Towards Sustainable Mechanized Sand Dredging: Assessing and Mitigating Socio-Ecological Footprints in Rural Nigeria

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Abstract- ***Sand dredging plays a crucial role in economic development, particularly in Nigeria, where it supports the development of infrastructure and urban expansion. However, the practice has major socio-ecological effects, particularly in rural areas where unregulated dredging has caused habitat loss, environmental damage, and socioeconomic disturbances. Focusing on the deterioration of water quality, erosion, damage of wetlands, and consequences on local livelihoods, this paper critically investigates the impact of mechanized sand dredging in rural Nigeria. It highlights poor regulatory systems, governance flaws, and absent sustainable dredging methods. Inspired by global best practices, the study supports environmentally friendly dredging methods that balance financial gains and preservation of the surroundings. It proposes policy reforms, eco-friendly technological innovations, and community-driven governance as essential strategies for mitigating socio-ecological footprints. In Nigeria, switching to sustainable sand dredging calls for a multi-stakeholder approach combining social equality, environmental responsibility, and economic viability.***

Indexed Terms- ***Dredging, Sustainable, Mechanized, Mitigating, Ecological, Footprints, Rural.***

I. INTRODUCTION

Sand dredging is the process of excavation of accumulated sediment from the bottom or banks of bodies of water, including rivers, lakes, or streams, transporting and depositing the materials to another location, using dredgers, which are specialized equipment (GeoForm International, 2022). In commercial sand dredging, hydraulic dredgers are used to pump a mixture of water, silt, and sand to nearby wetlands for storage, before transportation to end users. The process is thus hinged on a tripod of independent activities: excavation, transportation of excavated material, and then storage and proper disposal of dredged material. In the storage and disposal of the dredged sand, wetlands are extensively utilized and therefore, are adversely impacted.

Sand dredging has become common in Nigeria for great economic benefit to private industries as well as the government (Aanu and Melodi, 2023). Chilaka (2010) observed that dredging activities are carried out largely by limited liability companies including international oil companies, estate development companies, and dredging operators to stockpile sand for sale, and swamp reclamation for sundry purposes. This is a consequence of the rapid expansion of industries and massive development in urbanization that necessitated ever-increasing demand for new land development. Chilaka (2010) further opined that sand is needed for large land reclamation projects, e.g. waterfront development and the construction of artificial islands for airports, and residential or commercial estates. Examples abound in many cities in Nigeria, where estates such as Lekki peninsula, Victoria Garden City, etc., in Lagos have been established. The number of these estates is continually on the rise with a concomitant demand for sand. This shift in residential patterns in cities across the nation, especially coastal cities, has led to unprecedented pressure on sand, which is a product of dredging services (Chilaka, 2010). Indeed, dredging is considered vital to social and economic development (PIANC, 2005). Several authors have noted that sand mining is critical to the development and maintenance of infrastructures such as roads, highways, buildings,

and residences, structures upon which the economic prosperity and social well-being of a nation are hinged (Chilaka, 2011; Eke *et al.,* 2023).

Despite the economic benefits a country derives from sand dredging, it is also fraught with huge challenges and high costs/risks (Liu et al., 2022; Kaizer, A., and Neumann, 2021). There are many reports on its disruptive effects on the environment and the social well-being of communities (Ali, 2023; Bull & Scott, 1974; Collins & Dunne, 1990; Hackney et al., 2020; Haghnazar & Saneie, 2019; Koehnken & Rintoul, 2018; Lake & Hinch, 1999; Padmalal et al., 2008; Anooja et al., 2011; Chen et al., 2021; Lekomo et al., 2021). For example, in the Niger Delta, an area over-burdened with environmental stress, and where land reclamation is key in the creation of usable land for development, dredging has exacerbated the ecological disequilibrium and social disruptions, particularly in rural communities (Abam *et al.,* 2023). It is more worrisome given that the sector is largely informal, especially in rural communities where there are several illegal operators. These communities are often vulnerable ecologically, and these operations put various infrastructures at risk of destruction.

A major obstacle resides in the policies and legal framework controlling dredging in Nigeria. Unlike countries in Europe and North America, where environmental impact assessments (EIAs) and sustainable dredging techniques are enforced, Nigeria's legal system stays fractured and badly applied. This regulatory vacuum increases the social and environmental costs, therefore impeding initiatives to match dredging operations with objectives of sustainable development (SDGs).

Furthermore, the indigenous dredging industry, in recent times, has witnessed an exponential increase in investment in the sector, with the proliferation of operators with little or no requisite knowledge and expertise. This has led to unsustainable operations, affecting the investors, the communities, and the environment. In their contribution, Abam *et al.* (2023), observed that there is an upsurge of widespread illegal sand dredging in the Niger Delta, which has led to a serious threat to the safe operation of various infrastructure projects, especially river-crossing bridges.

Many authors have reported several studies on dredging operations in Nigeria. Most of these studies are focused on the socio-economic and environmental impact of dredging activities on the communities including a few that address the evaluation and management of dredging operations for economic development (Melodi and Agboola, 2017). These are centered mostly on urban areas, especially Lagos State. There is a dearth of information on rural communities in Nigeria, which are the nation's resource bases, and play a crucial role in its development. This area is also ecologically fragile, and here sand dredging is largely informal and illegal. To the best of our knowledge, there is a lack of comprehensive information on the socio-ecological effects of sand dredging in rural Nigerian communities, which analyzes the short-term gains and long-term ecological costs. This dearth of information is also hinged on the fact that mechanized sand winning is rarely considered a form of dredging (Weta and Hanson, 2011). Furthermore, studies exploring innovative, sustainable technologies or alternative methods for dredging that minimize environmental damage, are lacking. Furthermore, observable are gaps in interdisciplinary research combining environmental science, social studies, and economics to create holistic solutions.

