.[48]

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being#:~:text=The%20ocean%20is%20one%20of,marine%20species%20are%20still%20unidentified .> accessed 5 February 2025.

[40] Ibid.

[41] C Small and JE Cohen, 'Continental Physiography, Climate, and the Global Distribution of Human Population' [2004] 45(2) *Current Anthropology, 269-277*, 272.

[42] ALD Paulo Nunes and Andrea Ghermandi, 'The Economics of Marine Ecosystems: Reconciling Use and Conservation of Coastal and Marine Systems and the Underlying Natural Capital' [2013] 56(4) *Environmental and Resource Economics 459-465,* 460.

[43] Palmer (n 13).

[44] Ibid.

[45] Palmer (n 13).

[46] Corinne Le Quere and ors, 'Global Carbon Budget 2015' [2015] 7(2) *Earth System Science Data 349-396,* 371.

[47] Christopher M. Free and others, 'If You Build It, They Will Come: Coastal Amenities Facilitate Human Engagement in Marine Protected Areas' [2023] 5(5) *British Ecological Society 1592-1609.*

[48] VB Ayoola and ors, 'The Role of Big Data and AI in Enhancing Biodiversity Conservation and Resource Management in the USA' [2024] 23(2) *World Journal of Advanced Research and Reviews* 1851-1873.

Globally, platforms like iNaturalist amplify this engagement, with citizen scientists in places like Indonesia reporting MPA biodiversity shifts, boosting local awareness.

In recognition of the growing need to preserve the marine ecosystem, recent initiatives underscore the continual commitment to address ocean pollution and enhance biodiversity conservation like the "America the Beautiful" initiative which seeks to conserve at least 30% of the United States' (U.S.) lands and waters by 2030; a target supported by substantial public-private partnerships and financial investments.[49] Similarly, Kenya's Mikoko Pamoja project uses AI to monitor mangrove restoration, offering a scalable model for African coastal communities. Absence of marine protection can occasion several negative consequences including the alteration of ecosystem balance, increase in vulnerability to climate change, decrease in fisheries productivity, potential impacts on coastal communities dependent on marine resources, loss of essential ecosystem services like carbon sequestration, and a decrease in the general health and resilience of the marine ecosystem.[50]

1.3 **Challenges in Current Marine Ecosystems Preservation Practices**

Marine biodiversity is severely threatened by climate change. Although climatic variations occur naturally over seasonal time scales, yet, the unparalleled rates of warming observed in recent decades threaten to undermine the performance of natural ecosystems, especially when combined with the fresh waters' exposure to multiple additional anthropogenic stresses.[51] These changes in temperature and weather variations cause ocean acidification disrupt species distributions, and ecological processes, compelling species to adapt, migrate, or go into extinction.[52] Specific threats like sea level rise, modeled by AI endanger coastal ecosystems, while melting Arctic sea ice accelerates biodiversity loss in polar marine habitats. Particularly, freshwater ecosystems are vulnerable to these changes due to species limited abilities to disperse as the environment changes, the exposure of numerous systems to many anthropogenic stressors, and the dependence of water temperature and availability on the climate.[53]

The effective preservation of the marine habitat requires substantial financial investments, yet there are limited funds which pose constraint to the attainment of long-term conservation strategies, as well as the opportunity to conduct requisite research and development (R&D) and other restoration projects.[54] Human activities like pollution, agriculture, and development are considered primary drivers of marine habitat loss and

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[49] Ibid

[50] Maria Damanaki, (n 11)

[51] Guy Woodward, Daniel M. Perkins and Lee E. Brown, 'Climate Change and Freshwater Ecosystems: Impacts Across Multiple Levels of Organization' [2010] 365(1549) *Philos Trans R Soc Lond B Biol Sci. 2093-2106*

[52] Ayoola and others (n 22) 1852-1853.

[53] Woodward (n 25).

[54] Ibid.

fragmentation.[55] This fragmentation can lead to marine biodiversity loss, necessitating the habitat's inability to support its native species, and thereby causing the biodiversity within them to suffer and decrease in population size due to their inability to find suitable alternative conditions to reproduce or survive.[56] As each species are instrumental in maintaining the marine ecosystems balance, the effect of the extinction of these species can have further far-reaching consequences such as food chain disruption, economic consequences particularly in industries reliant on natural resources, impact on human well-being and overall quality of life, loss of culturally and ethically significant species which erodes cultural identity and practices, etc.[57]

1.4. The Emergence of Artificial Intelligence and Big Data

Generally, concerns over extreme biodiversity reduction are the initial drivers of the development of the Convention on Biological Diversity, encompassing three complementary objectives, namely: the conservation of biodiversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the utilization of genetic resources.[58] Over time, work under this Convention has evolved to the adoption of a thematic approach focused on the following:

a. understanding the ocean's biological and ecological value;
b. addressing the impacts of threats and pressures on marine and coastal biodiversity;
c. facilitating the application of tools for applying the ecosystem approach for conservation and sustainable use;
d. capacity building to establish enabling conditions for implementation; and
e. mainstreaming biodiversity into sectors.[59]

Aligning with one of the thematic approaches being to facilitate the application of tools for the preservation and sustainable use of the ecosystem, the rapid advancement of AI technologies and big data opens new frontiers in marine preservation. The concept of Artificial Intelligence (AI) refers to a set of technologies that enable computer systems to perform tasks requiring human intelligence, such as learning, reasoning, and problem-solving. By mimicking human capabilities, AI enhances functions like understanding and translating written and spoken language, analyzing large datasets, and making recommendations, often surpassing human performance by rapidly learning patterns and leveraging big data. The term, big data is used to denote the generation and analyzing of

[55] JOUAV, 'Habitat Fragmentation: Causes, Effects, and Solutions' (JOUAV, 14 September 2024) <https://www.jouav.com/blog/habitat-fragmentation.html#:~:text=Development%20and%20construction%3A%20Building%20roads,purposes%20can%20create%20fragmented%20landscapes.> accessed 6 February 2025.

[56] Faith Sayo, 'How to Reduce Habitat Loss to Save Endangered Species' (Earthly, 23 July 2024) <https://earthly.org/blog/how-to-reduce-habitat-loss-to-save-endangered-species> accessed 6 February 2025.

[57] Ibid.

[58] Palmer (n 13).

[59] Ibid.

large amounts of data from various sources, including remote sensing, environmental sensors, etc.[60]

The application of AI technologies and Big Data has the capacity to enhance more effective and precise approaches hence, reforming the strategies being deployed in the preservation of the marine ecosystems. Significantly, AI technologies, particularly machine learning, have through its ability to accurately process large volumes of data rapidly, identify patterns, and predict future trends, enhanced the analyzing of complex biodiversity data.[61] For example, aside the application of AI technology like geographic information systems (GIS) in mapping degraded ecosystems that require large-scale restoration projects and tracking the progress over time, AI algorithms have been used to monitor wildlife populations, conduct environmental DNA (eDNA) analysis, collate high-resolution data that can be used to assess the impact of human activities on ecosystems, etc., thereby assisting conservationists to effectively allocate resources and implement timely interventions.[62]

2.0. Artificial Intelligence in Marine Ecosystem Preservation

2.1. Overview of Artificial Intelligence Technologies

AI refers to a collection of technologies including machine learning, natural language processing, and deep learning, which allow a computerized performance of tasks similar to human cognitive functions using data, algorithms, and human feedback.[63] As an advanced technology, it allows the use of data to train algorithms for decision making or predictions, the processing of large amounts of ecological data to find patterns and solve complex problems, and the learning from experience and adjusting to new inputs.[64] AI technologies have become integral to marine biodiversity conservation, offering unique capabilities and innovative solutions for preservation efforts through the instrumentality of its diverse technologies. Agentic AI, a recent invention per MIT Sloan, adds autonomous decision-making, enhancing adaptive conservation strategies.[65]

AI-driven acoustic monitoring utilizes sound recordings for biodiversity monitoring, particularly in remote or inaccessible areas and machine learning models analyze audio data to detect and classify species based on their vocalizations. This method has thus, been

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[60] SEDNA, 'Big Data in the Maritime Industry: Use Cases and Challenges' (SEDNA, 15 December 2023) <https://sedna.com/resources/big-data-in-the-maritime-industry-use-cases-and-challenges> accessed 7 February 2025.

[61] Ayoola and ors (n 22)1854-1855.

[62] Sayo (n 30); Ibid.

[63] FINRA, 'Overview of Artificial Intelligence Technology' <https://www.finra.org/rules-guidance/key-topics/fintech/report/artificial-intelligence-in-the-securities-industry/overview-of-ai-tech#:~:text=The%20term%20artificial%20intelligence%20broadly,are%20said%20to%20involve%20intelligence.%E2%80%9D> accessed 8 February 2025.

[64] Ibid; Cole Stryker and Eda Kavlakoglu, 'What is Artificial Intelligence (AI)' (IBM, 9 August 2024) <https://www.ibm.com/think/topics/artificial-intelligence#:~:text=Artificial%20intelligence%20(AI)%20is%20technology,and%20respond%20to%20human%20language.> accessed 8 February 2025.

