

REVIEW

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Survey of wastewater issues due to oil spills and pollution in the Niger Delta area of Nigeria: a secondary data analysis

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Abstract

Background This paper presents a comprehensive analysis of the issue of wastewater due to oil spills and pollution in the Niger Delta region of Nigeria, which has led to significant environmental and socioeconomic consequences for local communities. The study employed a secondary data collection approach, drawing on various sources, including published research articles, reports, official records, and satellite imagery.

Main body of the abstract Through a systematic review and synthesis of the available literature, the paper identified key challenges, mitigation and remediation strategies, policy recommendations, and areas for future research. The findings of this study revealed that the existing regulatory framework has not been fully effective in preventing and addressing oil spills and pollution in the Niger Delta region due to factors such as weak enforcement, inadequate resources, and overlapping responsibilities among regulatory agencies. Moreover, existing measures for oil spill response, clean-up, compensation, and remediation have had limited success, leaving affected communities to continue suffering from the impacts of oil spills and pollution.

Short conclusion The paper highlights the potential of innovative approaches and technologies, such as advanced oil spill detection and monitoring technologies, bioremediation, and renewable energy, to enhance the effectiveness of mitigation and remediation efforts. Furthermore, the study emphasizes the importance of collaboration and cooperation among various stakeholders, including government agencies, oil companies, local communities, civil society organizations, and international partners, in addressing the challenges posed by oil spills and pollution in the Niger Delta region. Based on the findings, the paper presents several policy recommendations, such as strengthening the regulatory framework, enhancing transparency and accountability, promoting community participation and empowerment, and encouraging investment in sustainable development and clean technologies.

Keywords Niger Delta, Oil spills, Pollution, Wastewater, Regulatory framework, Mitigation, Remediation, Policy recommendations

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Background

The Niger Delta region, situated in southern Nigeria, is the largest wetland in Africa and among the largest globally (Izah and Aigberua 2023; Nnaemeka 2020). The region spans approximately 70,000 square kilometers and harbors diverse ecosystems, including mangroves, swamps, and tropical rainforests (Nnadi et al. 2022). With an estimated population of over 30 million people, the Niger Delta comprises nine states: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers as shown in Fig. 1 (Nzeadibe et al. 2011). The Niger Delta has vast natural resources, particularly oil and gas, which account for more than 90% of Nigeria's export earnings and approximately 80% of government revenue (Kadafa et al. 2012). Since the discovery of oil in the region in 1956, oil production has played a crucial role in Nigeria's economic development, making it the largest oil producer in Africa and the 12th largest globally (Olayungbo 2019). However, the region has been plagued by numerous environmental and socio-economic challenges, including widespread pollution and

wastewater issues due to oil spills, gas flaring, and other industrial activities (Ite et al. 2018).

These environmental challenges have been exacerbated by weak regulatory frameworks, inadequate enforcement, and insufficient investment in sustainable development and pollution control measures (Wilson 2012). Moreover, in recent decades, Niger Delta has witnessed a surge in social unrest, militancy, and conflict; local communities demand a fair share of oil revenues and improved living conditions (Nwalozie 2020; Okpebenyo et al. 2023; Tobi 2022). Consequently, the Niger Delta region is at the center of a complex nexus of environmental degradation, social inequity, and economic underdevelopment, with far-reaching implications for the future of Nigeria and the well-being of its people (Ijaiya 2014). In other climes, (Abou Samra and Ali 2022) investigated the tracking and mapping oil spills from 2019 to 2021 in the north-eastern part of the Nile Delta utilizing Sentinel-1 (SAR) and Sentinel-2 (MSI) data. The research identified 29 oil spills by processing images, depicting oil spills as different sized dark spots, via the oil spills detection model in SNAP Toolbox. The largest spill recorded spanned

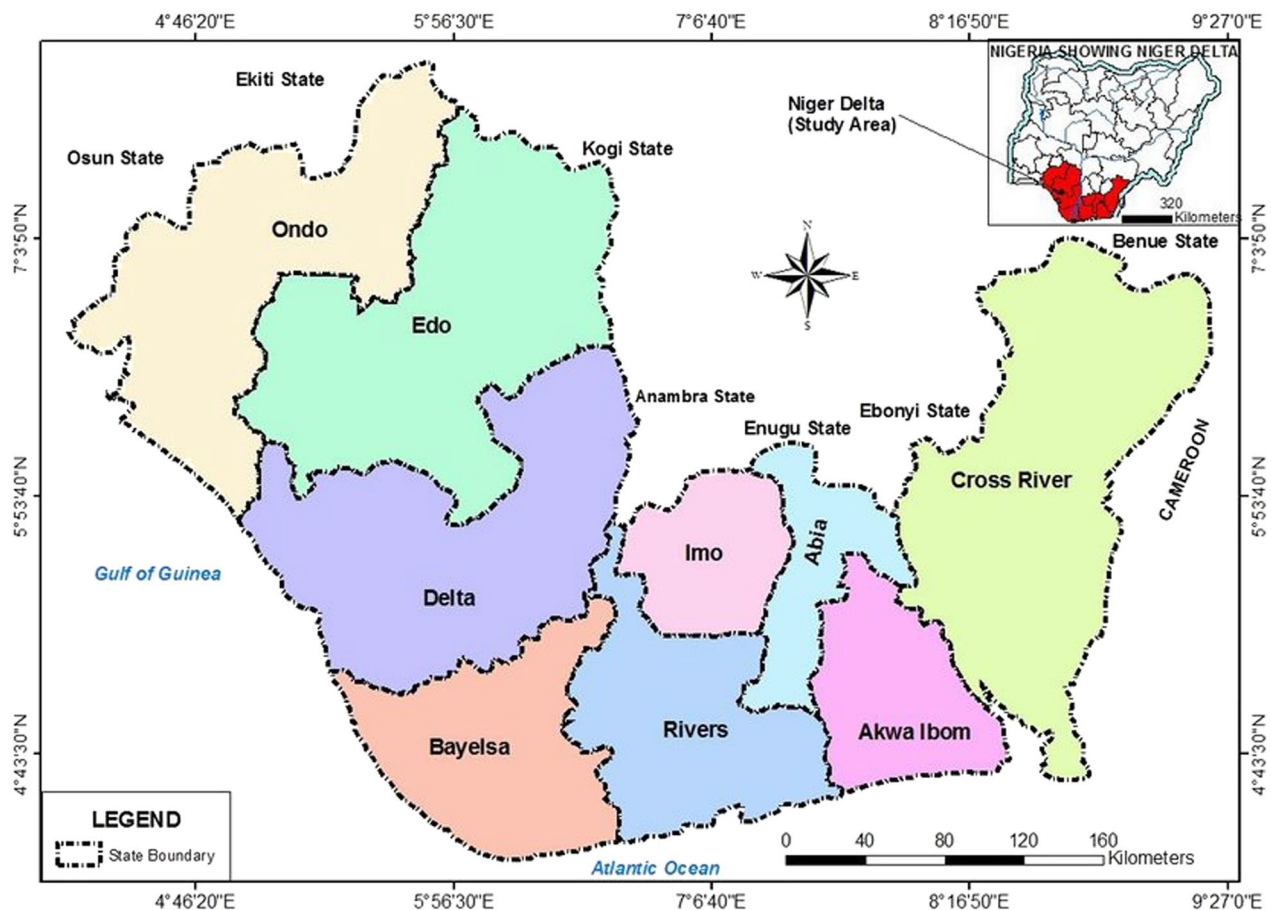


Fig. 1 Niger Delta Region. Source: Oweikeye (2017)

about 10.5 km² on February 23, 2019. The results from the SAR-C data were affirmed by band ratios and decorrelation stretch methods from available Sentinel-2 data. The accuracy of the spills was assessed using the parallel supervised classification model, revealing an overall accuracy between 86 and 98% and a Kappa coefficient between 0.73 and 0.97 for seawater, land, and oil spills classes. The study showed that the sensitivity zone of oil spills was more pronounced in winter than in summer. The results validate the efficiency of VV polarized data from the Sentinel-1 sensor in detecting and mapping oil spills, pointing to the need for strategic management plans to mitigate oil pollution impacts on the marine environment in the Niger Delta's offshore zone.