In summary, sand is an indispensable natural resource with far-reaching implications for construction, manufacturing, environmental health, and economic development. Its multifaceted importance underscores the need for sustainable management practices to ensure that the benefits of sand extraction do not come at the expense of ecological integrity or community well-being. Balancing its use with environmental conservation is crucial for achieving sustainable development goals. This paper, therefore, sets out to critically assess the socio-ecological costs of mechanized sand dredging operations in rural Nigeria and analyze the roadmap to a sustainable industry. It will also explore innovative solutions and best practices that can harmonize economic development, environmental preservation, and social justice. This will involve addressing the complexities surrounding sand dredging, discussing its impacts, and proposing actionable strategies for creating a sustainable framework that benefits both the environment and rural communities.

II. OVERVIEW OF MECHANIZED SAND DREDGING IN NIGERIA

In mechanized sand dredging, sand is excavated from beds of aquatic bodies using dredgers, and stockpiled in dumpsites for commercial purposes. Sand storage or stockpiling requires the deployment of equipment such as bulldozers, excavators, payloaders, etc. According to Chilaka (2025), the mechanized sand dredging in Nigeria dates back to the colonial era, solely operated by European companies, largely Dutch firms. According to the author, the companies included Ballast Ham Dredging, Nigerian Dredging and Marine Ltd (NDM), Netherlands Engineering and Consultancy Services (NEDECO), Royal Boskalis /Westminster Dredging, Jan de Nul, Van Oord, Dredging International, and Royal Haskoning. All the government, oil and gas industries, and private and public organizations dredging jobs including sand winning, land reclamation, and port dredging were executed by these companies. The dredgers were US-made, and these companies employed Nigerians whose capacities were developed over time, especially with the establishment of the Westminster dredging training school. The indigenous companies entered into the dredging business in the early 1970s. The following companies were specifically engaged in sand mining: Tayasa Dredging Company which commenced operations in 1972 and Fobi Dredging Nig Ltd (1995). Subsequently, there was a proliferation of sand dredging operations until 2007 when states like Lagos instituted and began to enforce strict regulatory measures to stem the spate of unregulated and illegal sand dredging (Chilaka, 2010). To circumvent compliance with these measures, rural communities have become their preferred destination. Here, the people lack environmental consciousness and are, therefore, subjected to operations that have dire socio-ecological consequences. It is noteworthy that in such rural communities there thrives traditional sand winning, in which wooden canoes are used for the operations. This group had existed in these communities several decades before the advent of mechanized dredging and had derived their livelihoods from this activity. The influx of companies that operate with dredgers has adversely affected the livelihoods and traditional economies of local sand miners, resulting in serious conflicts with dire consequences.

In Nigeria suction dredgers are deployed for sand mining, specifically cutter suction and the trailing suction hopper dredgers. In rural dredging, small and medium-sized dredgers (8 to 10-inch machines) are more common. These dredgers were imported initially from the USA and Europe up till 2010, before the emergence of China-made ones. The Chinese dredgers became the preferred machines because of the cheaper cost of acquisition. However, according to Chilaka (2010), these machines were ten times less durable than those from USA and Europe, thus making the business less sustainable, economically. Some Nigerian firms, with Jeph Kebbi International as pioneers, have also begun to manufacture dredgers using spares from China. Mechanized sand dredging operations are driven by two categories of entities, viz: the dredger owners, and contractors who lease dredgers from owners.

Deployment of dredgers is neither predicated on their suitability or appropriateness for a particular environment, nor are the various stakeholders involved to find a path to long-term sustainability. Their operations are entirely driven by economic gains without recourse to any other consideration. Sand is usually stockpiled on the wetlands adjoining the dredged water bodies, with a concomitant loss of ecosystem services and community livelihoods. Given that their operations in rural communities are essentially informal without compliance to, and enforcement of extant regulations, the consequential footprints are unimaginable. Despite regulatory efforts, unregulated sand dredging persists, often by small-scale operators using outdated equipment. This has led to continued environmental degradation and safety concerns. Informal dredging is widespread due to the high demand for sand, limited enforcement, and the availability of local labour willing to work in the industry.

Mechanical sand dredging is the excavation and movement of sand and silt from lakes, rivers, harbours, or coastal areas using specialist machinery. This procedure helps to preserve navigable rivers, gather building supplies, and recover land for urban expansion (UNEP, 2022; IADC, 2023).

Mechanical sand dredging in Nigeria has socio-ecological consequences spanning a wide range of

environmental, social, and financial issues. Both inside Nigeria and internationally, these effects have been extensively investigated, focusing on habitat destruction, pollution, and legislative shortcomings. Emphasizing the requirement of sustainable management of dredging operations, this review combines knowledge from current studies and global best practices.

Types of Mechanical Sand Dredging

- Cutter Suction Dredging (CSD): A common technique utilizing a rotating cutter head to dislodge silt, subsequently suctioned through a pipe. This method is especially efficient in eliminating compacted sediments in riverbeds and harbours (IADC, 2023).
- Trailing Suction Hopper Dredging (TSHD): Often utilized in deep-water dredging, this approach uses a ship fitted with suction pipes to gather sand in motion. For big projects like land reclamation, it's perfect (UNEP, 2022).
- Hydraulic Dredging: Uses water jets to remove sediments, then pipes carry them. Fine materials like sand and silt respond well to hydraulic dredging (Chilaka, 2010).
- Mechanical Clamshell Dredging: Utilizes a bucket to scoop sand and sediment. This method is often used in smaller-scale projects or areas where precision and accuracy are required (IADC, 2023) .

These methods are chosen based on the project's specifications, sediment type, and environmental considerations. Even with their efficiency, they might provide ecological problems like increased turbidity and disturbance of habitat (Peduzzi, 2014).

Historical Context and Evolution of Practices in Nigeria

From ancient techniques to mechanized systems driven by growing construction needs, the history of sand dredging in Nigeria mirrors the nation's fast urbanization and industrialization. The sand was mostly manually extracted before the 1970s using simple techniques. Although these techniques had little effect on the environment, their limited scope and labour-intensive nature made them somewhat small (Chilaka, 2010).

The mechanization era began in the 1970s and 1980s when infrastructure projects in Lagos and the Niger Delta helped to adopt technologies like cutter suction dredging to fulfill increasing demand (UNEP, 2022). By the 1990s, urbanization and expanded oil exploration promoted a significant increase in immense dredging activities, with private operators supplying materials for major projects like the Lagos-Epe Expressway (IADC, 2023).