[65] Mark Purdy, 'What is Agentic AI, and How will it Change Work?' (Harvard Business Review, 12 December 2024) < What Is Agentic AI, and How Will It Change Work?> accessed 12 February 2025.

deployed in various ecosystems, including the marine habitats, providing valuable data on the presence and abundance of species.[66] Natural language processing (NLP) technology as a subfield of AI relates to availing computers the ability to comprehend the text and spoken words just like human beings, through a combination of varying concepts and technologies like computational linguistics, thereby modeling the human language based on statistical models, data-driven models, and certain rules.[67]

Deep learning, on the other hand, specifically uses artificial neural networks with multiple layers, imitating the human brain to handle difficult tasks and gain insight from large datasets, often requiring significantly more data and computational power when juxtaposed with machine learning algorithms.[68] In preserving the marine biodiversity, deep learning models have been applied to identify and classify species from images and audio recordings with high accuracy.[69] Also, as agricultural runoffs and land-based wastes, including macro and micro plastics, enters the ocean in large quantities and these nonpoint sources, are considered significant contributors to marine pollution, deep learning is also applied in analyzing satellite images to detect changes in land use and cover, contributing to comprehensive conservation efforts.[70]

AI technologies can also be incorporated by robotics to enhance their capabilities in utilizing autonomous underwater vehicles to monitor marine biodiversity. This is because despite the global environmental monitoring through the widespread use of remote sensing, there exists difficulty in the detection of small objects like floating waste, the vast surface of the ocean, and light cannot reach these objects in deep ocean ecosystems. Hence, an autonomous monitoring system consisting of optimally controlled robots is essential for obtaining time-space rich marine data.[71] In India, IoT-enabled AUVs now track microplastic flows, offering scalable solutions for coastal monitoring.

2.2. Role of AI Technologies in Marine Preservation

2.2.1. Data Analysis and Pattern Recognition

The analysis of marine environmental variables and occurrence data are important determinants in marine biodiversity conservation. Accordingly, AI technologies play essential role in data analysis and pattern recognition by enabling researchers to efficiently

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[66] Ayoola and ors (n 22) 1861.

[67] Evan Palmejar, How Can Natural Language Processing (NLG) Improve Safety at Sea? (Thetius, 2022) <https://thetius.com/how-can-natural-language-processing-nlp-improve-safety-at-sea/> accessed 9 February 2025.

[68] IMD, Deep Learning vs. Machine Learning: What's the Difference? (IMD, January 2025) <https://www.imd.org/blog/digital-transformation/deep-learning-vs-machine learning/#:~:text=odyssey%20with%20IMD-,What%20are%20deep%20learning%20and%20machine%20learning?,next%20move%20based%20on%20feedback.> accessed 8 February 2025.

[69] Ayoola and ors (n 22) 1861.

[70] Muhling SMK, 'Utilizing Artificial Intelligence (AI) for the Identification and Management of Marine Protected Areas (MPAs): A Review' [2023] 11(9) Journal of Geoscience and Environmental Protection 118-132, 120-121.

[71] Ibid.

process large datasets, unravel patterns, and make predictions that inform preservation strategies.[72] These technologies have boosted marine data collection and analysis in hard-to-reach places, utilizing techniques such as autonomous underwater vehicles (AUVs) and drones, thereby increasing the data collection scope in both the temporal and terrestrial domains.[73]

Particularly, by learning from historical data for pattern identifications and predictions, machine learning algorithms are extensively used for marine biodiversity data analysis. It has been revealed that prediction accuracy can be increased by up to 30% when machine learning is used for species distribution modeling.[74]

Natural Language Processing ("NLP") technologies have also been used to analyze vast text data for biodiversity monitoring and identification of emerging threats, relying on scientific literature, social media conversations, and citizen science reports. As the NLP techniques can extract relevant information and decipher trends in marine biodiversity data, it has been utilized in analyzing social media data to provide insights into species occurrences and public views of biodiversity preservation issues.[75] In support of its role in data analysis and pattern recognition, deep learning algorithms have been applied to image and audio data to identify animal species and monitor wildlife populations with an accuracy rate of 90%.[76] Accordingly, this algorithm can also be deployed in marine biodiversity conservation efforts, significantly reducing the need for manual verification.

2.2.2. Real-Time Monitoring and Surveillance

A transformative approach towards protecting the marine habitat is by monitoring and surveillance, conservation efforts facilitated by AI's automated collection, processing, and analysis of large volumes of data. These algorithms can been used in marine conservation to analyze data gathered from remote sensing technologies, acoustic sensors, and underwater cameras so as to detect and identify species, observe their behaviors, and evaluate the health of the ecosystems.[77]

Particularly, with AI-driven monitoring and surveillance systems, machine learning and deep learning can be used effectively and accurately to monitor species and habitats as comparative studies have shown that the use of AI in real-time monitoring can increase the efficiency and accuracy of monitoring efforts by up to 80% unlike traditional methods.[78] Moreover, as an outbreak of disease in the marine ecosystem can impede species distribution and may lead to their eventual extinction, the efficacy of AI technologies in marine preservation also extends to disease surveillance. Advanced AI algorithms can analyze patterns in environmental data, such as temperature and humidity, together with

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[72] Ayoola and ors (n 22) 1861.

[73] Muhling (n 44) 120.

[74] Enrico Di Minin, Tenkanen Henrikki and Tuuli Toivonen, 'Prospects and Challenges for Social Media Data in Conservation Science' [2015] 3(63) *Frontiers in Environmental Science 1-6.*

[75] Ibid 2 - 4.

[76] Ayoola and ors (n 22) 1862.

[77] ibid.

[78] Niamh Eastwood and ors, '100 Years of Anthropogenic Impact Causes Changes in Freshwater Functional Biodiversity' [2023] 12 *eLife 1-28.*

species health indicators in order to predict disease outbreaks which allows for proactive steps to prevent its wide spread. Notably, this predictive capacity of AI-driven algorithms have been applied in monitoring the health of marine organisms, successfully predicting disease outbreaks in coral reefs with an 85% accuracy rate, enhancing speedy intervention strives.[79]

In enhancing the efficiency and accuracy of monitoring systems, deep learning algorithms can be used to facilitate more efficient surveillance by automating the identification of marine life in images, machine-learning techniques can use underwater photos to identify and categorize marine species while acoustic data can be used to follow their movement.[80] Clearly, these automations reduces the time and labor required for monitoring and surveillance activities, allowing conservationists to focus on strategic decision-making More so, these AI-driven techniques can be applied in further learning about the ecology and behavior of sea creatures[81] Citizen science apps in Australia now allow real-time reporting of marine health, amplifying AI's reach.

2.2.3. Predictive Analysis for Disaster Prevention

At present, advanced technologies are revolutionizing the way we approach natural disasters and other emergencies, providing unrivaled capabilities in forecasting, preparation, and response. AI-driven techniques impact the predicting and forecasting of ocean conditions which are instrumental for disaster prevention by processing and combining data from diverse sources like weather forecasts, population density, geological data, and infrastructure vulnerability, thereby enhancing the predictive creation of a comprehensive picture of potential disaster risks and early warnings to for its prevention.[82]

Machine learning algorithms have been used to predict ocean tides, currents, and weather patterns, as well as likelihood, severity, and potential impact of a disaster with high accuracy and with these predictions, the safety in marine operations such as shipping and fishing can be improved.[83] Thus, machine learning can, with sufficient data, demonstrate high predictive performance on tasks where good mathematical models are lacking. Equally, in scientific areas that do rely on well-understood mathematical models, such as

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[79] Ayoola and ors (n 22) 1863.

[80] Muhling (n 44) 120.

[81] Ibid.

[82] IEEE, 'Predictive Analytics in Disaster Prevention: Machine Learning Models for Early Warning Systems' <https://publicsafety.ieee.org/topics/predictive-analytics-in-disaster-prevention-machine-learning-models-for-early-warning-systems#:~:text=By%20leveraging%20advanced%20computational%20methods%2C%20predictive%20analytics,hurricanes%20and%20earthquakes%20to%20floods%20and%20wildfires.&text=These%20systems%20leverage%20the%20predictive%20power%20of,take%20proactive%20measures%20to%20mitigate%20potential%20risks.> accessed 14 February, 2025.

[83] Muhling (n 44) 120.

weather forecasting, ML can increase modeling performance at reduced computational cost.[84]

Also, deep learning significantly enhances predictive analysis for disaster prevention, enabling the identification of complex patterns within vast environmental datasets like weather patterns and satellite imagery, giving room for more accurate natural disaster predictions which in turn provides time for proactive mitigation and evacuation efforts.[85] In the Arctic, AI now models sea ice melt rates, predicting impacts on marine species with 87% accuracy. Support Vector Machines (SVMs) are also valuable for categorizing potential disaster events based on various input parameters. Accordingly, in flood prediction, for instance, SVMs can analyze crucial factors for emergency management such as rainfall intensity, soil moisture, river levels, and topography to classify areas as low, medium, or high flood risk.[86]

2.2.4. Illegal Fishing Detection

One of the leading causes of disturbances in the marine realm is Illegal and unregulated fishing with consequences such as trophic cascade as well as extinction threats to marine species. Strikingly, illegal or unregulated fishing is estimated to be as much as 20% of what is caught as up to 26 million tonnes of fish or one in every five fish are caught through such illegal, unreported and unregulated (IUU) fishing every year.[87] With these overfishing activities, the United Nations has noted that a third of global fish stocks are now being fished beyond biologically sustainable levels.[88] To curb this, AI technologies can be used in identifying these IUU patterns by analyzing vessel tracking systems and data, like routes and activities, coupled with examining aerial and satellite imagery as well as radar information to identify vessels that fail to broadcast their positions.[89] A clear example is the financial penalties that were imposed by the Spanish government on 25 Spanish-flagged fishing ships which had been operating near Argentina's territorial waters because the vessels illegally turned off the GPS-based automatic identification systems (AIS), which were transmitting their positions.[90] In West Africa, AI-driven surveillance has reduced IUU fishing by 15% since 2023, showcasing regional impact

Furthermore, although the use of AIS is not a legal requirement for all ships, and researchers have found that three quarters of the world's industrial fishing vessels are not publicly tracked, with particular hot spots around South Asia and Africa and, yet, AI's fishing detection algorithm can work out the likelihood of these "dark" vessels to be engaging in fishing

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[84] SA Reynolds and ors, 'The Potential for AI to Revolutionize Conservation: a Horizon Scan' [2025] 40(2) Cell Press Journal 191-207..