Importance of the Niger Delta in Nigeria's economy and ecology

The Niger Delta region holds immense significance for Nigeria, both economically and ecologically. The economic importance of the region can be attributed primarily to its vast reserves of oil and gas (Wapwera et al. 2023). Nigeria, which is the biggest oil producer in Africa and ranks 12th globally, has a strong reliance on the oil resources of the Niger Delta. These resources constitute over 90% of the country's export earnings and approximately 80% of its government revenue (Ite et al. 2018; Kadafa et al. 2012). The Nigerian economy heavily relies on the oil and gas industry, which contributes over 90% of its revenues and approximately 45% of its GDP, indicating that the country's economic and political stability are intrinsically tied to crude oil, making it crucial to its survival (Ezeh et al. 2023). The oil industry has been a key driver of Nigeria's economic growth and development, with revenues from the sector financing various infrastructural projects, social services, and other government initiatives (Wilson 2012). Moreover, the Niger Delta region hosts various other economic activities, such as agriculture, fisheries, and forestry, which provide livelihoods to a significant portion of the local population (Onyena and Sam 2020). The Niger Delta is a region of significant importance with various land uses (Chijioke et al. 2018). The primary land uses in the area include the oil and gas industry, which serves as a major hub for petroleum extraction and production, contributing to the region's economy while posing environmental and socioeconomic challenges. Agriculture, focusing on crops such as palm oil, rubber, cocoa, and other cash crops, takes advantage of the region's fertile soil and favorable climate, supporting local livelihoods and contributing to Nigeria's food security. Fishing and aquaculture are traditional practices that provide sustenance and income for many communities in the Niger Delta, although they face challenges due to the impact of oil spills and pollution on

marine life. The region is also home to diverse mangrove forests, critical ecosystems that protect against coastal erosion and require sustainable forestry practices. With growing populations and economic activities, urbanization and infrastructure development, including ports, transportation networks, and housing, are necessary to support the region's economic growth. Lastly, given the unique biodiversity of the Niger Delta, conservation efforts are crucial, with emerging ecotourism initiatives promoting sustainable practices and providing opportunities for visitors to appreciate the region's natural beauty and cultural heritage.

Ecologically, the Niger Delta is a critical area, boasting a wide range of ecosystems, including mangroves, swamps, and tropical rainforests. These ecosystems support a high level of biodiversity, including various endangered and endemic species, making the region a global hotspot for conservation (Akani et al. 2022; Elisha and Felix 2021). The wetlands provide essential ecosystem services such as flood control, water purification, and carbon sequestration, which have local, regional, and global implications for climate regulation and environmental stability (Clarkson et al. 2013). Additionally, the Niger Delta's ecosystems have significant cultural and historical importance for the local communities, who have relied on them for generations for their subsistence and spiritual needs (Wilson 2012). The intricate relationship between the people and their environment underscores the importance of preserving the region's ecological integrity for the social well-being and cultural identity of the Niger Delta communities. It is worth noting that the Niger Delta area plays a crucial role in Nigeria's economy and ecology. The region's oil and gas reserves, agricultural productivity, and diverse ecosystems are the key drivers of the country's economic growth and development, and they provide vital ecosystem services while sustaining the cultural heritage and livelihoods of millions of people (Adekola and Mitchell 2011).

The emergence of wastewater issues due to oil spills and pollution

Bamidele and Eramah (2023) have highlighted that Nigeria's Niger Delta region is facing severe environmental pollution due to the activities of multinational oil companies (MOCs) and government-owned agencies such as the Nigerian National Petroleum Corporation (NNPC) who have been involved in oil exploration and exploitation activities in the region. According to Numbere et al. (2023), the Niger Delta region is one of the most polluted ecosystems globally due to the oil and gas exploration and exploitation activities in the area. To put the issue of

oil spills into perspective, cases of oil spills from 1960 to present is presented in Table 1.

Wastewater issues in the Niger Delta region have emerged as a major concern due to the increasing frequency and severity of oil spills and pollution resulting from the exploitation of its vast hydrocarbon resources. As stated by Wallace et al. (2020), the extraction and transportation of oil pose an inherent risk of oil spills, which have caused significant damage to the environment and wildlife. Since the inception of the oil industry in the region, an estimated 240,000 barrels of crude oil have been spilled into the environment every year, causing widespread contamination of the water, soil, and ecosystems (Akinwumiju et al. 2020; Kadafa 2012; Kadafa et al. 2012). Azuka et al. (2023) stated that since petroleum drilling began in Nigeria in 1958, millions of barrels of oil ranging from 9.1 to 13.1 million have been spilled in the country. The information on oil spills and pollution in the Niger Delta is highly concerning, but the data available can sometimes be conflicting. One study by Faga and Uchekukwu (2019) found that the Department of Petroleum Resources (DPRs) estimated that over 4647 incidents occurred between 1976 and 1996, resulting in approximately 2,369,470 barrels of oil being spilled into the swamps and rivers of the Niger Delta. From 2015 to March 2021, NOSDRA documented 4919 oil spills, with 308 attributed to operational maintenance, 3628 to sabotage, and 70 still awaiting classification, leading to a cumulative 235,206 barrels of oil spilled into the environment (Morocco-Clarke 2023). The primary causes of oil spills in the Niger Delta can be attributed to a combination of factors, including aging infrastructure, equipment failure, operational accidents, sabotage, and theft (Ejiba et al. 2016; Ezeh et al. 2023). The process of exploring and producing crude oil often leads to unintended oil spills, which can occur due to various reasons such as pipeline leakage or rupture, sabotage of well head line and manifolds, equipment failure or overpressure, and blowouts of wells (Aigberua and Inengite 2019). Duru et al. (2023) defined oil spillage as the uncontrolled release of petroleum or its derivatives into the environment, resulting from operational errors, equipment failure, disasters, or acts of vandalism (sabotage).

The frequent oil spills have led to the pollution of rivers, streams, and groundwater, resulting in the degradation of water quality and the disruption of vital ecosystem services such as water purification and nutrient cycling (Akpan and Bassey 2020; Ite et al. 2018). Moreover, the Niger Delta region has experienced significant pollution from other sources, including gas flaring, industrial discharges, and agricultural runoff. Gas flaring, a common practice in the oil and gas industry, involves the burning of excess natural gas during oil extraction. This process

releases a variety of harmful air pollutants and greenhouse gases, which contribute to air and water pollution, climate change, and public health issues (Ite et al. 2018).