Mechanized dredging has grown essential for infrastructure development in recent years, but environmental damage and illicit activities increasingly threaten it. Weak regulatory systems aggravate these problems, therefore stressing the need for sustainable behaviours and more effective government (Peduzzi, 2014; UNEP, 2022).

Economic Significance of Sand Dredging in Rural Communities

Although its advantages are sometimes unevenly distributed, sand dredging is quite important economically in rural Nigeria since it generates jobs and supports local businesses. For operators, technicians, and transporters especially in areas like Lagos and Ogun, it creates job prospects. But many times, lacking fair pay and job stability, these positions leave employees economically insecure (IADC, 2023). By providing sand for urban infrastructure projects, rural communities also greatly help national development by so connecting local businesses to more general building projects (Chilaka, 2010; UNEP, 2022). Dredging also supports related businesses such as haulage and equipment maintenance, hence increasing rural economic activity (Peduzzi, 2014).

For rural towns, sand dredging offers major difficulties even with these advantages. Environmental damage lowers agricultural output and depletes fisheries resources by incorporating riverbank erosion and water contamination, therefore compromising traditional livelihoods (UNEP, 2022). Large-scale operators monopolizing profits leaves local workers with little pay, hence aggravating economic inequality (IADC, 2023). Weak laws exacerbate these problems by allowing illegal dredging methods that compromise sustainability and disproportionately affect rural areas (Peduzzi, 2014).

In Nigeria, mechanical sand dredging has developed greatly to support infrastructure building and economic growth. Its socio-ecological costs, which include unequal economic benefits and environmental damage, however, emphasize how urgently tighter regulations and sustainable practices are needed.

V. SOCIO-ECOLOGICAL COSTS OF SAND DREDGING

Mechanized sand mining like other dredging processes has often been associated with short- term or long-term impacts. These impacts are socio-ecological, and span a wide range of environmental, social, and economic issues.

To contextualize the socio-ecological costs of mechanized sand dredging in rural communities fittingly, Kapp's theory of social costs will be applied. Kapp defined social costs as *all direct and indirect losses sustained by third persons or the general public as a result of unrestrained economic activities. These social losses may take the form of damages to human health; they may find their expression in the destruction or deterioration of property values and the premature depletion of natural wealth, they may also be evidenced in an impairment of less tangible values* (Kapp, 1963). He further opined that for a loss to be classified as a social cost, the damages must be avoidable. Neves (2018) further posited that these are *unpaid costs by those who produce them*. Natural wealth here refers to land, forests, natural resources, and everything arising from natural creation. In other words, it encompasses the resources available in an environment, particularly focusing on the beneficial aspects provided by nature (including biodiversity and ecosystem services). From Kapp's theory, the socio-ecological costs of dredging have far-reaching impacts on the community and its environment. These impacts can lead to substantial environmental degradation, which invariably affects the livelihoods, health, and social fabric of the affected communities. These are as follows:

1. *Erosion of banks of Water bodies*

This is a consequence of excessive sand removal from riverbanks and coastal areas, which results in soil destabilization, leading to erosion. This process causes the weakening of riverbanks and shorelines, leading to their collapse and retreat, which can destroy property, farmland, and infrastructure (such as bridges) located near the water body. Abam *et al.* (2023) reported that the safety of several bridges in the Niger Delta communities has been compromised as a result of sand dredging. SocialAction (2023) in their contribution noted that there have even been cases of collapse of bridges and roads in rural Nigeria. Bridge damages have been attributed to the alteration of the hydrodynamics caused by incessant and unreasonable sand dredging operations, which expose bridge foundations (Abam *et al*., 2023)

The implications include: the loss of farmlands with the attendant loss of agricultural productivity and livelihoods, and also loss of housing. The latter results in the displacement of families. The situation is more disconcerting in rural communities where the natural economy is predominantly driven by farming, and here sand dredging is indiscriminate and illegal. Examples include Lekki beach erosion in Lagos, attributed to having caused damage to buildings and beachfront; Cross River illegal sand mining-mediated environmental degradation, in which farmlands, and forests were destroyed (Okereke and Eze, 2020). Conflicts between farmers and sand miners have often arisen due to the reduction or loss of farmlands (Ross, 2001). Ecologically valuable seed banks that are necessary for the regeneration of vegetation are usually lost because they are washed away into surface waters together with the nutrient-rich topsoil excavated by sand miners (Adedeji, 2014). This renders the land unusable for agricultural purposes, and the land may not be easily restored. Adedeji *et al.* (2014) further reported the damage to infrastructural facilities such as roads, water, electricity, and others by the activities of these illegal sand miners in communities in the Lusada area of AdoOdo/Ota local government area. They observed in some communities that the base of the electricity substation had been evacuated exposing the whole area to severe erosion.

2. *Degradation of Water Quality*

During sand dredging sediments are stirred up from the bottom of the water body, increasing the turbidity of the water. This reduces water transparency and can lead to the disruption of photosynthesis, which will cause low productivity of the aquatic flora and fauna (including fish and other seafood). Thus, leading to a

decline in biodiversity and poor ecosystem health. Also, the stirred-up sediments can release contaminants, such as heavy metals, pesticides, hydrocarbons, and other pollutants trapped in them into the water, thereby degrading the water quality, and making it unconducive as a potable water source for aquatic life. The polluted water has long-term health risks to humans, wildlife, and aquatic life, creating ecological imbalance in the system. Furthermore, nutrient overloading can take place when nutrients such as nitrogen and phosphorus locked up in the sediments are released into the water. This will lead to hyper-eutrophication, in which algal blooms cause depletion of dissolved oxygen and ultimately lead to fish kills and dead zones in the water. Other impacts of sand mining on water include: temperature variation, in which the thermal structure of water is changed due to the removal of sand from deeper areas, which facilitates the movement of cooler water to the water surface, causing stress for thermo-sensitive species; and changes in pH and DO which impact aquatic life. These changes can lead to a decline in population or shifts in species composition of resident biota. Depleted populations of food organisms such as fish and wildlife will deepen food insecurity in rural communities that derive their food primarily from the wild.