[85] IEEE (n 76).

[86] Ibid.

[87] Emma Woollacott, 'How AI is Being Used to Prevent Illegal Fishing' (BBC, 3 April 2024) <https://www.bbc.com/news/business-68564249> accessed 15 February 2025.

[88] Ibid.

[89] Gibin WO, 'The Role of Artificial Intelligence in Marine Environmental Protection Introduction' (LinkedIn, 17 December, 2024) <https://www.linkedin.com/pulse/role-artificial-intelligence-marine-environmental--ac1zf> accessed 14 February 2025; Muhling (n 44) 121.

[90] Woollacott (n 61).

using information like the vessel's length, environmental information as to the vessel's location, the imaging of the area, the density of vessel traffic in the area, the ocean condition, etc. [91]

2.2.5. Sustainable Resource Management

AI-driven models are fundamental to marine research and management of resources. AI can analyze data on fish populations, migratory patterns, and the impact of fishing activities, aiding the effective establishment of more sustainable management policies.[92] By using these models, fishing activities can be done sustainably, overfishing can be avoided, and resources can be allowed to regenerate naturally.

Again, as improperly disposed wastes, debris from coastal activities like beach litter, dumping from boats, as well as poor waste management practices exacerbates the large garbage patches that accumulate and pollute marine health, AI technologies also play a role in curbing ocean pollution through the instrumentality of a deep learning algorithm called YOLOv3 which enhanced the detection of floating debris on the ocean and underwater sea life with 77.2% and 69.5% sensitivity, respectively.[93] Thus, AI-driven systems are revolutionizing marine conservation efforts and imperatively, enhancing the sustainable management of marine resources.

3.0. Big Data in Marine Biodiversity Preservation Strategies

Generally, Big Data integration is fundamental for detailed biodiversity monitoring and effective conservation strategies. In marine ecosystem preservation, Big Data entails the diverse-sourced large and complex datasets, including environmental sensors, remote sensing, global biodiversity databases, and citizen science initiatives which cannot be handled, analyzed, stored, and shared with common tools.[94] These Data can emanate from structured sources like species databases and unstructured sources like social media posts and images and their volume, variety, veracity, and velocity in addition to technological advancement enable their vast collection and analysis which are essential for identifying patterns and changes in biodiversity over time and across different spatial scales.[95] Equally, this diversity of data types enhances the ability to conduct varying analyses that consider different aspects of biodiversity and ecosystem health.[96]

Big Data in marine preservation has helped identify MPAs i.e. areas irreplaceable for species conservation as well as multi-species hotspots requiring improved protection.[97] Notably, these track-based protected areas take the form of Essential Fish Habitats (EFHs), Ecologically or Biologically Significant Areas (EBSAs), Important Bird and Biodiversity Areas

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[91] Ibid.
[92] Gibin (n 63).
[93] Muhling (n 44) 121.
[94] D Gremillet, D Chevallier and C Guinet, 'Big Data Approaches to the Spatial Ecology and Conservation of Marine Megafauna' [2022] 79 *ICES Journal of Marine Science 975-986*, 976; Ayoola and ors (n 22) 1856.
[95] Ayoola and ors (n 22) 1856.
[96] Ayoola and ors (n 22) 1856.
[97] Gremillet, Chevallier and Guinet (n 68) 980.

(IBAs), and of Important Marine Mammal Areas (IMMAs).[98] Tracking data as a component of big data therefore provide important information on distribution and connectivity, which is critical to overcoming the monitoring and enforcement challenges associated with large-scale governance of dynamic and remote seascapes while informing government policy and management actions.[99] In the Philippines, citizen science data via iNaturalist has identified new EBSAs, filling gaps in remote areas.

3.1. Sources of Big Data in Biodiversity and Marine Preservation

Undoubtedly, comprehensive monitoring and management efforts in marine preservation are influenced by the use of Big Data. Its innumerable role in preserving the marine ecosystem notwithstanding, it is important to consider the diverse sources of these data that collective aid marine preservation and these sources include remote sensing data, global biodiversity databases, and citizen science initiatives.

3.1.1. Remote Sensing Data

A healthy marine habitat enable species to thrive therein and without a thriving ocean, the species on earth will also begin to die out given their interconnectedness. To this effect, remote sensing data, aerial biodiversity monitoring, and satellite imagery provide extensive coverage and high-resolution data on habitat fragmentation, environmental parameters, and changes the structure of ecosystems.[100] Clear examples are the NASA's Landsat and the European Space Agency's Sentinel satellites and by offering such critical, spatially comprehensive and large-scale information about the ocean conditions like sea surface temperature, chlorophyll concentration, and ocean current, the presence and distribution of marine life can be inferred, particularly in areas that are difficult to access directly through traditional field surveys.[101] IoT networks in the Caribbean now complement this, tracking real-time water quality shifts.

3.1.2. Global Biodiversity Databases

Generally, data's velocity requires the constant generation of new data, making it difficult for organizations to cope with its constant flow.[102] When large datasets are to be obtained from diverse sources, its non-unified collection through various means like remote sensing, automated survey, and Edna Analysis may pose a challenge. In addressing this limitation, Databases such as the Ocean Biodiversity Information System (OBIS), NatureServe and Global Biodiversity Information Facility (GBIF) provide unified repositories of biodiversity, making data openly accessible and also supporting research and

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[98] Ibid.

[99] RA Magris, 'Effectiveness of Large-Scale Marine Protected Areas in the Atlantic Ocean for Reducing Fishing Activities' [2021] 8 *Frontiers in Marine Science 1-7.*

[100] Ibid 1857-1858.

[101] MT Kavanaugh and ors, 'Satellite Remote Sensing and the Marine Biodiversity Observation Network: Current Science and Future Steps' [2021] 215 *Oceanography*; Ayoola and ors (n 22), 1857-1858.

[102] Helen Zhuravel, 'How Big Data and AI Work Together: A Deeper Dive' (Binariks, 3 February 2025) <https://binariks.com/blog/how-big-data-and-ai-work-together/> accessed 17 February 2025.

conservation efforts. OBIS serves as a comprehensive open-access repository for marine life observations worldwide, NatureServe offers comprehensive distribution data for species of conservation interest in North America while GBIF hosts over 1.9 billion occurrence records from around the world.[103]

3.1.3. Citizen Science Initiatives

As a means of gathering large datasets for expanding the scope and scale of marine biodiversity monitoring, Citizen Science Initiatives engage the public in data collection through Platforms like eBird and iNaturalist and which enable non-scientist volunteers to record their observations of marine species and ecosystem health across wide geographic areas, effectively enhancing scientists' ability to track species distributions and population trends and fill data collection gaps especially in understudies regions.[104] Notably, these platforms have recorded millions of observations globally, with eBird accounting for over 100 million bird observations per year. [105] IoT networks in the Caribbean now complement this, tracking real-time water quality shifts.

When Big Data technologies are applied in integrating these interconnected data sources, it enables more effective data collection and informed decision-making, contributing to comprehensive biodiversity monitoring and management efforts.

4.0. Relationship Between Artificial Intelligence and Big Data in Marine Preservation

The emergence of the digital era has birthed an unrivalled generation of data, with each click, swipe, and search query leaving a digital trail that prompts the creation of AI and Big Data. While these two concepts are distinct, a combination of both offers enormous benefits in preserving the marine habitats. Accordingly, integrating AI and Big Data in the preservation of the marine habitat is transforming decision-making, real-time monitoring, and resource management practices.

On the one hand, Big Data houses the undiscovered patterns and insights that may be the source of transformative marine preservation strategies and harnessing its advantages requires powers devices like AI. On the other hand, AI as an advanced technology is equipped with algorithms and processing capabilities for exploring these large datasets by filtering diverse information to obtain requisite knowledge, recognize patterns,

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[103] UNESCO, 'COP16 Outcomes: Ocean Observing and Data for Biodiversity Conservation' (UNESCO, 20 November 2024)<https://oceandecade.org/news/cop16-outcomes-ocean-observing-and-data-for-biodiversity-conservation/#:~:text=The%20Ocean%20Biodiversity%20Information%20System%20(OBIS)%20is,largest%20open%2Daccess%20database%20of%20marine%20life%20observations.> accessed 17 February 2025; GBIF, 'Global Biodiversity Information Facility' ,https://www.gbif.org> accessed 17 February, 2025; Ayoola and others (n 22), 1857-1858.

[104] Olivia Moller, 'How Citizen Science Expands Ocean Data Collection' (Alchemy, 16 September 2024) <https://alchemy.gr/post/912/the-power-of-citizen-science-in-ocean-conservation#:~:text=For%20ocean%20conservation%20specifically%2C%20citizen,temporal%20scope%20of%20data%20collection.> accessed 17 February 2025.

[105] Ayoola and ors (n 22) 1857-1858.

and predict future trends.[106] Hence, while Big Data houses huge amount of requisite structured and unstructured complex data without the ability to analyze them, AI technologies rely on these data supplied by Big Data to extract deep and valuable pattern and learning, which also improves the next round of data collection.[107] With this, large datasets can now be handled in an accurate, efficient, and insightful manner. Scalable cloud platforms now make this synergy accessible to smaller organizations, a trend noted in MIT Sloan.