Industrial activities, particularly from the oil and gas sector, also generate wastewater that is often discharged into the environment without proper treatment. This wastewater typically contains high levels of toxic chemicals, heavy metals, and other contaminants, which further exacerbate water pollution in the region (Kadafa 2012). Additionally, agricultural practices involving the use of chemical fertilizers and pesticides contribute to the pollution of surface and groundwater resources, posing additional challenges to the sustainable management of water resources in the Niger Delta (Eyankware et al. 2021). The emergence of wastewater issues due to oil spills and pollution has had profound environmental and socioeconomic consequences for the Niger Delta region. The contamination of water resources has led to the loss of aquatic habitats, the decline of fish stocks, and the disruption of local livelihoods dependent on fishing and agriculture (Ite et al. 2018). Iwubeh et al. (2020) have reported that numerous aquatic plants found in the Niger Delta region of Nigeria are in danger of becoming extinct as a result of oil spills. Furthermore, Omozue (2021) noted that when crude oil is spilled into tidal waters, mobile organisms can swim away from the contaminated area. However, the sediment where sedentary organisms reside becomes coated with oil, leading to environmental damage. Moreover, polluted water poses significant health risks for local communities, who often rely on these resources for their domestic needs, including drinking, cooking, and sanitation (Zhang et al. 2010).

The overarching aim of this study is to comprehensively analyze the wastewater issues resulting from oil spills and pollution in the Niger Delta region of Nigeria, with a particular focus on understanding their environmental, social, and economic implications. In pursuing this aim, the study seeks to achieve the following specific objectives:

1. To assess the extent and severity of water pollution in the Niger Delta, with particular attention to the primary sources of pollution, including oil spills, gas flaring, industrial discharges, and agricultural runoff.
2. To evaluate the environmental impacts of wastewater issues on the Niger Delta's diverse ecosystems, including mangroves, swamps, and tropical rainforests, as well as the implications for biodiversity conservation and ecosystem services.
3. To investigate the socioeconomic consequences of wastewater issues for local communities in the Niger Delta, with a focus on the effects on livelihoods, food security, and public health.

Table 1 Oil spill incidences in Nigeria (1960–Present)

Year	Quantity of oil spilled (barrels)	Place/incident	Company	Impact and notes	References
1970	–	Bomu 11 Oil Well/Kegbara Dere-Bomu	Shell	It resulted in serious hydrocarbon fire and spillage of thousands of barrels of crude oil that negatively impacted tremendously on adjoining creeks and mangrove forests and rendered vast agricultural land barren to date	Weli and Arokoyu (2014) and Zabbey (2009)
1978	300,000	GOCON's Escravos	–	It was one of the major spills in the coastal zone of Nigeria. It had untold devastation to plants, birds, fisheries resources, and ultimately livelihoods of the people	Nnabuenyi (2012) and Zabbey (2009)
1978	580,000	Forcados Terminal	Shell	One of the largest oil spills in Nigeria's history, impacted aquatic life, agriculture, and livelihoods of local communities	Nnabuenyi (2012) and Zabbey (2009)
1980	–	Oyakama	Shell	The spill contaminated farmland and a river, upending livelihoods in fishing and farming communities in part of the Niger Delta	Eriegha and Sam (2020) and Zabbey (2009)
1980	400,000	Texaco Funiwa 5	Texaco	It was another major spill in the coastal zone of Nigeria that had a negative impact on agriculture, and the livelihoods of local communities	Aroh et al. (2010) and Zabbey (2009)
1982	18,818	Abudu	–	The oil spill incident resulted in environmental degradation, social annihilation, and economic impoverishment in the Niger Delta region of Nigeria	Nnabuenyi (2012) and Zabbey (2009)
1984	–	Ikata	Shell	A 50% reduction in fish abundance was reported	Eriegha and Sam (2020) and Zabbey (2009)
1993	–	Oshika	–	This spill confirmed the death of floating and submerged aquatic vegetation, especially water lettuce, crabs, fish, and birds	Eriegha and Sam (2020), Sakib (2021) and Zabbey (2009)
1998	40,000	Idoho	Mobil	The spill had a heavy impact on fishing communities and cooperatives in the region, leading to many being unable to fish as well as others losing occupational tools such as nets due to oil damage	Zabbey (2009)
1998	–	Jesse	NNPC	The Jesse pipeline explosion claimed the lives of over a thousand persons in Jesse, Ethiope West local government area of Delta State	Nnabuenyi (2012)
2008–2009	560,000	Bodo	Shell	It is one of the biggest spills in decades of oil exploration in Nigeria. As a fishing town, the livelihoods of the majority of Bodo's inhabitants were destroyed. In 2015, after many years of battles with campaigners, Shell announced it would pay out \$83.2 m in compensation for the spill	Pegg and Zabbey (2013) and Zabbey (2009)

Table 1 (continued)

Year	Quantity of oil spilled (barrels)	Place/incident	Company	Impact and notes	References
2009	–	K. Dere	Shell	It is a region that has been affected by oil spills. Villagers argue that some spills are due to operational factors	Eriegha and Sam (2020) and Zabay (2009)
2012	–	Kegbara-Dere	Shell	The oil spills devastated the villager's farms, damaged their health, and left them with bleak prospects for the future	Amnesty-International (2015) and Saint (2022)
2013	6000	Creeks and waterways of Bodo	Shell	The Ogoni people vowed not to allow oil exploration to resume in the area until conditions addressing the challenges of environmental pollution were met	Saint (2022)
2023	–	Eleme	Shell	The oil spill contaminated farmland and a river, upending livelihoods in fishing and farming communities	Reuters (2023)

4. To critically examine the existing regulatory frameworks, policies, and strategies for pollution prevention, control, and remediation in the Niger Delta and assess their effectiveness in addressing wastewater issues and mitigating their adverse impacts.
5. To identify and analyze the key challenges, opportunities, and best practices for promoting sustainable development and environmental protection in the Niger Delta, with an emphasis on collaborative approaches and innovative solutions involving various stakeholders, such as the government, oil companies, local communities, and civil society organizations.

The scope of this study is primarily focused on the analysis of secondary data related to wastewater issues resulting from oil spills and pollution in the Niger Delta region of Nigeria. Secondary data analysis involves the use of existing data collected by other researchers or organizations, for the purposes of addressing new research questions or validating previous findings (Johnston 2014). This approach offers several advantages, including cost-effectiveness, time efficiency, and the ability to access a wide range of high-quality data sources, such as academic articles, government reports, and datasets from international organizations. However, the secondary data analysis approach also presents some limitations, which must be considered when interpreting the findings and drawing conclusions from the study. These limitations include:

1. *Data Availability* The quality and relevance of the secondary data analysis are contingent on the availability of suitable data sources. Gaps in the existing

literature or a lack of recent, reliable, and comprehensive data may hinder the study's ability to address its objectives fully or accurately (Johnston 2014).

2. *Data Consistency and Compatibility* Secondary data sources may vary in terms of their methodological approaches, measurement instruments, and data collection procedures. These variations may result in inconsistencies or discrepancies between data sources, making it challenging to compare or integrate the findings (Smith 2008).
3. *Temporal and Spatial Limitations* Secondary data may be subject to temporal and spatial limitations, as they may not capture the most recent developments or accurately represent the specific geographic context of the Niger Delta region. These limitations may reduce the study's ability to provide a current and contextually appropriate understanding of wastewater issues (Johnston 2014).
4. *Lack of Control over Data Quality* As the researchers do not have direct control over the data collection process in secondary data analysis, they may be unable to verify the accuracy, reliability, or validity of the data sources. This limitation may introduce potential biases or errors in the study's findings (Smith 2008).