Furthermore, at Ado–Odo completed buildings were found to be almost collapsing. This study has shown that the communities pay a greater environmental price due to sand mining activities. Inland sand mining generates extra vehicle traffic, which negatively impairs the environment. Were access road crosses riparian areas, the local environment may be impacted. It was observed that owners of mines are mostly from outside the locations where the mining was taking place. They are regarded in local parlance as “non-indigenes” and are all males while the women are on

3. *Aquatic Habitat and Biodiversity loss*

During sand dredging, sand and other materials that form the bed of the water body are excavated. This disrupts the benthic habitats in those water bodies and thus affects the resident biota, which include aquatic plants, invertebrates, etc. that form the base of the food chain in the aquatic ecosystem. Furthermore, there is the destruction of the breeding grounds of fish and other aquatic animals. This invariably affects the population of the aquatic communities negatively, leading to biodiversity loss and local ecosystem disequilibrium. In particular, the local fishery is heavily impacted due to the damage to the habitat, spawning and nursery grounds, and natural food of the fish, thereby impairing recruitment. This can lead to long-term declines in fish stocks, raising the issue of sustainability of the local fisheries, and leading to the economic downturn and fish insecurity in the communities. Erondu (2003) observed that the local fishery of the sand-dredged Orashi River was drastically changed. The biodiversity loss and local ecosystem disequilibrium can lead to the emergence of invasive species and algae that can further degrade water quality. Adekumbi *et al*. (2018) reported the loss of some species of phytoplankton, zooplankton, and macro-benthos, which are expected to impact the local fishery of a local community, Ibeshe, along Lagos Lagoon. Finally, sand dredging can have serious impacts on sensitive and endangered species, especially those with specialized habitat requirements. There is the risk of extinction of these organisms, which will also result in the loss of biodiversity with the attendant impact on the social and economic well-being of the communities.

4. Destruction of Wetlands and Riparian Zones

Sand dredging affects these areas extensively because of de-vegetation and de-forestation carried out to facilitate activities along the banks and the creation of an expansive area on the wetlands for sand stockpiling and evacuation. Heavy-duty trucks and articulated machines are used for this purpose resulting in the loss of topsoil, and the change of soil structure from soil compaction by the trucks and the machines. It is noteworthy that these areas (especially mangroves and coral reefs in coastal ecosystems) play critical roles in the ecosystem by providing ecosystem services and serving as biodiversity hubs and hotspots, which are of immense benefits to the environment and humans. These include: the provision of nurseries for various aquatic species, serving as carbon sinks (thus mitigating climate change), habitats for wildlife and a variety of other species, providing natural buffers against erosion and flooding, and serving as a water filtration system (against pollutants). For example, inland wetlands, which exist on floodplains along rivers and streams,

have their vegetation dominated by trees and other critical forest products that sustain community livelihoods, and function in the provision of critical ecosystem services that have immense benefits to the environment and humans. These flood plains, which are nutrient-laden, are extensively used for dry season farming (*Fadama* agriculture) by rural communities, especially the women. Sand dredging has been observed to cause degradation of wetlands and riparian zones with far-reaching consequences. Once damaged, it is difficult or impossible to replace all of its functions and values.

The fall-outs include the increased vulnerability of the communities to extreme weather events (erosion, flooding, storms, etc), which in extreme cases result in displacement of the human population; biodiversity loss along riverbanks, coastlines and wetlands, arising from the loss of critical habitats, and loss of farmlands (leading to food insecurity and loss of livelihoods); decline in water quality, affecting drinking water sources and agricultural water supplies; release of carbon due to de-forestation and de-vegetation, contributing to climate change. Degradation of coral reefs, which are sensitive and support high biodiversity and provide important opportunities for tourism, fishing, and coastal protection, impacts seriously on biodiversity and the resilience of marine ecosystems. Thus, leading to a decline in tourism and fishing industries, affecting local economies.

5. Disruption of local economies and livelihoods

In rural Nigeria, the local economies are dependent largely on natural resources and agriculture. The degradation of the ecosystem due to sand dredging, therefore, disrupts the economic stability of the communities. The impacts on the local economy and livelihoods are severe and are attributed to many factors. The decline in fish stocks, a consequence of habitat degradation, directly affects fishers' livelihood leading to loss of income and food insecurity for their families and community at large. Additionally, the devastation of wetlands, used for farming, and the riparian zones, which offer natural wealth (such as wildlife, food, medicinal herbs, etc) has long-term negative effects on livelihoods, household incomes, and food security in the communities. Also, the damage to water bodies, which are scenic, coastal habitats, and ecosystems such as coral reefs, beaches, and wildlife areas that attract tourists, leads to income and employment opportunity losses in the community. Given the loss in community livelihoods and local businesses, the overall spending power diminishes, and the local economy becomes depressed.

Associated Health risks

Multiple health risks are associated with communities within sand-dredged areas, affecting the workers and residents. The stirred-up sediments often promote the growth of pathogenic organisms and so compromise the quality of the drinking water, thus leading to outbreaks of water-borne diseases such as cholera, dysentery, and typhoid. The sediments can also contain toxic substances, including heavy metals, pesticides and other industrial effluents released into the dredged water, resulting in contamination of the water. Drinking the water, eating seafood from it and direct exposure to the contaminated water have long-term health implications. These include neurologic disorders, kidney damage, skin disorders, developmental ailments in children, etc. The entire gamut of activities during sand dredging unleashes air and noise pollution. Dust and particulate matter are released from the process, essentially from sediment disturbance and plumes and hydrocarbon pollution from the diesel-fuelled machines. This scenario exposes those who inhale the generated air pollutants to the risk of respiratory disorders and exacerbates the grave health condition of those with pre-existing respiratory disorders.

Also, given the heavy machines involved, sand dredging operations are fraught with loud persistent sounds, which are linked to psychological stress, impairment of hearing, disruption of sleep, and other health issues, which ultimately lead to a declined quality of life for nearby community residents. Finally, work-related hazards abound in the sites, which include accidents (sometimes fatal), and incidents involving community residents living close to the dredge sites.