More so, Big Data lays the foundation upon which AI algorithms learn their understanding of complex scenarios and then respond with predictions, decision-making, and recommendations in marine preservation strategies.[108] By understanding these complex datasets, its analysis can then be automated, enhancing the data processing and analysis as well as decision-making without human intervention. This also extends to the uncovering of hidden patterns, detection of anomalies, and predicting outcomes of marine biodiversity conservation efforts with greater precision and speed which would be impracticable for humans to accomplish manually.[109] For instance, the speed of biodiversity data processing has increased by about 60% through the use of AI models in analyzing satellite imagery and sensor data.[110]

The combined use of these two important tools unlocks the transformative potential they offer in enhancing the preservation of the marine ecosystem. The advancements offered by the synergy between AI and Big Data such as the provision of more accurate predictions, enhanced real-time data analysis, and reduced operational costs for more informed decision-making, underscore the critical role of technology and Big Data in driving effectiveness and efficiency in marine ecosystem preservation efforts.

4.1. Benefits of a Combined Approach in Marine Preservation

With AI acting as the engine (algorithms) and Big Data providing the fuel (data) for the functioning of this engine, the combined use of AI and Big Data in marine preservation helps in achieving the following:

a. **Large datasets analysis for key trends**: With the traditional manual approaches of data analysis, the identification of certain key trends and connections are made impossible.[111] With AI and Big Data however, the analyzing of large datasets is enhances, improving the understanding of key trends like environmental changes and potential threats, species distribution, and ecosystem dynamics, which is essential for effective conservation planning.[112]

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106 Zhuravel (n 76).

107 Ibid.

108 Ibid.

109 Enterprise Big Data Framework, 'Unlocking the Synergy: The Difference and Relationship of Big Data and AI' (Enterprise Big Data Framework, 13 September 2023) <https://www.bigdataframework.org/knowledge/unlocking-the-synergy-the-difference-and-relationship-of-big-data-and-ai/> accessed 17 February 2025; Ayoola and ors (n 22) 1864.

110 ibid.

111 Zhuravel (n 76).

112 Ayoola and others (n 22) 1865.

b. **Efficiency and precision in species identification and decision-making**: The effective tracking of biodiversity changes, biodiversity-related decision-making, and the implementation of appropriate conservation strategies requires high level of precision. With AI and Big Data, decision-making capabilities are enhanced and such decisions made in the realm of marine biodiversity preservation will be based on actual experiences, which improve both efficiency and precision.[113] Equally, its use in the identification of species and habitat assessment improve the accuracy level of the results.[114]
c. **Speedy data processing and analysis with reduced cost:** The use of AI and Big Data in marine preservation allows for more extensive and frequent data collection from various sources, which is crucial for timely and effective conservation actions.[115] By combining data from Internet of Things (IoT) sensors, satellite imagery, and ground observations, AI can provide a comprehensive and cost-effective view of ecosystem health.[116] For instance, compared to traditional methods, the monitoring of coral reefs using automated systems have shown a 99% cost reduction and process data at 200 times the speed of traditional methods.[117] Also, the integration of these data sources helped Dow Inc. identify nature-positive and cost-effective solutions, leading to an estimated $2 million in savings over ten years by restoring natural habitats (California Management Review, 2023).[118]
d. **Automation of complex steps and procedures**: Deploying the combined use of AI and Big Data in marine preservation strategies enhances the automation of complex procedures by enabling habitat mapping, real-time monitoring, predictive analysis, and species identification, allowing for targeted interventions and efficient ecosystem management, thereby reducing the need for human resources in manual data collection and analysis in complex processes and making same available for other strategic purposes.[119]
e. **Enhanced predictive analysis for disaster prevention:** A combined use of AI and Big Data in marine preservation also supports predictive analysis for disaster prevention. By processing and combining data from diverse sources like weather forecasts, population density, geological data, and infrastructure vulnerability, the predicting and forecasting of ocean conditions is made possible.[120] Accordingly, through continuous data mining, Big Data constructs historical patterns which are used by AI algorithms to make forecasts and predict future outcomes of potential disaster risks and timely warnings to for its prevention.[121]

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[113] Zhuravel (n 76).
[114] Ayoola and others (n 22) 1865.
[115] Zhuravel (n 76).
[116] Ayoola and others (n 22) 1865.
[117] Ibid.
[118] Ibid.
[119] Zhuravel (n 76).
[120] IEEE (n 76).
[121] Zhuravel (n 76).

4.2. Challenges in the Integration of Artificial Intelligence and Big Data in the Preservation of the Marine Ecosystem

While the benefits of a combined approach in the use of AI and Big Data in marine preservation cannot be overemphasized, their integration is not without its challenges and limitations some of which includes:

i. **Dependence on data quality and quantity:** The efficiency of AI technologies is enhanced by the quality and volume of available marine data. Accordingly, as data that meets the above requirements which are essential for developing accurate machine learning models can be limited, the accuracy of AI models can be impacted occasioning inaccurate or unreliable outputs and hindering effective marine preservation strategies based on these analyses.[122] Also, due to the uneven coverage of digital data across different regions and the diversity of languages globally, creating these datasets can be particularly difficult and such insufficiency of data may not provide enough information required for training models accurately for complex marine ecosystems.[123]

ii. **Data privacy and security considerations**: The effective functioning of AI algorithms is data-dependent which offers both opportunities for convenience and worries related to data privacy violations, particularly when it involves sensitive information about the locations of vulnerable species, vessel movements, fishing activities.[124] Thus, while harnessing the potential of AI and Big Data in marine preservation is crucial, ensuring that its use is does not compromise data privacy and security or harm biodiversity or is equally essential so as to avoid exploitation.[125]

iii. **Computational power demands:** running AI algorithms on large marine datasets can require substantial computational resources which presents a significant challenge for marine preservation efforts. Building and managing AI infrastructure can also be expensive and challenging; including the purchasing of hardware and software and paying for cloud computing services that supports the computational power of AI.[126] Accordingly, these challenges limit the accessibility and scalability of these technologies, limiting the ability of researchers' smaller organizations with limited resources to effectively utilize AI for marine preservation analysis.[127] Although the efficiency of the systems can reduce the high short-term costs overtime, such efficiency can however, only be achieved when the requisite datasets are effectively processed and analyzed which in itself, requires such significant resources.[128]

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[122] Ayoola and ors (n 22) 1865.

[123] Ketil Malde and ors, 'Machine Intelligence and the Data-driven Future of Marine Science' [2019] 77(4) *ICES Journal of Marine Science 1274-1285.*

[124] Ayoola and ors (n 22) 1866.

[125] Zhuravel (n 76).

[126] Ibid.

[127] David B Olawade, 'Artificial Intelligence in Environmental Monitoring: Advancements, Challenges, and Future Directions' [2024] 12 *Hygiene and Environmental Health Advances 100-114.*

[128] Ayoola and ors (n 22) 1866.

iv. **Requirement of sophisticated data management and processing capabilities:** Marine biodiversity data are sourced from diverse origins including remote sensing, satellite imagery, citizens science initiatives, field observations, IoT devices, etc each with different standards and formats. Accordingly, the integration of these divergent data sources into a harmonized framework requires sophisticated data management and processing capabilities, in the absence of which the quality and usability of marine datasets are affected.[129]

4.3. The Way Forward

The integration of AI and Big Data offers innumerable potential in marine preservation, though certain challenges are encountered in the course of harnessing of these potential. One of such challenges is the limited nature of marine data quality and quantity since AI algorithms are trained on the available data to discover patterns and make predictions. Addressing this therefore requires the identification of critical data points, implementation of strong data collection systems using sensors and IoT devices, establishing processes for data cleaning and validation using quality tools so as to eliminate errors, ensuring cooperation with multiple marine data sources, and monitoring data quality through feedback loops on a regular basis so as to support the development of accurate machine learning models and the capturing of comprehensive and accurate marine data which are essential in marine preservation.[130] Open-source tools like TensorFlow can lower entry barriers, enabling scalable solutions in regions like Southeast Asia

There is an overwhelming need for regulatory frameworks to be put in place and effectively implemented to avoid the potential risk associated with collection, storage, analysis, and privacy infringement in the use of data and AI technologies.[131] This ensures transparency and addresses the ethical concerns and policy implications in the use of AI technologies and Big Data in preserving the marine ecosystems. Importantly, these frameworks must ensure that while AI technologies utilize data to enhance their functionality, there must be strict compliance with data privacy regulations.[132] For example, the EU's GDPR provides a model for balancing innovation and privacy in marine data use.

The absence of an overarching structure in the storage and management of data undeniably propels disorganization, duplication, and inconsistency in data quality. It is therefore important to establish a well-designed data management system which will ensure data quality and usability, considering the level of processing capabilities and sophistication that is required in managing marine data from different sources.[133] A well-structured data management system supports the automation and integration of data to

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[129] ibid

[130] Envision, '5 Data-Driven Steps to Boost Marine Offshore Efficiency' (Envision, 10 October 2024) <https://www.envisionesl.com/blog/5-data-driven-steps-to-boost-marine-offshore-efficiency> accessed 19 February 2025.

[131] Ayoola and ors (n 22) 1866.

[132] Zhuravel (n 76).

[133] Ayoola and ors (n 22), 1866.

seamlessly exchange identifiers, measurements, and more with key software for cataloging species, mapping, and running analyses.[134] This will also aid the creation of centralized information networks when responding to environmental incidents, improve access to field data collections from any location, and enable more strategic and data-driven decision-making over time**.**

5.0. Conclusion

Artificial intelligence is neither a magic solution nor not a knowledge collection but a technique that helps machines substitute human intelligence using Big Data and when applied correctly and ethically, can be a significant asset in the fight to preserve the oceans, turning marine environmental challenges into opportunities for the restoration and protection of the vital ecosystems of our oceans. This article underscores the transformative potential in leveraging AI and big data as essential tools that provide innovative solutions to track, analyse, and combat the threats affecting the marine habitats so as to ensure a more sustainable future for generations to come.