Although there are certain limitations associated with secondary data analysis, it can still offer valuable insights and contribute to a deeper understanding of the wastewater issues in the Niger Delta region. Through a critical review, synthesis, and evaluation of the available data, this study aims to provide a comprehensive and evidence-based assessment of the environmental, social, and economic implications of oil spills and pollution in the

region. The study intends to provide policymakers, industry actors, and other stakeholders with valuable insights and recommendations to tackle the urgent wastewater issues in the Niger Delta area and create a sustainable, equitable, and healthy future for its residents. Additionally, the study seeks to identify the challenges and opportunities for promoting sustainable development and environmental protection in the region.

Main text

Literature review

Numerous studies have documented the extent and severity of oil spills and pollution in the Niger Delta, highlighting the environmental and socioeconomic implications of these issues for the region and its inhabitants (Elum et al. 2016; Ite et al. 2013).

Oweikeye (2017) evaluated the impact of oil spillage in the Niger Delta region of Nigeria by analyzing data on the frequency and estimated quantity of spills between 2013 and 2015. The study found that various sources of spillage were present within the region, including wellheads, pipelines, tanks, and more. Barges were found to have the highest frequency of spillage, indicating the impact of theft, while pipelines recorded the highest total estimated quantity of spillage. Bayelsa and Delta states were found to have the highest frequencies and quantities of spills, while Abia and Imo states had lower incidence of spillage. The study suggested that the prevalence of oil spills in the region was due to a lack of proper maintenance by multinational companies, as well as vandalism and sabotage of facilities by individuals.

In their study conducted in the Bdere community in Ogoniland, which is considered one of the world's most crude oil-polluted regions, Aigberua and Inengite (2019) assessed the bioavailability of Pb, Cd, Zn, and Mn in crude oil-contaminated soil and compared it with uncontaminated soil, revealing that Zn and Mn were mainly found in residual fractions, while Pb and Cd were predominant in amorphous Fe-oxide and plant available fractions, suggesting that the introduction of crude oil into the soil matrix led to the presence of these metals.

In a study conducted in the Niger Delta Region of Nigeria Ozigis (2020) explored the use of optical and SAR images, along with machine learning classifiers, to identify and locate oil spill sites in cropland, grassland, and tree cover areas, and found that integrating multi-frequency L, C, and X band SAR during the wet season resulted in the highest overall classification accuracy, indicating that SAR-based monitoring of petroleum hydrocarbon impacts on vegetation is viable and could potentially substitute the use of optical data for oil pipeline monitoring and facility management.

Amakama et al. (2021) found that environmental modeling tools, such as the fugacity model using EPI SuiteTM and Ecological Structural Activity Relationship, can be useful in assessing the risk of toxic volatile organics from crude oil spills in the Niger Delta Region of Nigeria and can aid in developing appropriate disaster management plans. The study also highlighted that pipeline sabotage and operational failures are the primary causes of crude oil spillages in the region.

Abayomi et al. (2021) carried out a study by reviewing over 60 articles on the impact of petroleum exploration on the Niger Delta ecosystem and found that oil spills caused by mismanaged pipelines and environmentally unsustainable gas flaring by oil companies, illegal refining and pipeline vandalism by militant groups, and government negligence in regulating oil operations have resulted in severe environmental degradation and negatively affected the socioeconomic activities of local communities, emphasizing the need for all stakeholders to take responsibility in protecting the environment and involving local communities in the maintenance and monitoring of pipelines to improve the quality of life for all stakeholders.

Sabran and Burhan (2023) investigated the resiliency and sustainability of the Niger Delta region in the face of continued oil spills over a period of 50 years, specifically in Imo State and the wider region of Nigeria. The study found that the people of the region exhibit a cultural tendency toward endurance and resourcefulness and are empowered to navigate challenging situations through their knowledge, self-reliance, and entrepreneurial abilities.

Since 1956, when oil was first discovered in the Niger Delta Region of Nigeria (Orukpe 2022), there has been an influx of multinational oil companies (MNOCs) to prospect for petroleum and natural gas (Adesanya et al. 2023). This resulted in disproportionate exploitation of the region's environmental resources, which has become the mainstay of Nigeria's economy (Sam and Zibima 2023). MNOCs claim that most spills are due to sabotage, while the public blames poor maintenance and negligence. According to the United Nations Environment Programme (UNEP 2011), more than 60 years of oil exploration and production in the region have resulted in widespread environmental degradation, particularly in terms of water and soil pollution. Various factors have been identified as contributing to oil spills and pollution in the Niger Delta, including aging infrastructure, equipment failure, operational accidents, sabotage, and theft (Ejiba et al. 2016). In addition to oil spills, other sources of pollution, such as gas flaring, industrial discharges, and agricultural runoff, have further exacerbated the

environmental challenges facing the region (Ugboma 2015).

The environmental impacts of oil spills and pollution in the Niger Delta have been widely studied, with researchers emphasizing the consequences for water quality, ecosystems, and biodiversity (Eregba and Irughe 2009; Kadafa 2012). For instance, UNEP (2011) reported that oil spills have contaminated surface and groundwater resources, disrupting vital ecosystem services such as water purification and nutrient cycling. In addition, the degradation of habitats and the loss of biodiversity due to pollution have been identified as critical concerns for the region's diverse ecosystems, including mangroves, swamps, and tropical rainforests (Onyena and Sam 2020). Oil spills often result in soil contamination, which can lead to the loss of soil fertility and productivity, as well as the infiltration of pollutants into the groundwater (Kadafa et al. 2012; Sahoo and Goswami 2024). Soil contamination can also impact plant growth and agricultural activities (Zandalinas and Mittler 2022), further exacerbating food security concerns in the region (Udoh and Chukwu 2014). The contamination of water and soil resources has led to the degradation of various ecosystems in the Niger Delta, including mangroves, swamps, and tropical rainforests (Kadafa 2012). These ecosystems play crucial roles in carbon sequestration, climate regulation, and the provision of habitat for diverse flora and fauna, but their functions are increasingly compromised by pollution (Ite et al. 2013). The Niger Delta is home to a rich variety of plant and animal species, many of which are threatened by oil spills and pollution (Anejionu et al. 2015). As habitats become degraded and food sources dwindle, species may become locally extinct, leading to a decline in overall biodiversity (Onyena and Sam 2020). This loss of biodiversity can have cascading effects on ecosystem stability and resilience, as well as on the livelihoods of local communities that depend on these resources (Lancelotti et al. 2016). In addition to water and soil contamination, oil spills and pollution contribute to air pollution and greenhouse gas emissions in the Niger Delta (Kolawole and Iyiola 2023). Gas flaring, a common practice in the oil and gas industry, releases significant amounts of carbon dioxide, methane, and other air pollutants, which can exacerbate climate change and cause respiratory problems for local populations (Nnaemeka 2020). Gas flaring in the Niger Delta is a major source of air pollution (Usiabulu et al. 2023), resulting in the burning of extra gases that produces harmful chemicals and has inflicted significant damage to human, plant, and animal life, causing a reduction in agricultural production, deadly diseases affecting the respiratory tract, central nervous system, and blood stream, and the government has not taken action to stop this practice

despite deadlines given to oil companies (Faga and Uchechukwu 2019). The Niger Delta region of Nigeria is currently home to at least 123 gas flaring sites, which has made Nigeria one of the top greenhouse gas emitters in Africa (Bodo and Gimah 2020; Oghenetega et al. 2022). According to Oghenetega et al. (2020), there is evidence to suggest that both oil spills and gas flaring have a negative impact on the health outcomes of mothers and newborns. Exposure to gas flaring over a prolonged period, such as in the Niger Delta region of Nigeria, can lead to a rise in health anomalies among local residents, according to Adinkwu et al. (2020).