Social Implications of Sand Dredging

- Displacement of Communities: Projects involving dredging often replace communities depending on rivers and coasts for their means of survival. Dredging in Lagos has driven fishing populations

to migrate as fish supplies drop and rivers become inaccessible (Chilaka, 2010). These displacements upset cultural links and social systems, hence aggravating poverty and inequality. Like similar problems elsewhere, large-scale sand mining has displaced thousands of people in India (Pandey et al., 2023).

- Health Risks Associated with Dredging Activities: Communities near dredging sites face significant health risks. While stagnant water left in dredging pits promotes mosquito breeding, hence increasing the incidence of malaria, noise pollution and dust from machinery aggravate respiratory issues. Contaminated water also increases the chances of gastrointestinal illnesses like cholera.
- Impact on Local Livelihoods and Economies: Sand dredging destroys ecosystems, therefore upsetting traditional livelihoods including farming and fishing. Artisanal fisherman in the Niger Delta says declining catches resulting from habitat damage and water pollution have driven many of them to give up their trade (UNEP, 2022). Moreover, the flood of big operators sometimes monopolizes earnings, therefore depriving local workers of any economic gain (IADC, 2023).

Current Regulatory Framework

- Overview of Existing Policies and Regulations: Laws including the Environmental Impact Assessment (EIA) Act and Ministry of Environment policies control Nigeria's sand dredging regulatory system. These rules necessitate EIAs for dredging projects and call for permissions to operate (Chilaka, 2010). Nonetheless, the application of these rules is uneven; many operators evade rules because of corruption or lack of control.
- Challenges in Enforcement and Compliance: Key obstacles include limited technical expertise, inadequate funding for monitoring organizations, and poor interagency collaboration. Driven by great demand and lax fines for breaches, illegal dredging is prevalent. Similar problems are seen worldwide; reports of uncontrolled sand mining in more than 70 countries abound (Peduzzi, 2014).
- Role of Local Communities and Stakeholders: Effective dredging depends on including nearby communities in decision-making. Community involvement guarantees that initiatives fairly distribute rewards and cover local issues. Community-led projects have effectively opposed illicit dredging in some areas of Nigeria, although their effectiveness depends on institutional support (UNEP, 2022).

Other fall-outs

This includes the loss of the aesthetic and cultural values of rivers, lakes, and coastlines, which serve as spaces for recreation, rituals, and community identity. Ohimain *et al*. (2004) observed that dredging has the potential of damaging or destroying submerged cultural and historical heritage sites. This can lead to the erosion of cultural and traditional values of the people, and ultimately affect community cohesion, and loss of cultural identity. Another consequence is social conflicts and community displacement. In rural communities, sand dredging is typically carried out by non-indigenes whose sole interest is profit-making, without consideration for the environment and community well-being. Conflicts usually arise when there are disputes over land rights, water access and issues of environmental degradation. This can result in social unrest, and if unchecked full-blown conflagration. These conflicts are also mediated by the usual inequitable management of operations, and uneven disbursement of benefits. These can be intra- or inter-communal. On the other hand, displacement of communities takes place when flooding, erosion, landslides, etc. render their land uninhabitable. The community structure and traditional livelihoods are disrupted and can lead to social tensions, especially when compensation or relocation is inadequate.

Case Studies

Successful Examples of Sustainable Dredging Practices

Advanced dredging countries offer insightful analysis on how to balance environmental protection with economic growth. The Netherlands is notable for its creative ideas, like the extensive nature-based dredging Sand Motor Project. Using the Sand Motor, which is implemented along the Dutch coast, one deposits a large volume of sand at one point. Without constant dredging interventions, natural forces like wind and waves progressively disperse the sand, replenishing beaches and conserving the shoreline.

This approach lowers ecological disturbance, improves coastal resilience, and supports biodiversity (UNEP, 2022; IADC, 2023).

Another such is Singapore, where sand shortage has resulted in sustainable methods including importing sand from controlled markets and funding research on substitute materials including manufactured sand and recycled building aggregates. During dredging operations, Singapore also strictly monitors the environment to reduce silt plumes and safeguard marine habitats ((Jordan et al., 2019).

Analysis of Failures and Lessons Learned from Problematic Projects

Unregulated dredging is seen in Nigeria's Ogun River, which also shows severe riverbank erosion, loss of arable land, and disturbance of aquatic habitats have all resulted from over-extraction. The lack of appropriate environmental impact assessments (EIs) and enforcement systems aggravated these problems. Furthermore, lacking compensation for relocated people resulted in socioeconomic instability (Chilaka, 2010).

Extensive sand mining along the Yamuna River in India has caused groundwater depletion and lessened sediment movement, therefore affecting downstream agriculture. Illegal sand mining has flourished due to a lack of stakeholder involvement and corruption in regulatory authorities, so stressing the need for openness and responsibility in government (Pandey et al., 2023).

Comparative Assessment with Other Countries' Practices

Global dredging methods expose striking differences in sustainability and government. Strict rules enforced by European nations including Denmark and the Netherlands demand thorough EIAs and stakeholder discussions before to project starts. Additionally, heavily investing in environmentally beneficial technologies such as dredgers with low emissions and real-time monitoring systems (IADC, 2023) are these countries.

On the other hand, several emerging nations including Bangladesh, India, and Nigeria have poor enforcement of their laws. Lack of community involvement and the frequency of illegal dredging sometimes cause environmental damage and social unrest. Nonetheless, nations such as South Africa are making progress by putting community-driven monitoring mechanisms in place, which enable local players to supervise dredging operations and document infractions (UNEP, 2022).