This paper recommends that proactive steps be taken to boost data quality and quantity, the enactment and effective implementation of a robust framework that address the associated risk of data privacy infringement and other ethical considerations while using AI technologies, the investment in technological infrastructure to boost the computational demands involved in the application of AI technologies and Big Data, and the establishment of well-designed data management system to ensure data usability and improvement in its quality to support a coordinated and effective approach towards marine preservation. It also advocates for scalable, low-cost solutions like cloud platforms and citizen science apps to ensure accessibility across diverse regions.

Above all, there is need for strategic collaborative efforts involving multiple stakeholders, including federal agencies, private partners, and local communities as global actions will affect local territories, and vice versa. More so, as nature does not observe national boundaries, stakeholders at all levels will need to be conscious of how their behaviours and actions affect the marine ecosystems on which we all depend, and make conscious decisions to improve our relationships with the ocean. This is because the continuous depletion of the marine ecosystems would cause the extension of such consequences to the ecosystems on land and the species on earth will also begin to die .If we are to achieve the Sustainable Development Goals (SDGs), we need to effectively and efficiently deploy the benefits of AI technologies and Big Data in marine conservation strategies as doing so will ensure a balance in economic development and marine preservation, securing a sustainable and resilient future for both the marine ecosystems and the earth.

[134]ioMoVo, Managing Marine Conservation Data With DAM Software (ioMovo, 13 June 2024) <https://www.iomovo.io/blog/managing-marine-conservation-data-with-dam-software> accessed 19 February 2025.

EXPLORING THE CRITICAL NEXUS IN INFORMAL CROSS-BORDER TRADE BETWEEN NIGERIA AND CAMEROON: IMPLICATIONS FOR POLICY REFORM IN NIGERIA

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Abstract
The environment of restrictive trade policies, high tariffs, and inadequate infrastructure often give rise to informal cross-border trade (ICBT) with a corresponding loss of revenue for governments and potential economic instability. However, ICBT has remained a potential source of employment, economic well-being and livelihood for many people. This study examines the critical nexus underlying ICBT, with a focus on the implications for policy reform. Three objectives and three research questions were proposed and answered respectively in this study. Data was generated from 269 respondents, comprising of cross-border traders and boat owners using a researcher developed questionnaire titled 'Cross-Border Trade Assessment Questionnaire' (CBTAQ). Using descriptive statistics with qualitative insights from case studies, the researchers identified key products such as fuel, electronics, cosmetics, beverages, rice, vegetables, fairly used clothes and shoes among others as key traded products in ICBT between Nigeria and Cameroon. Again, findings revealed an estimated trade value of not less than 6billion Naira per month. Result also revealed that simplifying trade regimes and reducing barriers can encourage informal traders to formalize their operations. Based on the findings of this study, the researcher concluded that formalizing commercial links and trade between Nigeria and Cameroon will be of benefits in terms of generation of substantial revenue and employment opportunities in the border areas and beyond. Consequently, the researcher recommended the need for a comprehensive policy reform agenda that addresses the root causes of ICBT, promotes trade facilitation, and enhances access to finance for small-scale traders.

Keywords: Informal cross-border trade, trade policy, traded products, economic sustenance and formal cross-border trade.

Introduction

The need to know what we produce, what we consume, what comes into our country and what moves out of our country cannot be overemphasized and will remain an essential ingredient for policies. This knowledge facilitates targeted programmes in security management, incentives for agro and industrial production, control of flow of dangerous and substandard goods, job and wealth creation. The creation of custom services and trade regulations are essential for capturing and monitoring transactions of merchandise.

Particularly at major manned entry points such as airports, seaports and land transits border sites, governments has achieved a measure of success in getting trade data to enable it plan targeted response to push forward overall development goals. However, Informal Cross-Border Trade (ICBT) is an interesting trend which is gaining increasing attention from government, research community, international development agencies and academia. ICBT has been referred to as 'survival economy' or 'parallel trade' at different time and places and by different scholars. Elucidating on why it matters to have a knowledge of ICBT, Afrika and Ajumbo (2012) asserted that informal cross-border trade provides a source of income for approximately 43 percent of Africa's population.

This paper is an economic study of informal transactions of merchandise across the border trade points between Nigeria and Cameroon. Such transactions are not monitored and captured by custom authorities, and hence not included in the official statistics. However, when aggregated, these small transactions become significant due to their frequent occurrences. If properly harnessed, informal cross-border trade (ICBT) have the potential to support Nigeria's on-going efforts at poverty alleviation and youth engagement. The purpose of the ICBT study is to assess and measure the magnitude of informal (unrecorded) trade flows between Nigeria and Cameroon.

Despite what has been defined by law or regulations as informal or/and illegal in the exchange of products, services and technologies across our borders, these economic activities still constitute the nexus of transnational-local exchange and a means of economic sustenance of border area traders and allied business. The critical nexus in informal cross-border trade refers to the complex relationships between trade policies, economic conditions, and social factors that drive informal trade. Informal cross-border trade (ICBT) is a significant phenomenon in Africa, accounting for a substantial portion of the continent's trade volume.

Karingi (2023) averred that informal cross-border trade involves a diverse range of goods, including non-processed and locally manufactured items, re-exports, and sometimes contraband, with variations across regions and borders. In the opinion of Farrell (2004), ICBT is associated with avoidance of paying taxes, ignoring product quality and safety regulations, as well as failure to register and to operate within established regulations. However, ICBT usually includes all economic activities that contribute to the Gross Domestic Product (GDP) but are not officially reported (International Labour Organisation, (2013).

The possible reasons for the growth of ICBT and other informal business activities in Africa may not be divorced from poor levels of economic growth, resultant weak employment conditions and increasing levels of poverty. Busani (2022) submitted that the size of the informal sector is a direct measure of the failure of socio-economic policies, mismanagement of economic resources, increase in population, rural and urban migration as well as the youth bulge.

Suffyan, Nimarkoh, Ny, Ogalo, and Owino (2017) defined an informal economy as all economic activities by workers or economic units that are in law or practice not covered or sufficiently covered by formal arrangements, including legitimately-produced goods and services that do not necessarily follow formal processes such as standards regulations, business registration or operational licenses.

ICBT is a double-edge sword with concomitant advantages and disadvantages. In matters of advantages, it has remained a source of livelihood to young graduates, youths, men and women, and most residents of borders points. On the other hand, it is dangerous if not regulated since it can create room for importation and exportation of dangerous and harmful products.

Types of products traded

Nigeria and Cameroon, although belonging to two separate regional economic communities, they have common boundaries which facilitates strong trading relationship. The trading corridors that exist between Nigeria and Cameroon via Akwa Ibom and Cross Rivers states, the $36 million border bridge, have given rise to ICBT and generating economic sustenance to traders and border area dwellers.

Alade (2016) reported from a survey that food products, vegetable products, animal and animal products, and foodstuffs constituted the bulk of the goods traded in ICBT depending on the predominant economic activities of the communities around a border area.

Some of the goods that Nigeria sells to Cameroon comprises of spare parts, building materials, cosmetics, household appliances, plastic buckets, and petroleum products (fuel, lubricants).

The World Bank estimates that actual bilateral trade amounts to more than USD 230 million, significantly higher than the officially recorded non-oil trade flows of between USD 10 and 40 million. Of these, Nigerian-made exports are estimated at $176 million, consisting largely of cosmetics, plastics, footwear, and other general merchandise, while Cameroon made exports are estimated at $62 million, largely consisting of paddy rice, soap, and agricultural products such as eru (Afang).

Suffyan, Nimarkoh, Ny, Ogalo, and Owino (2017) description of traded products in ICBT are industrial and agricultural commodities ranging from electronics, vehicle spare parts, cereals, fruits and vegetables to mattresses, duvets and other household goods. Soprano (2014) identified agricultural commodities, electronics, household appliances, clothes, shoes and cosmetics, among others as traded products in ICBT and observed that such trade supports livelihoods, and contributes to welfare and poverty reduction.

Meagher (2003) gave a striking description of ICBT as involving import and export of 'legal goods' outside the official channels. Njikam and Tchouassi (2011) has it that what is traded in ICBT in West African countries are mining and forestry products, agriculture products and services.

Value of traded products

Suffyan, Nimarkoh, Ny, Ogalo, and Owino (2017) asserted that ICBT constitutes a major form of informal activity in most African countries with reference to Southern African Development Community (SADC), with an estimated value of $17.6bn. World Bank (2020) reported that Cameroon and Nigeria both have large informal cross-border trade estimated at 80.4% and 90%.

Zarrilli, and Lopez (2020) asserted that informality is pervasive across the developing world and that a substantial share (30%-40%) of Africa's regional trade is

informal, and that four times as many cross border traders are likely to be operating outside the formal economy than within it.

Thus, the study recommends the following - fully integrated e-payment systems for duties, streamlined goods clearing systems, robust whistle blowing system tied to good reward system, frequent transfer of officers in and out of the border posts, enhanced compensation system for officers, adoption of incentive and regulatory policies by government to promote indigenous entrepreneurship and lastly, enhanced profiling system of duty payers for extension of discounts, rebates and waivers based on their transaction history from time to time.

Alade (2016) conducted a survey to measured informal cross-border trade in Nigeria in June 2013 – May 2014. Using sixteen (16) active border sites (Oron, Seme, Idiroko, Jato Aka, Chikanda, Babana, Jibia, Belel, Illela, Kamba, Zango Daura, Ikang, Maigatari, Kongolam, Mfum, and Gembu) which provided trading platforms between Nigeria and three of her key trading neighbouring countries: Cameroon, Benin Republic and Niger, the survey discovered that the total informal trade across the selected borders during the period stood at N1, 090, 890.58 million (US$ 6,912.96 million). The survey also revealed that vegetable products accounted for 56.7 per cent (or N618, 271.34 million) of the total informal trade between Nigeria and her neighbours during the survey period. This was followed by animal and animal products (12.6 per cent or N137, 907.53 million), transportation equipment (8.6 percent or N93, 322.01 million) and foodstuff (6.4 per cent or N69, 560.58 million).