Oil spills and pollution in the Niger Delta have also affected the region's coastal and marine environments (Onyena and Sam 2020). Oil slicks (a thin layer of oil that spreads over the surface of water, forming a smooth and shiny layer) can suffocate fish and other aquatic organisms, destroy habitats such as coral reefs and seagrass beds, and disrupt the reproductive cycles of marine species (Ite et al. 2013; Shyam et al. 2023). In a recent study by Atonye (2023), it was highlighted that oil spill pollution can pose significant risks to the health of rural communities. The inhalation of dangerous fumes resulting from oil spills, along with the contamination of drinking water and soil, can lead to a range of acute health problems, including respiratory issues, skin irritation, and gastrointestinal distress. Furthermore, prolonged exposure to oil spill pollution can contribute to the onset of chronic health conditions, such as cancer and neurological disorders. Furthermore, Bruederle and Hodler (2019) found that oil spills can have significant adverse effects on neonatal and infant mortality rates, with nearby oil spills before conception increasing neonatal mortality by 38.3 deaths per 1000 live births, and the effect persisting for several years after the spill, which is consistent with medical and epidemiological evidence showing that exposure to hydrocarbons can pose risks to fetal development. Anyanwu and Lein (2019) have noted that oil spills caused by pipeline breakages and operational failures during oil exploration are a recurring issue in the Niger Delta region. The authors have further pointed out that these oil spills pose significant health risks to human beings, including the development of derma-toxic diseases, cancer, and high rates of neonatal and child mortality. A study conducted by Oghenetega et al. (2020) established a correlation between oil pollution in Nigeria's Niger Delta region and higher rates of miscarriage, stillbirth, and infant mortality. The long-term effects of oil pollution on marine ecosystems and their resilience remain a critical area of concern for researchers and policymakers.

Several studies have explored the socioeconomic consequences of oil spills and pollution in the Niger Delta,

particularly in terms of their effects on local livelihoods, food security, and public health (Agbonifo 2016; Elum et al. 2016; Onyena and Sam 2020). For example, Numbere and Maduikwe (2022) found that the contamination of water resources has led to the decline of fish stocks and the disruption of local livelihoods dependent on fishing and agriculture. Additionally, polluted water has been linked to various health risks for local communities, who often rely on these resources for their domestic needs (Nriagu et al. 2016; Nriagu 1990). The negative socioeconomic impacts of oil spills and pollution in the Niger Delta have contributed to social unrest and conflict in the region (Albert et al. 2018). Local communities may perceive the unequal distribution of the benefits and burdens associated with the oil industry as a form of injustice, leading to tensions between community members, oil companies, and government authorities. This social unrest can manifest in protests, sabotage, and even violence, further destabilizing the region and hindering sustainable development efforts (Albert et al. 2018; Eregha and Irughe 2009). As a result of the socioeconomic challenges posed by oil spills and pollution, many people in the Niger Delta have been forced to migrate to urban areas in search of alternative livelihoods (Elum et al. 2016). This migration can result in overcrowding, social tensions, and increased pressure on already strained urban resources, while those who remain in the affected areas may face even greater hardships due to the loss of social and economic support networks. The contamination of water, soil, and air resources due to oil spills and pollution has been linked to various health risks for local communities, who often rely on these resources for their domestic needs (Onyena and Sam 2020). Exposure to pollutants can result in acute and chronic health problems, including respiratory issues, skin diseases, gastrointestinal disorders, and an increased risk of cancer (Kuppusamy et al. 2020). These health risks further exacerbate the vulnerability of local communities, particularly in areas with limited access to healthcare services.

Efforts to tackle oil spills and contamination in the Niger Delta have involved the creation and execution of numerous regulatory structures, policies, and approaches focused on preventing, managing, and rectifying the ecological harm (Ukhurebor et al. 2021). Denny and Jacob (2022) highlight that there are various environmental rules and guidelines in the oil and gas industry, such as the Oil in Navigable Waters Acts (1968), Oil Pipelines Act 1956 (revised in 1965 and 2004), Mineral Oils (Safety) Regulations (1963), Petroleum Industry Act (2021), Associated Gas Re-injection Act (1979), Federal Environmental Protection Agency (FEPA) Act (1988), The National Policy on the Environment, 1989 (updated in 1999), National Environmental Protection (Effluent Limitations)

Regulations (1991), Department of Petroleum Resources (DPR) Environmental Guidelines, and Environmental Impact Assessment (EIA) Act (1992). The following are some policies and regulations regarding oil production and waste management in Nigeria:

- *The Petroleum Industry Act (2021)* The Petroleum Industry Act (PIA) is a recently passed law in Nigeria that replaces the outdated Petroleum Act of 1969. The PIA aims to modernize the regulation of the Nigerian petroleum industry and attract more investment into the sector by establishing a more transparent and efficient regulatory framework. It also seeks to increase the government's revenue from the industry and provide more benefits for local communities impacted by petroleum operations. The PIA establishes new regulatory bodies, such as the Nigerian Upstream Regulatory Commission and the Nigerian Midstream and Downstream Petroleum Regulatory Authority, and sets out guidelines for petroleum exploration, production, and transportation. It also includes provisions for environmental protection, local content development, and community engagement (Umenweke and Chukwuma 2021).
- *The Oil Pipelines Act (2004)* The Oil Pipelines Act from 2004, which updated and replaced the previous version of the Act from 1956. The 2004 version of the Act provides for the regulation of pipelines used for the transportation of crude oil, natural gas, and petroleum products in Nigeria. The Act sets out penalties for pipeline vandalism and oil theft, as well as provisions for compensation and dispute resolution in case of damage or loss resulting from pipeline operations. The primary goal of the Oil Pipelines Act is to ensure the safe and efficient transportation of petroleum products across the country, while also protecting the environment and the health and safety of citizens (Onyi-Ogelle 2020).
- *The Environmental Impact Assessment (EIA) Act (1992)* The EIA Act mandates that all major development projects, including oil and gas activities, undergo an environmental impact assessment before implementation. The EIA process aims to identify potential environmental and social impacts of proposed projects, as well as to develop appropriate mitigation measures. The EIA Act requires project proponents to consult with relevant stakeholders, including local communities, throughout the assessment process, promoting transparency, and public participation (Nzeadibe et al. 2015). However, Abugu et al. (2021) have asserted that environmental impact assessments (EIAs) are often regarded as ineffective tools for promoting environmental sustainability due

to the inadequate implementation of environmental management plans (EMPs).