III. TOWARDS SUSTAINABLE SAND DREDGING

Given the fact that the expansion of urban cities in Nigeria is intricately tied to sand dredging, the activity will continue to increase at an alarming rate. This is because, according to Adekunbi *et al.* (2018), sand dredging is a major resource for land reclamation purposes and building materials for housing development. It is therefore, posited that sand dredging operations would still be very much relevant to the development of urban centres in Nigeria in the foreseeable future. It is thus expedient to institute responsible governance, which will strike a balance between enabling economic development and conservation of the environment. In other words, there is a need to strike a balance between the demands of infrastructural development (ie economic benefits) from sand dredging and the protection of fragile aquatic ecosystems, particularly in rural Nigeria. Sand dredging like other types of dredging had always been driven essentially by an understanding of the costs and benefits of the activities. However, in recent decades, the concept of costs and benefits has evolved significantly; it now includes not only direct monetary costs and accruing benefits but also environmental costs (IADC, 2023). This change is associated with the trending environmental consciousness, championed by the environmental movement in the last 50 years. To mitigate the environmental costs of dredging, globally, environmental regulations have been instituted. This was necessitated because of the frequent conflicts between the different stakeholders – groups supporting development and those in support of the preservation of the environment. While these regulations have had positive outcomes in developed countries, where compliance is strict, in countries like Nigeria the reverse has been the case. This is largely a consequence of inadequate governance structures that adequately promote best practices. Even in developed countries these regulations have not

completely addressed the issues (environmental, social and economic costs), and have also produced negative outcomes. Globally, the current thinking is to have a holistic approach, which incorporates values for people, planet and profit. This means having a dredging industry that would focus on making the world safer, better and more sustainable – ie sustainable dredging industry. IADC (2023) has thus advocated integrating dredging into the UN Sustainable Development Goals (SDGs) to use dredging to create value across the three pillars of sustainability.

To have a sustainable industry, it has to align with the concept of sustainable land management. This according to UNEP (2019) implies *Ensuring that (a) consumption does not exceed levels of sustainable supply and (b) that the earth's systems can perform their natural functions (e.g., that sediment flows in river basins continue). The objective is to ensure the long-term material basis of societies in a way that resource extraction, use, and waste and emissions management do not surpass key thresholds for long-term environmental sustainability and human well-being*. This encompasses instituting measures that guarantee the delimitation of appropriate dredge sites, a well-thought-out site-specific plan, and approval permits by relevant agencies. In drawing up the plan, an inclusive stakeholder engagement, involving government agencies, scientists, community-based organizations, residents, etc is expected carried out to foster a conducive ecological, social and economic ecosystem. This is important because the variables in any project are considered site-specific. The process would involve the generation of data that elucidates the sand profile of the area, ecological sensitivity or fragility, and community resilience (environmental and social).

Sustainable Dredging System is therefore, a departure from the 'normal' concept of dredging operations, and revolves around innovations, which optimize the set of operations that are part of a project of dredging, minimizing costs, operating times, reducing both ecological and social footprints, and adopting co-management governance structures. In the short-term, sand dredging has economic benefits but these cannot be sustained because of the long-term impact of its activities on community wellbeing and environment. This implies that irreversible ecosystem degradation and social inequities can arise from unsustainable dredging practices. It is therefore, expedient to adopt an approach that is a mix of sustainable practices, respect for community rights and prioritization of environmental health. This would engender or promote community resilience and protection of critical ecosystems for successive generations. This is achievable in rural Nigeria through active inclusive stakeholder engagement (with local community participation), the introduction of eco-friendly innovations, the institution of adequate regulatory frameworks, the promulgation and enforcement of robust environmental regulations, and improved monitoring practices that can facilitate compliance and protection of environmental resources.

V. CONSTRAINTS TO SUSTAINABLE DREDGING IN RURAL NIGERIA

Technological Deficit

Globally there is a shift towards novel technologies that are eco-friendly, but in Nigeria, poor technologies persist. The consequence is severe ecological and social footprints, which unleash untold devastation of the rural communities in particular. For example, in developed countries like the Netherlands, the United States of America and other countries that have adopted sustainable dredging, the novel dredging technology that allows for precision dredging, like GPS-based positioning systems, dredgers that utilize alternative energy and automated dredging systems, is being gradually introduced. These technologies reduce to the barest minimum sediment disruption, habitat destruction, fuel consumption, degradation of water quality, emission of greenhouse gases, etc, and ultimately result in production optimization (Wasim and Nine, 2017; Eke, 2023).

According to Peter *et al*. (2021), it is envisaged that these dredging methods will increasingly mitigate the socio-ecological impact of this vital process. Adoption of these technologies could help reduce environmental impact and improve the efficiency of dredging operations in Nigeria.

Skills Gap

There is a dearth of skilled manpower in Nigeria's dredging industry. According to Cohen (2007), this

industry requires a highly skilled workforce, with a variety of skills needed. Most of the workers in Nigeria do not have formal training and are also not certified (Chilaka, 2020). There is a mismatch between the skills required in this industry and the skills in the job market, leading to a disconnect that has a significant impact on the production process (Futurize, 2024). These skill imbalances are consequential upon technological advancements, evolving industry demands and the quest for operational sustainability. This results in operational errors arising from poor equipment handling and incompetence, and ultimately leads to equipment wrecks, economic losses (astronomical cost of production), risk of accidents and injuries, environmental degradation, etc. To mitigate these issues there is the need to address skill gaps through training and certification programmes.

Lack of Funding Mechanisms

Sand dredging is a capital-intensive project, and to operate a sustainable industry the innovations and other processes involved will skyrocket the capital outlay. Financing is, therefore, a critical factor for the transition into a sustainable system. For operators in rural communities whose operations are illegal, and who work with outdated and make-shift equipment, updating their production system is nearly impossible. This is because they are oblivious to the socio-ecological footprints of their activities and are not subject to compliance with existing regulations. Therefore, avoiding the prohibitive cost of embracing eco-friendly innovations might be more convenient. Moreover, securing adequate funding for dredging is usually herculean. This is because of the difficulty in accessing credit facilities by small-scale sand dredgers (usually operating in rural areas), because it is perceived as a high-risk business. It is also possible because government, lending institutions and dredging companies have not developed an appropriate lending system that could mitigate the funding bottlenecks. Funding platforms such as *Trans-Sand, a* public-private dredging fund (de Boer *et al*., 2021), are a model that can be replicated in Nigeria.