Socio-behavioural effects of formalizing cross-border trade.

Soprano (2014) opined that traders involved in ICBT choose informality because of distrust, misunderstandings and complaints emanating from the activities of border officials. There is the need to make border a place where traders can cross safely, and officials can work efficiently. In other words, traders can safely use the formal border post and avoid prosecution and goods confiscation, which in turn is a boost to revenue generation as well as giving way to a gradual formalization of informal cross-border trade. There are conflicting opinion about the effects of ICBT on economic growth leading to two advocacies. Some believe that the ICBT needs to be formalized, while others view it as an indispensable economic phenomenon that can never be completely eradicated. The social costs of informality in terms of forgone taxes, lower productivity and lack of social security outweigh the benefits and therefore encouraging the formalization of informal activities should enhance social welfare (World Bank, 2011).

Simplifying trade regimes by way of reducing tariff and non-tariff barriers, enhancing infrastructure, streamlining customs procedures, and reducing bureaucratic hurdles can make formal trade more attractive as well as encourage informal traders to formalize their operations (Andrew, 2024). Additionally, enhancing access to finance and support to small-scale informal cross-border traders can help them transition to formal trade. Ultimately, addressing the critical nexus in informal cross-border trade requires a comprehensive approach that balances policy reform with economic development and social welfare considerations.

Ajayi (2021) investigated the impact of informal cross-border trade on national economic development using Nigerian Southern Borders as a case study. The sample size 101 and data generated was analyzed using descriptive statistics, multiple regression and pearson product moment correlation coefficient analysis. The result of the analysis indicated a positive and significant relationship between cross-border trade and per capita income whereas a negative and insignificant relationship was identified between informal goods coming in and going out of the country.

Statement of problem

Good policies are products of reliable data and information. The lack of reliable data on ICBT has long hindered the development of targeted policies and interventions. There is no record emanating from official monitoring of border crossings and that which provide a comprehensive view of ICBT dynamics. The social costs of informality in terms of forgone taxes, low quality of traded goods, dumping and lack of social security are matters of concern. ICBT is associated with the loss of revenue for governments and potential economic instability.

Objectives of the study

The aim of this study is to investigate the nexus between informal cross-border trades, regimes of regulations, and economic sustenance of traders operating between Nigeria and Cameroon borders. Specifically, this study will achieve the following objectives;

1. To review the nature of products traded informally between Nigeria and Cameroon borders
2. To estimate the value of the traded products between Nigeria and Cameroon borders.
3. To predict the socio-behavioural effects of a formalized cross-border trade between Nigeria and Cameroon borders.

Research questions

This study provided answers to the following research question;

1. What are the products traded informally between Nigeria and Cameroon borders?
2. What is the estimated value of the products traded in the past five months between Nigeria and Cameroon borders?
3. What will be the socio-behavioural effects of a formalized cross-border trade between Nigeria and Cameroon borders?

Methodology

This section of this paper provides the methods of the study, a sort of road map to the realization of the objectives of the study.

Area of study

This study was conducted in Nigeria using Akwa Ibom state and Cross Rivers states border trade points as focus areas. Akwa Ibom state and Cross Rivers states are Border States to Cameroon by land and sea. The choice of these areas was informed by the

significance of trade flow on these border points. Again, the time frame of this conference could not allow the researchers a wider area coverage which in turn constitute a limitation to this study.

Population of the study

The population of this study are all potential and consistent cross-border traders and boat owners operating between Nigeria and Cameroon through Akwa Ibom state and Cross Rivers states border trading points. Since there are no records or statistics of ICBT operators, the researchers cannot estimate the population of this study.

Sample and sampling techniques

The sample of this study is 269 respondents selected through accidental sampling methods. The choice of this sampling method was considered more appropriate because the sample are not known and are not located in a particular area, making them difficult to access. The researchers selected the sample who were readily available at different point in time. The sample frame is presented in table 1.

Table 1. Sample frame

Border Areas	Sampled Population	Percentage (%)
Ebughu	25	9
Ibaka	77	29
Ibeno	27	10
Ikang	51	19
Oron	89	33
Total	**269**	**100%**

Source: This study, 2025.

Methods of data collection

Data was collected on trade flows using a researcher developed questionnaire titled 'Cross-Border Trade Assessment Questionnaire' (CBTAQ), at five (5) informal cross-border trade points; Oron, Ibaka, Ebughu, Ibeno (Akwa Ibom state) and Ikang (Cross River state) and purposively selected based on the significance of trade flows on these border trade points. This ICBT survey report provides direction of trade, type of goods traded, estimates of informal trade flows and direction of socio-behavioural effect of transition to formal cross-border trade. The researchers visited the cross-border trading points at different intervals and administered the CBTAQ on respondents.

Methods of data analysis

Data generated using the CBTAQ was analyzed using descriptive statistics, specifically percentage analysis and interviews.

Results and interpretations

Results from analysis of data generated through the CBTAQ are analyzed and presented in relevant tables with interpretations.

Table 1: Analysis of respondents' gender

Sex	Frequency	Percentage
Male	193	72
Female	76	28
Total	269	100

Source: This study, March, 2025.

From table 2, male respondents accounted for 72 percent of the total sample, while the female folk made up the remaining 28 percent. This gender analysis revealed that there are more male in ICBT. This is possibly due to the high risk associated with ICBT, which invariably includes confrontation with security agents and sea pirates and the logistics for loading/offloading of traded products

Table 3: Analysis of respondents' educational levels

Educational Qualification	Frequency	Percentage
FSLC	19	7.1
WAEC/NECO	85	31.6
First Degree and above	165	61.3
Total	**269**	**100**

Source: This study, March, 2025.

From table 3, holders of First School Leaving Certificate (FSLC) accounted for 7.1 percent of the total sample, while the holders of WAEC or NECO accounted for 31.6 percent of the respondents. Furthermore and interesting, 61.3 percent of the sample were graduates, indicative of ICBT as a source of economic livelihood.

Table 4: Respondents' respondents' periodic trade analysis

Trading periods	Frequency	Percentage	Trips per Month
Weekly	28	10	4
2 Weeks Intervals	41	15	2
3 Weeks Intervals	23	9	1
Once a Month	177	66	1
Total	**269**	**100**	**8**

Source: This study, March, 2025.

Table 4 shows that each respondent makes a minimum of a single trip in a month. However, some make two trips while other make up to four trips in a month.

Table 4: Analysis of products traded

Products Traded	Frequency	Percentage
Single Product	71	26
Multiple Products	198	74
Total	**269**	**100**

Source: This study, March, 2025

Table 4 shows that while some ICBT traders trade on a single product, others trade on multiples of products

Table5: Most popular/common products traded

Most popular/common products	Frequency	Percentage
Fuel	97	36.1
Electronics	32	11.9
Cosmetics	18	6.7
Beverages	33	12.2
Rice	24	8.9
Vegetables	37	13.8
Fairly used clothes	7	2.6
Fairly used shoes	5	1.9
Yam	16	5.9
Total	**269**	**100**

Source: This study, March, 2025.

Table 5 shows that fuel is the most popular, most common and the main dominant product traded involving 97 traders, constituting 36.1% of the respondents. This was distantly followed by vegetable 37(13.8%), beverages 33(12.2%) and 32(11.9%). Other products traded includes rice, cosmetics, yam fairly used clothes and fairly used shoes, the last two being the least traded products.

Respondents' estimates of the value of the traded products

The estimated value of the traded products made by respondents on monthly bases were analyzed and presented in table 5:

Table 6: Respondents' estimate of single trip value of traded products

Value of traded products in Naira per trip	Frequency	Percentage
Below N10 million	33	12.3
N11 to N50 million	49	18.2
Above N50 million	187	59.5
Total	**269**	**100**

Source: This study, March, 2025.

From table 6, 33 cross-border traders and boat owners, constituting 12.3% of the respondents, estimated the value of their traded products per trip to be below 10 million

naira. Furthermore, 49, constituting 18.2% of the respondents estimated the value of their traded products per trip to be between, 10 to 50 million naira. Again, 187, constituting 59.5% of the respondents estimated the value of their traded products per trip to be above 50 million naira, indicative of the highest investment necessary to take advantage of ICBT.

Table 7. Analysis of socio-behavioural effects of a formalized cross-border trade between Nigeria and Cameroon borders

S/N	Socio-behavioural effects **Instruction:** Imagine a formalized cross-border trade where the barriers to official status are lowered and capital provided; tick how you will respond to it.	Frequency and percentage of response Frequency	%
1.	Invade tariff at all possibilities	27	10.03
2.	Invade regulations at all possibilities	31	11.52
3.	Opt out since formality is with little benefit	18	6.69
4.	I will formalize and get registered.	269	100

Source: This study, March, 2025.

Table 7 shows that 27 respondents constituting 10.03% will invade tariff, 31 (11.52%) will invade regulations, while 18 (6.69%) will opt out of formalized trade if cross-border trade is formalized. The study however revealed that 269 (100%) of the respondents will formalize and register officially if cross-border trade is formalized.

Table 8. Respondents' knowledge and dislikes of formal cross-border trade.

S/N	Socio-behavioural effects **Instruction:** Imagine a knowledge of formalized cross-border trade; tick one major reason for disliking formal cross-border trade	Frequency and percentage of response Frequency	%
1.	High tariff	87	32.34
2.	Corruption by border officers	57	21.19
3.	Bureaucracy	71	26.40
4.	Regulations	54	20.07
	Total	**269**	**100**

Source: This study, March, 2025.

Result from table 8 indicated that high tariff as reported by 87 respondents, constituting (32.34%) of the sample is the most reason for dislike of formal cross-border trade. This is followed by bureaucracy 71 (26.40%), corruption by border officers 57 (21.19%) and regulations 54 (20.07).