- *The National Oil Spill Detection and Response Agency (NOSDRA) Act (2006)* The NOSDRA Act establishes the National Oil Spill Detection and Response Agency as the principal agency responsible for oil spill management in Nigeria. NOSDRA is mandated to coordinate oil spill preparedness, detection, response, and remediation efforts across federal, state, and local government levels. The agency is also tasked with enforcing compliance with environmental regulations, conducting investigations into oil spills, and implementing measures to prevent future incidents (NOSDRA 2006).
- *Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN)* EGASPIN is a set of regulations and standards developed by the Nigerian government to guide the operations of the petroleum industry in the country. The guidelines cover various aspects of petroleum operations, including exploration, drilling, production, transportation, and waste management. EGASPIN provides a framework for the management of environmental impacts and sets out requirements for environmental impact assessments, monitoring, and reporting. It also establishes standards for air and water quality, soil management, and the control of waste and hazardous materials. The goal of EGASPIN is to promote sustainable practices in the petroleum industry and minimize the negative environmental and social impacts of oil and gas operations in Nigeria (Olawuyi and Tubodenyefa 2018).
- *The Niger Delta Development Commission (NDDC) Act (2000)* The NDDC Act establishes the Niger Delta Development Commission as a federal agency responsible for the sustainable development of the Niger Delta region. The NDDC is mandated to formulate and implement policies, plans, and programs aimed at addressing the environmental, social, and economic challenges facing the Niger Delta, including those related to oil production and waste management. The commission also plays a role in promoting environmental protection, resource management, and stakeholder engagement in the region (Ebeku 2004).
- *The National Environmental Standards and Regulations Enforcement Agency (NESREA) Act (2007)* The NESREA Act establishes the National Environmental Standards and Regulations Enforcement Agency as the primary body responsible for enforcing environmental regulations and standards in Nigeria. NESREA's mandate includes the protection and sustainable development of the environment, as well as the

conservation of natural resources. One of the key functions of NESREA is to ensure compliance with environmental laws, guidelines, and policies, particularly those pertaining to waste management and pollution control. This includes the enforcement of regulations on oil production and waste management, working in close collaboration with other agencies like NOSDRA and DPR. NESREA is also responsible for developing and implementing environmental standards, monitoring compliance, and initiating legal actions against individuals or organizations that violate environmental regulations. Additionally, the agency promotes public awareness and understanding of environmental issues, encouraging the adoption of sustainable practices and technologies (Suleiman et al. 2019).

Although Nigeria has these policies and regulations in place, the country is still struggling to address the problem of oil spills and pollution in the Niger Delta (Ite et al. 2013). The effectiveness of the current regulatory framework has been questioned, with critics pointing to inadequate enforcement, weak penalties for non-compliance, and a lack of coordination among regulatory agencies as key challenges (UNEP 2011). Additionally, the capacity of government agencies such as NOSDRA and DPR to effectively monitor and regulate the oil and gas industry has been constrained by limited resources, technical expertise, and institutional challenges.

Several studies have highlighted the opportunities and challenges for promoting sustainable development and environmental protection in the Niger Delta, with an emphasis on collaborative approaches and innovative solutions involving various stakeholders, such as the government, oil companies, local communities, and civil society organizations (Ite 2007). For instance, Ordini-oha and Brisibe (2013) emphasized the need for greater transparency, accountability, and community empowerment in the management of the region's resources, while Akpomuvie and Orhioghene (2011) called for investment in clean technologies and alternative livelihoods to reduce dependence on oil and gas extraction. Recent research has increasingly emphasized the importance of community-based approaches and environmental justice in addressing the waste water issues and promoting sustainable development in the Niger Delta (Obi 2010). These studies argue that empowering local communities to participate in decision-making processes, hold stakeholders accountable, and advocate for their rights is critical to achieving lasting solutions to the region's environmental challenges.

Kalu and Ott (2019) noted that multinational oil companies (MNOCs) have engaged in oil exploration without

being held responsible for the adverse environmental consequences, such as ecological deterioration, significant pollution, toxicity to living organisms, ecosystem impacts, loss of biodiversity, effects on human health, and infringement of human rights. The responsibility of oil firms in reducing the effects of oil spills and contamination in the Niger Delta has been a subject of extensive discussion, with researchers analyzing the efficiency of corporate social responsibility (CSR) programs and the necessity for more robust environmental performance criteria (Amaeshi et al. 2016). While some CSR initiatives have contributed to community development and environmental management, concerns remain about the adequacy of these efforts in addressing the systemic issues underlying wastewater problems in the region (Amaeshi et al. 2016). Onuh et al. (2021) have contended that the environmental degradation and oil pollution in most oil-producing nations are not solely the responsibility of multinational oil corporations. Instead, they have highlighted that the illegal activities of artisans and their use of crude technology in illegal oil refining also contribute significantly to the environmental issues in the Niger Delta. Technological innovations for pollution prevention, control, and remediation have been identified as potential avenues for addressing wastewater issues in the Niger Delta (Omofonmwan and Odia 2009; Udjoh 2019). Previous literature on oil spills and pollution in the Niger Delta provides valuable insights into the environmental, social, and economic implications of these problems, as well as the challenges and opportunities for promoting sustainable development and environmental protection in the region. Expanding on the findings of these studies, the current research strives to enhance our comprehension of wastewater issues and formulate efficient strategies for their mitigation and management.

Methodology

Data sources and collection methods

This study is based on a comprehensive review and analysis of secondary data sources, including academic articles, policy documents, government reports, industry reports, and relevant legislation. By focusing on secondary data, we aim to develop an extensive understanding of the policies and regulations governing oil production and waste management in Nigeria, as well as their effectiveness, limitations, and potential for improvement. The data collection methods employed are as follows:

1. *Literature Review* A thorough literature review was conducted, utilizing electronic databases such as Scopus, Web of Science, JSTOR, and Google Scholar. Relevant keywords related to oil production, waste management, policies, regulations, and Nigeria were used to identify academic articles and research studies. This literature review provided insights into the existing knowledge base, highlighting key challenges, gaps, and opportunities for improvement.
2. *Policy Documents and Legislation* A review of policy documents and legislation related to oil production and waste management in Nigeria was performed. This review encompassed acts such as the Petroleum Act, Oil Pipelines Act, EIA Act, NOSDRA Act, NES-REA Act, NDDC Act, and the DPR Guidelines and Standards. The objective was to gain a comprehensive understanding of the policies and regulations in place, including their objectives, scope, and enforcement mechanisms.
3. *Government and Industry Reports* Pertinent documents from governmental bodies (e.g., Department of Petroleum Resources, National Oil Spill Detection and Response Agency, National Environmental Standards and Regulations Enforcement Agency, Niger Delta Development Commission) were assessed, along with industry reports from International Oil Companies (IOCs) operating in Nigeria and autonomous research institutions. This data collection method aimed to gather information on the enactment and efficiency of policies and regulations.
4. *News Articles and Media Reports* Reviewing news articles and media reports allowed us to identify recent developments, events, and incidents pertaining to oil production and waste management in Nigeria. This provided a current understanding of the challenges, successes, and ongoing debates surrounding the implementation and effectiveness of the policies and regulations.

Our research undertakes a thorough examination of Nigeria's oil production and waste management policies and regulations by systematically collating and analyzing data from diverse sources. Our primary objective is not only to understand these legislative measures in their totality but also to critically evaluate their effectiveness, identifying potential gaps and areas requiring augmentation. In our pursuit of an all-encompassing and rigorous analysis, we have extensively relied on secondary data sources. The utilization of these sources allows us to delve deeper into the subject matter and to contextualize our findings, thereby providing comprehensive insights into the broader implications of our study. A large corpus of more than 300 documents was initially identified and retrieved for this research. However, to maintain the integrity and relevance of our analysis, we meticulously curated this collection and narrowed it down to the 100 most pertinent documents, ensuring our study

is grounded in the most significant and high-quality sources available.