Lack of requisite Information and knowledge

Information and knowledge have been tagged as the *most valuable and most important intangible assets of enterprises* (Holsapple *et al*., 2001). According to Lis and Ptak (2022), they are related to human development, including technological innovations. The goals of having access to them include keeping up with and anticipating the changing needs and societal expectations. Feasible solutions to sustainable enterprises such as dredging can thus be developed through appropriate information and knowledge (Prakash, 2013). This includes both modern scientific knowledge and traditional knowledge. Given the complexity of the modern dredging industry, information and knowledge have become central to the development of a sustainable enterprise. This is because education and training are key factors that decouple the diversity and complexity of the sustainable dredging ecosystem (IADC), driven exclusively by the transmission of knowledge and information.

In Nigeria, there is a lack of information, especially in rural communities where the industry is informal and the activities illegal. It is quite disconcerting that both the operators and the communities lack knowledge of the ecological footprints of sand dredging, extant regulations and ways of mitigating these. The ill-equipped machine operators lack the competence to operate the outdated equipment, and so create adverse consequences in their operating environment. It is, therefore, unthinkable to introduce innovative products since the workforce is largely untrained. Lack of information is thus a constraining factor for the transition to sustainable dredging in diverse ways. Firstly, the lack of comprehensive data on environmental issues as they relate to sand dredging creates a bottleneck to the development and implementation of strategies needed to mitigate ecological impacts. Secondly, the gap in knowledge dissemination and lack of information exchange of novel and sustainable approaches will translate to the persistence of unsustainable methods of sand dredging, which are less efficient. Thirdly, limited access to information on available innovative dredging technologies vital for sustainability would lead to non-adoption of these advancements. Fourthly, a Lack of scientific data on the environment will lead to defective regulations, which are also poorly enforced, and so fail to promote sustainable practices. Finally, the lack of knowledge of community residents of environmental issues and

their citizens' rights in the context of environmental justice, makes inclusive stakeholder engagement that promotes sustainable practices, difficult.

Inappropriate Governance Structure

Yasmin *et al*. (2024) posited that governance is crucial for achieving sustainable sand mining. The authors identified governance as a means of addressing global and local blueprints for sustainable sand extraction. In Nigeria, the governance regime has key components such as Federal and State governments that oversee sand dredging through regulatory bodies like the National Environmental Standards Enforcement Agency (NESREA), charged with superintending over the Environmental Impact Assessment of projects; the National Inland Waterways Authority (NIWA), and Ministry of Mines and Steel Development, which issue licenses to project owners. Other components of the governance structure include Local government authorities, who regulate sand dredging within their area of jurisdiction, working in concert with state and federal agencies. The last component is the Legal framework, consisting of laws and regulations at both national and state levels, which govern sand dredging.

The flawed governance regimen has resulted in the proliferation of illegal sand dredging, particularly in rural communities, and with dire consequences. This state of affairs has arisen essentially since Nigeria is faced with significant challenges that make enforcement and compliance with dredging regulations near impossible. These challenges include: *weak regulatory oversights*, which enable dredging operators to bypass licensing requirements, EIA procedures, or mitigation measures, resulting in unregulated and environmentally harmful practices; *overlapping jurisdiction of regulatory institutions* such as federal, state and local government agencies contesting the right of oversight functions, with the resultant regulatory conflicts, chaotic situation and reduced accountability, which engender illegal sand dredging. Other factors include *corrupt regulatory agencies*, whose lack of transparency encourages unlicensed dredging, thereby undermining enforcement and compliance with regulations; and *inadequate sanctions or penalties*, which cannot sufficiently deter violators.

V. MITIGATION OF SOCIO-ECOLOGICAL IMPACTS OF SAND DREDGING: PATHWAY TO A SUSTAINABLE INDUSTRY IN NIGERIA

In exploring the strategies that are best fit for mitigating the socio-ecological costs of sand dredging, this discourse will be appropriately situated using an integrated system-based approach. This will involve the application of a hybrid of theoretical frameworks in an integrated manner, to show how local governance interacts with formal regulations to mitigate socio-ecological impacts, also taking into consideration informal governance mechanisms in rural Nigeria. These theories are system thinking and will reflect the complexities of rural Nigeria.

We advance the following theories: *Ecological Modernism* and *Place-based Governance*. These theoretical frameworks are integrated to offer a comprehensive analysis of existing mitigation strategies while highlighting actionable solutions to reduce the socio-ecological impacts of sand dredging in Nigeria. By synthesizing these theories:

1. Ecological Modernization emphasizes sustainable technological and institutional advancements (Huber, 2004). EM is the most effective theoretical approach for tackling challenges in environmental policy. It advances that a link between economic activity (such as sand dredging), government and civil society is necessary to achieve best practices for sustainable environmental outcomes. In order words, the collective action of the various actors is a requirement for effective management of the environmental impact of a project. This change is considerably driven by technology and innovation. This is hinged on the notion that technological innovations from advancements in science and technology are fundamental for the resolution of environmental challenges. Also, institutional changes, and incorporation of NGOs, civil society organizations, etc., in environmental decision-making are imperatives in environmental governance. This will involve the progressive transformation and modernization of existing institutions to forestall ecological crises.
2. Place-Based Governance tailors policies to local needs and involves stakeholders meaningfully

(Ostrom, 1990). This approach refers to community-led initiatives that target the specific settings of a locale, engaging the local people as active participants to build local strengths or respond to a complex social problem (Victorian Government, 2020). In this approach, the government shares decision-making with the local people in socio-economic and environmental governance. This approach allows for the building of community resilience, trust and cohesion. Thus, it requires collaborative efforts that take cognizance of the peculiarities of a place, enabling informed decisions that would engender more effective service delivery, and resilient communities.

Sand dredging impact is a multifaceted and complex problem in any community, which cannot be redressed solely through services, innovations and infrastructure (as advocated by Ecological Modernization). It also needs local people and organizations to be actively involved in developing clear solutions and significant responses (Pace-based Approach). This integrated approach ensures that the socio-ecological impacts of sand dredging can be significantly mitigated, promoting a more sustainable future for the industry. This hybrid approach integrates technological innovations with community engagement and responsive management strategies.