Discussion of findings

The nature of products traded informally between Nigeria and Cameroon borders

Results from research question one revealed that products traded in Nigeria and Cameroon borders based on the selected border points are fuel, vegetables, beverages,

rice, cosmetics, yams, fairly used clothes and fairly used shoes. This finding is in consonance with Karingi (2023) who averred that informal cross-border trade involves a diverse range of goods, including non-processed and locally manufactured items, re-exports, and sometimes contraband, with variations across regions and borders. It also lends credence to Alade (2016) survey that found food products, vegetable products, animal and animal products, and foodstuffs as constituting the bulk of the goods traded in ICBT. This finding is quite revealing and indicative of the need for border trade monitoring, record keeping and appropriate regulations as a check against food insecurity, loss of income or revenue leakages for governments, smuggling and border insecurity. The quest for wealth and money-making is quite alarming today especially amongst the youth. This has culminated into ritual killings and sales of human parts, human and drug trafficking and fake drugs. Consequently, border points which are corridors for ICBT should be closely monitored.

Value of the traded products between Nigeria and Cameroon borders.

Result from the second research question revealed that a greater percentage of the ICBT traders trade with 50million naira and above per trip and at least ones in a month. This is estimated to be an aggregate of above 9billion naira in a month. This findings is in congruent with World Bank (2020) that Cameroon and Nigeria both have large informal cross-border trade estimated at 80.4% and 90% and further reinforces Zarrilli, and Lopez (2020) assertion that a substantial share (30%-40%) of Africa's regional trade is informal. With an informal trade that is above 90billion naira per month, government is seriously losing revenue. Again, if ICBT is formalized, it will encourage more entrants and thus help to further ameliorate the level of youth unemployment in Nigeria.

Socio-behavioural effects of a formalized cross-border trade between Nigeria and Cameroon borders.

Result from the third research question indicated that while possible effect of trade formalization will lead to evasion of tariff and regulation as well as opting out of formal arrangement, yet traders will formalize and register officially if cross-border trade is formalized. This findings is not contradicting. It implies that a formalized arrangement with high tariff, costly barriers, stringent, time-wasting custom procedure and bureaucratic hurdles will lead to negative responses. This findings has bearing with Andrew (2024) that simplifying trade regimes by way of reducing tariff and non-tariff barriers will encourage informal traders to formalize their operations. Result indicated ICBT traders dislikes high tariff, bureaucracy, corruption by border officers and harsh regulations. There is need for an environment of trust, cooperation and collaboration, reduced taxes, simplified procedures, access to finance and incentives from government and their agents to encourage ICBT traders to transit to formal trade.

Conclusions

Based on the findings of this study, the researchers drew the following conclusions;

1. Informal cross-border trade plays a significant role in the economic livelihood of communities and other traders along the border regions as they engage in trading on goods and services.

2. Formalizing commercial links and trade between Nigeria and Cameroon will be of benefits interms of generation of substantial revenue and employment opportunities in the border areas and beyond.
3. Formalizing cross-border trade with simplified trade procures, providing access to funds and reduced tariff and trade barriers would encourage ICBT traders to transit to formal trade.

Recommendations

Consequent upon the conclusions drawn, the researchers made the following recommendations;

1. Government through appropriate MDAs should provide training programmes for cross-border traders that can help enhance their knowledge and skills in formal trade procedures, regulations, and standards.
2. Government should develop a comprehensive policy reform agenda that addresses the root causes of ICBT, promotes trade facilitation, and enhances access to finance for small-and medium scale traders.
3. Government should provide access to finance, such as loans or grants as well as reduce trade tariffs and barriers to encourage formal trade.

Implications

The results of this study would influence the formulation of policy and review of existing ones as well as regulatory framework that will enhance the role of informal cross border trade and its mainstreaming into the formal economy. Integrating the informal trade flow into the compilation of national accounting would contribute to the completeness of the country's Gross Domestics Product (GDP) and Balance of Payment (BoP) accounting.

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TRANSFORMING MARITIME EDUCATION AND TRAINING IN NIGERIA: STRATEGIC HUMAN RESOURCE MANAGEMENT, CHALLENGES, OPPORTUNITIES, AND STRATEGIC PATHWAYS

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Abstract

This paper explored the critical role of maritime education and training (MET) strategic human resource management in Nigeria, a nation with significant maritime potential due to its strategic geographical location and abundant natural resources. Anchored on Human Capital Theory and Systems Theory, the article examines MET's historical evolution, current state, and challenges in Nigeria. It highlights gaps in infrastructure, funding, curricula, and regulatory oversight while emphasizing the opportunities for leveraging digitalization, international collaboration, and public-private partnerships to enhance MET. The paper concludes with actionable recommendations to strengthen Nigeria's MET framework, aligning it with global standards and ensuring the development of a highly skilled workforce to drive the maritime sector's growth. This systemic approach offers policymakers, educators, and industry stakeholders a roadmap to unlock the sector's economic potential.
K**eywords:** *Maritime Education, Human Capital Theory, Systems Theory, Digitalization, Workforce Development*

Introduction

Maritime education and training (MET) are critical and urgent in developing any nation with a significant naval industry. Nigeria has immense potential to leverage its maritime sector for economic growth and global competitiveness as a country with vast coastlines, abundant natural resources, and strategic positioning along significant shipping routes. The workforce that drives this sector must possess specialized skills, knowledge, and

competencies that only effective MET can provide (Gumel, 2017). Despite its importance, the state of MET in Nigeria faces numerous challenges, including inadequate infrastructure, insufficient funding, and a lack of alignment with international standards (Abubakar et al., 2022).

Maritime education and training have been recognized globally as essential for developing skilled personnel capable of managing complex naval operations. The International Maritime Organization (IMO) has established several conventions and standards, such as the International Convention on Standards of Training, Certification, and Watch keeping for Seafarers (STCW), to ensure uniformity in training across nations (Nhleko, 2023). For Nigeria, adopting and implementing these international standards is crucial to maintaining competitiveness in the global maritime sector. However, the country faces challenges that hinder its ability to fully comply with these standards. These challenges are compounded by historical under investment in educational infrastructure and the limited adoption of technology in training programs (Amuka & Ezinna, 2021).

Nigeria's maritime sector holds immense economic potential, contributing significantly to trade, transportation, and employment. This potential, if fully realized, could transform the industry and the economy. Yet, the industry remains underutilized due to the absence of a robust MET system capable of producing world-class professionals (Emelogu, 2023). The shortage of adequately trained personnel has far-reaching implications, including inefficiencies in port operations, low productivity, and missed economic opportunities. Addressing these issues requires a holistic approach that integrates international best practices, fosters industry-academia collaboration, and ensures consistent policy implementation (Esangbedo et al., 2024). The historical context of MET in Nigeria provides valuable insights into how these gaps have emerged and what steps are necessary to address them.

In addition to structural challenges, there is a pressing need to modernize Nigeria's MET curricula to reflect contemporary industry demands. As the maritime sector increasingly embraces digital tools and technologies, MET institutions in Nigeria must update their training methodologies to prepare graduates for the evolving landscape. This includes incorporating simulation-based learning, e-navigation, and cyber security modules into existing programs (Rehman, 2023). Such advancements will enhance the quality of training and align Nigeria's MET institutions with global standards, improving their reputation and attracting international students.

Another significant aspect of MET in Nigeria is the role of public-private partnerships (PPPs) in addressing funding and infrastructural gaps (M. Kumar et al., 2023) . Collaborative efforts between the government and private sector can facilitate investments in modern training equipment, faculty development, and research initiatives (Anand & Kaur, 2024). These partnerships, crucially, provide students with internship opportunities, enabling them to gain practical experience and improve employability. Nigeria can strengthen its maritime sector and contribute to regional and global trade by fostering a supportive ecosystem for MET, where students play a vital role (Peretomode, 2014).

Conceptual Framework

Maritime education and training encompass the systematic impartation of theoretical and practical knowledge necessary for personnel engaged in naval operations. This includes a wide range of skills and knowledge, such as navigation techniques, ship handling, maritime law, and safety procedures (Kumar & Rajini, 2024). It also includes programs designed to produce seafarers, port operators, naval administrators, and other professionals critical to the sector (Kim et al., 2023). MET is about equipping individuals with these skills and fostering a culture of safety, environmental awareness, and innovation within the maritime industry.

The global nature of marine operations necessitates that MET aligns with international conventions and best practices, such as the International Convention on Standards of Training, Certification, and Watch keeping for Seafarers (STCW). In the Nigerian context, this alignment is crucial to ensuring that graduates are not only employable locally but also competitive on a global scale. This demands deliberate efforts in policy formulation, curriculum development, and, most importantly, strategic partnerships with international maritime bodies (Okolie et al., 2019). These partnerships are key to enhancing the quality and recognition of Nigerian MET programs, emphasizing the importance of collaboration in the maritime industry.

Human Capital Theory

The human capital theory was pioneered by Mincer (1958) and further developed by Schultz (1961) and Becker *(*1964), key figures whose work has significantly shaped the field of human capital theory (Fix, 2021). This theory underscores the importance of investing in education and skills to improve individual and national productivity. By equipping individuals with specialized maritime knowledge, nations can enhance their economic output and global standing. In the Nigerian context, MET has the potential to address youth unemployment, improve national security through efficient port operations, and increase the country's share of global maritime trade. Furthermore, investment in MET can stimulate ancillary industries, such as shipbuilding and maritime logistics, thereby creating a multiplier effect on the economy.