Published research articles and reports

Table 2 is a list of some published research articles and reports that focus on oil production, waste management, policies, regulations, and their implications in Nigeria. These sources provide valuable insights into the challenges, successes, and recommendations for improving

the regulatory framework and environmental management in the country's oil and gas industry.

These articles and reports cover a wide range of topics related to oil production, waste management, policies, regulations, and their implications in Nigeria, offering valuable insights for researchers, policymakers, and industry stakeholders interested in understanding and addressing the challenges in the country's oil and gas sector.

Table 2 Some publications and reports that focus on oil production, waste management, policies, regulations, and their implications in Nigeria

Author(s)	Summary
Ite et al. (2013)	The study discussed the negative environmental impacts resulting from petroleum exploration and production in Nigeria's Niger Delta region, along with weak environmental regulation in the country. The authors recommended several measures to improve environmental protection, including strengthening regulation and enforcement, increasing public awareness, promoting sustainable development practices, and compensating affected communities
Nriagu et al. (2016)	The study examined the association between exposure to oil pollution and health outcomes, as well as the role of emotional reactions in moderating these outcomes. It involved 600 participants from five local government areas in Nigeria's Niger Delta region. The study found high levels of disease symptoms and environmental distress associated with oil pollution, and recommended intervention to alleviate psychological distress. The study found that risk perception in the area was mediated by dreaded hazards, visual and chemosensory cues. The exposure metrics significantly predicted health effects, with direct contact with oil pollution and emotional distress being important mediators. Demographic variables were also important mediators of functional capacity limitation at the individual level
Frynas (2000)	The author provided an analysis of the conflicts between oil companies and village communities in the Niger Delta. The study examined the legal and political framework of oil production in Nigeria and the conflicts that have arisen between oil companies and local communities over land rights, environmental pollution, and compensation. The author also discussed the role of international organizations in mediating these conflicts
UNEP (2011)	The United Nations Environment Programme (UNEP) conducted an independent assessment of the environmental and public health impacts of oil contamination in Ogoniland, in the Niger Delta, with the agreement and support of Ogoni communities, the Rivers State Government and other partners. Over a 14-month period, the UNEP team examined more than 200 locations, surveyed 122 km of pipeline rights of way, reviewed more than 5000 medical records and engaged over 23,000 people at local community meetings. The assessment has been unprecedented. The report provided a comprehensive overview of the environmental degradation in Ogoniland and its impact on human health. It also provided recommendations for remediation options
Nwilo and Badejo (2006)	The research investigated the consequences of oil spill contamination along Nigeria's coastal regions and offered suggestions for its administration. With a coastline of around 853 km along the Atlantic Ocean, Nigeria's coast consists of four unique geomorphological units: the Barrier-Lagoon Complex, the Mud Coast, the Arcuate Niger Delta, and the Strand Coast. The study discovered that oil spills profoundly affect marine life, human well-being, and socio-economic pursuits in Nigeria. The authors advised implementing oil spill prevention strategies to decrease the occurrence of such spills
Omofonmwan and Odia (2009)	This research focuses on the Niger Delta region of Nigeria, where oil extraction has led to environmental deterioration, soil depletion, pollution, and the decline of aquatic life and biodiversity, among other issues. The study found that the crises in the Niger Delta stem from the failure of multinational companies engaged in oil exploration and production, as well as the federal government, to effectively address the repercussions of their activities in the area. The paper recommends implementing proper mitigation measures, such as building access roads, health-care facilities, educational institutions, electricity infrastructure, income-generating ventures (cassava mills, rice mills, palm oil mills, etc.), piped water supply schemes, provision of microcredit facilities, capacity building, and agricultural development, which could significantly reduce the crises in the region to a minimum
Obi (2010)	The article examines how global oil extraction contributes to the dispossession of local communities and incites violent opposition in Nigeria's oil-rich Niger Delta. The shift in resistance from non-violent to violent methods is characterized by high-profile attacks by ethnic-minority militias from the Niger Delta against the partnership between the Nigerian state and oil multinationals. The primary contention is that oil extraction and the unequal distribution of its advantages ignite dissatisfaction and conflict between the Niger Delta inhabitants and those perceived as the exploiters and beneficiaries of the region's oil resources. Furthermore, the article explores the local and transnational elements and complexities that underlie resistance politics and the potential for addressing the contradictions created by "fossil fuel capital" in the Niger Delta

Official records and databases on oil spills

Official records and databases on oil spills can provide valuable information about the frequency, severity, and impacts of such incidents in Nigeria. Some of the key sources for obtaining official data on oil spills in Nigeria include:

- *National Oil Spill Detection and Response Agency (NOSDRA)* NOSDRA is the primary government agency responsible for oil spill management in Nigeria. The agency maintains a database of oil spills in the country, including information on the location, date, cause, volume, and response actions taken for each incident. NOSDRA's Oil Spill Monitor (<https://oilspillmonitor.ng>) provides an online platform for accessing and reporting oil spill data in Nigeria.
- *Department of Petroleum Resources (DPR)* DPR is the regulatory authority for Nigeria's oil and gas industry, responsible for ensuring compliance with environmental guidelines and standards. The DPR also maintains records and data on oil spills, as well as conducts investigations, and enforces penalties for non-compliance.
- *Joint Investigation Visit (JIV) Reports* JIV reports are prepared following the investigation of an oil spill incident in Nigeria, typically involving representatives from the relevant oil company, government agencies (such as NOSDRA and DPR), and local communities. These reports provide detailed information on the cause, volume, and impact of oil spills, as well as recommendations for remediation and compensation. For example, Moses et al. (2019) utilized geospatial technology to estimate the number of oil spill incidents that occurred in the Niger Delta region of Nigeria in 2015. Their method involved analyzing existing reports from the SPDC Oil Spill

Joint Investigation Visit (JIV) and resulted in the estimation of 132 incidents.

- *United Nations Environment Programme (UNEP) Reports* UNEP has conducted assessments and published reports on the environmental impacts of oil spills in Nigeria, particularly in the Niger Delta region. These reports, such as the 2011 Environmental Assessment of Ogoniland, provide valuable insights into the extent and consequences of oil pollution in the country.
- *Oil Companies' Records* International and local oil companies operating in Nigeria are required to maintain records of oil spills and report such incidents to regulatory authorities like NOSDRA and DPR. Some companies also publish data on oil spills as part of their sustainability reporting or in response to public information requests.

Official records and databases hold significant potential for providing crucial information on oil spills in Nigeria, which can inform policymaking, research, and response efforts targeting the environmental and socioeconomic impacts of oil pollution. However, data reliability and accessibility may be compromised by several factors, such as underreporting, inconsistent reporting standards, and limited public access to specific records.