Strategies for Mitigation and Sustainability

Best Practices in Sand Dredging

Adopting sustainable dredging practices can significantly reduce environmental and social impacts. Key best practices include:

- Environmentally Responsible Planning: Thorough Environmental Impact Assessments (EIAs) should be conducted to evaluate potential impacts and establish mitigation measures. Projects must prioritize areas with inactive sand deposits to minimize disruption to ecosystems (UNEP, 2022).
- Rotational Dredging: Implementing a rotation system for dredging sites allows ecosystems sufficient time to recover and minimizes the risk of long-term damage to aquatic habitats (IADC, 2023).
- Nature-Based Solutions: Integrating approaches like the Sand Motor, which harness natural processes to achieve project goals, can reduce dredging frequency and promote ecological resilience (Jordan et al., 2019).

Technological Innovations for Reducing Environmental Impacts

Technological advancements offer new opportunities to mitigate the environmental footprint of sand dredging:

- Eco-Friendly Dredging Equipment: Using low-emission dredgers and noise-reduction technologies minimizes pollution and disturbances to marine life.
- Real-Time Monitoring Systems: Technologies such as Geographic Information Systems (GIS) and drones enable precise monitoring of dredging activities, sediment plumes, and ecological changes in real-time (IADC, 2023).
- Sediment Management Techniques: Innovations in sediment stabilization can reduce erosion and restore natural sediment flows. For example, geotextile tubes are used to contain dredged materials, preventing the release of pollutants into water systems (UNEP, 2022).

Community Involvement and Empowerment in Decision-Making

Empowering local communities is essential for sustainable dredging. Successful strategies include:

- Stakeholder Engagement: Engaging local stakeholders in planning and decision-making ensures that their concerns are addressed and benefits are equitably distributed.
- Capacity Building: Providing training programs for communities enables them to participate in monitoring and enforcement, fostering accountability and reducing illegal activities.
- Benefit-Sharing Mechanisms: Allocating a portion of profits from dredging projects to community development initiatives can improve livelihoods and build trust between stakeholders (Jordan et al., 2019).

CONCLUSION

Sand dredging is an essential economic activity in Nigeria, supporting urban expansion and infrastructure development. But its unchecked and

sometimes unsustainable methods in rural areas have had dire socio-ecological effects including environmental damage, community dislocation, and the ruin of livelihoods. The report emphasises how urgently sustainable dredging methods that strike a balance between social well-being and environmental preservation over economic development.

With poor application of regulations permitting unlawful and destructive dredging operations to continue, Nigeria's present governance structure still falls short. Unlike industrialised nations where rigorous environmental rules and sustainable dredging methods are implemented, Nigeria's regulatory flaws are aggravating the harmful effects of sand mining. Unchecked dredging might cause long-term damage to ecosystems, higher poverty in impacted areas, and more chances of infrastructure collapse without forceful action.

A multi-stakeholder approach is absolutely necessary to shift towards sustainable sand dredging. Stronger regulatory control, the acceptance of environmentally friendly dredging techniques, research and development funding, and active community participation in decision-making comprise this as well. Furthermore, investigated should be substitute materials such recycled building aggregates and produced sand to lessen reliance on natural sand. Along with safeguarding Nigeria's natural surroundings, a thorough and well-regulated dredging plan will provide long-term financial gains and better social equality for impacted populations.

In the end, attaining sustainability in the sand dredging sector for Nigeria calls for policy and practice change. The country can guarantee that the advantages of sand dredging do not come at the expense of ecological damage and social displacement by combining environmental responsibility with financial feasibility. The time to act is now—before the environmental and social costs become irreversible.

Policy Recommendations for Sustainable Practices
To ensure sustainable dredging, governments and industry stakeholders should adopt the following policy measures:

- Strengthen Regulatory Frameworks: Stiffer rules must be followed if we are to solve the problems with sand dredging in Nigeria. Tougher fines for illegal dredging activities would discourage uncontrolled activity and encourage environmental standard compliance. Furthermore, requiring extensive Environmental Impact Assessments (EIAs) for every dredging project together with well-defined, legally enforceable criteria for approval would help to guarantee that possible socio-economic and environmental effects are fully assessed and reduced. Along with improving sustainability, these steps would safeguard rural livelihoods and advance fair economic gains.
- Promote Alternatives to Natural Sand: By encouraging the use of manufactured sand and recycled building materials, dependency on natural sand resources can be greatly lowered, therefore relieving the environmental stresses resulting from large-scale dredging. While manufactured sand is a good substitute for natural sand in many uses, recycled materials like crushed concrete and reclaimed asphalt present sustainable alternatives for building. Encouragement of these substitutes by industry standards, public awareness campaigns, and incentives will help to support long-term resource sustainability (UNEP, 2022), thereby preserving river ecosystems and lowering environmental damage.
- Enhance International Collaboration: Ensuring that dredging operations are carried out in an environmentally appropriate way depends on establishing worldwide standards for sustainable dredging techniques. These criteria would provide unambiguous rules for reducing environmental effects, including water pollution and riverbank erosion, while so advancing operational efficiency and safety. Encouragement of worldwide alliances to exchange technological advances and best practices can also help to enable the acceptance of more sustainable approaches in many different areas. Through cooperative research and development, nations can use sophisticated dredging technologies that minimize environmental damage and increase operational efficiency, thus supporting worldwide efforts to

offset the negative impacts of dredging (IADC, 2023).

- Invest in Research and Development: Reducing the environmental impact of dredging operations requires supporting research on alternative materials and environmentally friendly dredging technology. Investing in innovations such as low-impact dredging equipment, sediment management technology, and alternative building materials including produced sand can help to reduce the environmental impact of dredging activities. Creating data-driven tools to forecast and minimize dredging effects would also help to guide wise decisions. By modelling environmental repercussions, evaluating risks, and guiding sustainable practices, these instruments could help to better plan and control dredging operations thereby safeguarding ecosystems and communities (Peduzzi, 2014).
- Implement Community-Driven Monitoring Systems: Ensuring that environmental and socioeconomic issues are addressed depends critically on local people being able to monitor dredging activities. Giving communities the means, knowledge, and legal systems to track dredging operations will help them to actively document infractions and guarantee regulatory compliance. Including local stakeholders in decision-making guarantees not only openness but also guarantees that the interests and concerns of those directly impacted by dredging are considered. Since communities are more suited to promote responsible behaviour and hold operators responsible, this participatory method can result in more fair and sustainable results.

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