The Human Capital Theory also highlights the role of lifelong learning in maintaining workforce competitiveness. For Nigerian MET institutions, this translates to the need for continuous professional development programs for maritime personnel. These programs ensure that workers remain abreast of technological advancements and regulatory changes in the marine sector, enhancing their employability and overall productivity. By linking Human Capital Theory to MET, the article reinforces the vital role of education and training as strategic levers for advancing Nigeria's maritime sector, inspiring all stakeholders to contribute to this advancement.

Systems Theory

The Systems Theory was primarily developed by Ludwig von Bertalanffy, a biologist. Bertalanffy introduced the concept in the 1940s and formalized it in his book General System Theory published in 1968 (Drack & Schwarz, 2010). Systems Theory focuses on the interconnectedness of various elements within an organization or sector. In MET, this

theory highlights the interdependence of institutions, curricula, funding, regulatory frameworks, and industry stakeholders in producing a well-functioning maritime sector. A systemic approach to MET ensures that all components work synergistically to produce skilled professionals who meet the industry's needs. Aligning these elements with international standards, such as the International Convention on Standards of Training, Certification, and Watch keeping for Seafarers (STCW), is critical for achieving global competitiveness. Systems Theory also underscores the importance of feedback loops in optimizing sectoral performance.

For Nigeria, this means establishing mechanisms to gather industry input on MET programs and incorporating this feedback into curriculum development and institutional policies. Such an approach ensures that MET remains responsive to the evolving needs of the maritime sector. By anchoring the analysis on Systems Theory, the article highlights how the success of Nigeria's MET depends on the harmonious operation of its interconnected parts, ensuring that they collectively address the industry's challenges and opportunities

Historical Context of Maritime Education in Nigeria

The history of maritime education in Nigeria dates back to the establishment of the Merchant Navy Training School in the early 20th century, which aimed to develop indigenous manpower for the maritime industry (Emomoemi, 2019). This initiative laid the foundation for subsequent efforts to formalize MET through institutions such as the Maritime Academy of Nigeria (MAN) in Oron. Over the decades, the academy has served as the cornerstone of MET in the country, providing a range of diploma and certificate programs. However, the sector has faced challenges, including inconsistent policy frameworks and insufficient government investment. The lack of continuity in leadership and policy direction has further hindered the growth of MET institutions (Akande, 2022). Recent efforts to modernize the curriculum and upgrade facilities indicate a recognition of MET's strategic importance, but significant gaps remain.

The evolution of MET in Nigeria has also been influenced by global trends and international collaborations. In the 1980s and 1990s, efforts were made to align Nigerian MET programs with international standards, partly through technical assistance from organizations such as the International Maritime Organization (Adeniran et al., 2021). However, these initiatives often lacked sustainability due to limited follow-up and inadequate local capacity-building measures (Akinshipe et al., 2019). Addressing these historical gaps requires a long-term commitment to strengthening institutional frameworks and fostering international partnerships (Ogunkan, 2022).

Current State of Maritime Education and Training in Nigeria

The current state of MET in Nigeria reflects a mixed picture of progress and persistent challenges. Institutions such as the Maritime Academy of Nigeria, the Nigerian Maritime University in Okerenkoko, and various private training centers offer programs in navigation, marine engineering, and logistics management. However, many of these institutions operate with outdated equipment, inadequate funding, and insufficiently trained faculty (Ayoko et al., 2023). These limitations impact the quality of training and hinder graduates' competitiveness in the global maritime labor market. Furthermore,

industry-academia collaboration remains weak, leading to a mismatch between the skills taught in MET programs and the demands of the maritime sector (Rauf et al., 2023).

Despite these challenges, there have been notable efforts to address some of the issues. For instance, the Nigerian Maritime Administration and Safety Agency (NIMASA) have initiated programs to improve MET infrastructure and provide scholarships for maritime studies(Muktar et al., 2024). Additionally, there is growing recognition of the importance of integrating digital technologies, such as simulation-based training, into MET curricula (Haleem et al., 2022; Shaheen & Imran, 2024). However, these initiatives are often fragmented and lack the coordinated approach advocated by Systems Theory.

Comparative Analysis

A comparison of Nigeria's MET system with global standards highlights significant gaps in infrastructure, curriculum, and industry alignment. Leading maritime nations such as the Philippines and Greece have established robust MET frameworks supported by strong public-private partnerships and adherence to international standards. For instance, the Philippines is renowned for its high-quality seafarer training programs, which contribute significantly to the global supply of maritime labor (Chibana, 2023). In contrast, Nigeria struggles to attract similar recognition due to the fragmented nature of its MET system and a lack of strategic investment (The World Bank, 2020).

By studying the strategies employed by these leading nations, Nigeria can identify best practices to adopt. Key measures include enhancing simulator-based training, implementing faculty exchange programs, and pursuing international accreditation for MET institutions. These steps can help bridge the gap between Nigeria's current MET capabilities and global standards, ultimately boosting the country's competitiveness in the maritime sector.

Strategic Human Resources Management in Maritime Education and Training

The availability of a competent and effective workforce does not just happen by chance but through an articulated and strategic human resources management. The ever changing and dynamic organisational environment characterized by advanced technological innovations such as digital communication and collaboration, e-navigation, and cyber security protection, seafarers certification, maritime training courses, social protection among others have continued to make the maritime industry especially in most developing countries like Nigerian maritime industry more competitive. In other words, a robust and effective human resources management in the maritime sector is pivotal for the success of shipping companies and other maritime operations. The human resources management as it concerns maritime sector include all the experience, skills, judgement, abilities, knowledge, contracts, risk-taking and wisdom of individuals and associates within the sector. The efficiency with which the sector can perform will depend to a large extent, on how its human resource can be managed and utilized. Human resource management in this aspect covers a wide range of activities including manpower planning, recruitment,

training and development, performance management and ensuring global best practices with maritime laws and standards.

From the views of Stone and Deadrick (2015) and Arik and Ukpai (2018), the efficiency with which the maritime sector can perform will depend to a large extent, on how its human resources can be managed and utilized. However, with the recent finding from the Global Maritime Survey in 2024 which presently ranked the Nigerian maritime industry 48th position globally in terms of merchant shipping fleet, with country's sector contributing an insignificant 1..6 million tonnage, occurrence of maritime accidents, violations of maritime rules and regulations, poor compliance to standard operating procedures on safety rules, poor remuneration, inadequate funding training programmes, and aging workforce in the maritime industry, the need to strategize human resources management in maritime industry falls under priority list. Significantly, prioritizing maritime education and training in Nigeria must address the human capital sustainability and retention of qualified and competent skilled seafarers, maritime engineers, and other technical crew teams and professions at all level. Key areas such the Quality Specification for Maritime Education and Training (QMET), Occupational Accident Management System (OAMS), digital transformation, mapping competency, safety compliance and multicultural adaption and value orientation must be addressed.

Challenges and Opportunities

The challenges facing MET in Nigeria are multifaceted and deeply rooted, requiring immediate attention. Key issues include inadequate infrastructure, outdated training facilities, and insufficient funding, which collectively limit the capacity of MET institutions to deliver quality education (Ayoko et al., 2023). The shortage of qualified faculty further exacerbates this problem, leading to a skills gap affecting MET graduates' competitiveness (United Nations, 2020). Policy inconsistencies and weak regulatory oversight also undermine efforts to standardize and improve MET programs nationwide (Akang, 2024). These challenges are compounded by limited access to international maritime resources and poor alignment with global standards, which hinder Nigeria's ability to compete in the global marine industry (Amuka & Ezinna, 2021).

Despite these challenges, significant opportunities exist to transform MET in Nigeria. The global shift toward digitalization in the maritime sector presents a chance to integrate advanced technologies, such as simulation-based training and e-learning platforms, into MET programs, thereby enhancing the quality of education (Scanlan & Hopcraft, 2022). Partnerships with international organizations like the International Maritime Organization (IMO) can provide technical assistance and funding for capacity-building initiatives, leading to a more robust MET system (Ramanujam & Runde, 2022). Additionally, fostering stronger collaborations between MET institutions and the maritime industry can help bridge the skills gap and enhance job readiness among graduates, thereby improving their employability (Wulandari, 2024). By leveraging these opportunities, Nigeria can align its MET system with international best practices and position itself as a maritime education and training leader in Africa.

Recommendations

To improve Maritime Education and Training in Nigeria, the following recommendations are proposed:

- **Increase Government Funding:** Prioritize financial support for MET institutions to upgrade infrastructure, acquire modern training equipment, and develop faculty capacity.
- **Update Curricula:** Regularly review and align MET programs with current industry demands and international standards to ensure relevance and competitiveness.
- **Enhance Industry-Academia Collaboration:** Foster stronger partnerships between MET institutions and the maritime industry to provide students with hands-on training opportunities and improve job placement rates.
- **Leverage International Collaborations:** Actively pursue partnerships with global organizations and institutions to benefit from technical expertise, funding, and knowledge transfer.
- **Adopt Theoretical Frameworks:** Apply Human Capital Theory to emphasize the economic benefits of investing in MET and Systems Theory to ensure a cohesive approach to improving the sector.

Conclusion

This paper has explored the challenges and opportunities surrounding maritime education and training (MET) in Nigeria, emphasizing its critical role in economic and social development. Despite significant barriers such as inadequate funding, outdated curricula, and limited international integration, MET holds immense potential to address youth unemployment, improve global competitiveness, and enhance national security. By adopting a systemic approach and leveraging the principles of Human Capital Theory and Systems Theory, Nigeria can create a robust MET ecosystem that aligns with international standards and industry demands.

However, this transformation requires not just commitment but sustained government commitment, enhanced public-private partnerships, and proactive engagement with global maritime stakeholders. This emphasis on the need for sustained commitment underscores the urgency and importance of the issue. Moving forward, research should focus on empirically evaluating the outcomes of proposed interventions to ensure sustainable growth and development in Nigeria’s maritime sector.

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