Satellite imagery and remote sensing data from existing studies

Satellite imagery and remote sensing data have proven to be valuable tools for monitoring and assessing oil spills and their impacts on the environment. Numerous existing studies have utilized these technologies to investigate oil spills in the Niger Delta region of Nigeria. Some examples of such studies are shown in Table 3

These studies highlight the value of satellite imagery and remote sensing data for understanding the extent

Table 3 Existing studies that utilized satellite imagery and remote sensing data

Author(s)	Study/findings
Adamu et al. (2015)	The research aimed to determine which vegetation indices can identify vegetation impacted by oil pollution and the characteristics that make them appropriate for this objective. The study evaluated the temporal variations in vegetation indices (before and after oil spills) at both control sites (with no recorded oil spills) and affected sites (with recorded oil spills) in the Niger Delta. The findings indicated that broadband multispectral vegetation indices can effectively detect the influence of oil pollution on vegetation conditions
Obida et al. (2021)	The research employed satellite remote sensing to observe the effects of pollution over extensive areas in a geographically isolated and difficult setting. The study uncovered that two oil spills in Ogoniland during 2008/9 were the most significant in terms of both duration (combined 149 days) and volume (combined 82,939,170 L). However, little is known about the scope of the impact of these incidents since traditional field-based surveys are nearly unfeasible in this region
Adamu et al. (2018)	The research utilized Landsat 8 data to explore the effects of oil spills on vegetation by employing five vegetation indices. The study identified a notable distinction between vegetation conditions at spill sites (SS) and non-spill sites (NSS) in 2013, with an even more significant difference observed in 2014 following the oil spill. The spectral approaches applied to vegetation in this study could be useful in detecting and tracking the influence of oil spills on vegetation

and impacts of oil spills in the Niger Delta region of Nigeria. These technologies can provide a cost-effective and efficient means of monitoring oil spills and informing the development and implementation of policies, regulations, and response efforts aimed at mitigating the environmental and socioeconomic consequences of oil pollution in the region.

Mitigation and remediation strategies

Existing measures and their effectiveness

The Nigerian government and the oil industry have implemented various measures to mitigate and remediate the environmental and socioeconomic impacts of oil spills and pollution in the Niger Delta region. This section reviews the existing measures and assesses their effectiveness in addressing the challenges posed by oil spills and pollution.

- (a) *Regulatory Framework* As discussed earlier, Nigeria has a comprehensive legal and regulatory framework governing oil production and waste management, including the Petroleum Act, Oil Pipelines Act, EIA Act, NOSDRA Act, NESREA Act, NDDC Act, and DPR Guidelines and Standards. These policies and regulations aim to prevent oil spills, ensure proper waste management, and hold oil companies accountable for their environmental performance. However, the effectiveness of this regulatory framework is limited by factors such as weak enforcement, inadequate resources, and overlapping responsibilities among regulatory agencies.
- (b) *Oil Spill Response and Clean-up* The National Oil Spill Detection and Response Agency (NOSDRA) is responsible for coordinating oil spill response and clean-up efforts in Nigeria. NOSDRA works closely with the Department of Petroleum Resources (DPR), the Nigerian Navy, and other relevant agencies to detect, monitor, and respond to oil spill incidents. While these efforts have resulted in some successful clean-up operations, the overall effectiveness of oil spill response and clean-up in the Niger Delta region remains limited due to factors such as delayed response, inadequate resources, and insufficient technical expertise.
- (c) *Compensation and Remediation* Nigerian laws and regulations require oil companies to compensate affected communities for damages caused by oil spills and pollution, as well as to remediate the impacted environment. However, the implementation of compensation and remediation measures has been inconsistent and often inadequate, leading to continued suffering for affected communities and long-term environmental degradation.

- (d) *Community Engagement and Development Programs* Many oil companies operating in Nigeria have established community engagement and development programs to address the social, economic, and environmental impacts of their operations. These programs include initiatives such as infrastructure development, education and training, healthcare services, and environmental restoration projects. While some of these programs have had positive effects on local communities, their overall effectiveness is limited by factors such as lack of transparency, inadequate funding, and insufficient community involvement in decision-making processes.

Innovative approaches and technologies

To enhance the effectiveness of mitigation and remediation strategies in the Niger Delta region, it is essential to explore innovative approaches and technologies to address the unique challenges of oil spills and pollution. Some promising examples include:

- (a) *Advanced Oil Spill Detection and Monitoring Technologies* The use of satellite imagery, remote sensing, and aerial surveillance can significantly improve the detection and monitoring of oil spills and pollution in the Niger Delta region. These technologies can provide real-time information on oil spills' location, extent, and severity, enabling more timely and effective response efforts.
- (b) *Bioremediation and Phytoremediation* When hydrocarbons are present in soil, they can displace oxygen and nutrients, leading to negative impacts on plant growth and productivity (Onyia et al. 2019). Bioremediation and phytoremediation are innovative approaches that use microorganisms and plants, respectively, to break down and remove pollutants from the environment. There are several types of bioremediation methods available, including biodegradation, bioventing, composting, biopile, and land farming. In addition to bioremediation techniques, there are other effective methods available for remediation of oil-contaminated land, such as soil flushing and soil vapor extraction (Raju and Scalvenzi 2017). These techniques offer a more sustainable and environmentally friendly alternative to traditional clean-up methods, such as the use of chemical dispersants, which can have harmful side effects.
- (c) *Renewable Energy and Energy Efficiency* Promoting renewable energy and energy efficiency can help reduce Nigeria's reliance on fossil fuels and, conse-

quently, decrease the risk of oil spills and pollution. This can be achieved through policy incentives, technological innovation, and public awareness campaigns.

Collaboration between stakeholders

Effective mitigation and remediation of oil spills and pollution in the Niger Delta region require close collaboration and cooperation among various stakeholders, including government agencies, oil companies, local communities, civil society organizations, and international partners. Some key strategies for fostering collaboration between stakeholders include:

- *Strengthening Regulatory Coordination and Enforcement* Improved coordination and collaboration among regulatory agencies, such as NOSDRA, DPR, NESREA, and the Nigerian Navy, can enhance the effectiveness of oil spill detection, response, and clean-up efforts. This can be achieved through joint training programs, information sharing, and the establishment of integrated monitoring and response systems.
- *Public–Private Partnerships* The establishment of public–private partnerships can help mobilize the necessary resources, expertise, and technologies for more effective mitigation and remediation of oil spills and pollution. These partnerships can involve government agencies, oil companies, research institutions, and technology providers working together to develop and implement innovative solutions to the challenges posed by oil spills and pollution in the Niger Delta region.
- *Community Involvement and Empowerment* Ensuring the active involvement and empowerment of local communities in decision-making processes related to oil production and waste management is crucial for the success of mitigation and remediation efforts. This can be achieved through participatory planning, capacity building, and the establishment of community-based monitoring and response systems.
- *Civil Society Engagement* Civil society organizations can play a vital role in promoting transparency, accountability, and environmental justice in the oil industry. This can be achieved through advocacy, public awareness campaigns, and the provision of technical and legal support to affected communities.
- *International Cooperation* Collaboration with international partners, such as the United Nations, the World Bank, and other donor agencies, can help enhance the capacity of Nigerian institutions to effectively address the challenges posed by oil spills and

pollution. This can include financial and technical assistance, as well as the sharing of best practices and lessons learned from other countries.

Therefore, addressing the issue of wastewater due to oil spills and pollution in the Niger Delta region of Nigeria requires a comprehensive and collaborative approach involving various stakeholders. By assessing the effectiveness of existing measures, exploring innovative approaches and technologies, and fostering collaboration between stakeholders, it is possible to develop and implement more effective mitigation and remediation strategies that can help protect the environment, local communities, and the Nigerian economy from the adverse impacts of oil spills and pollution.

Policy recommendation

To address the issue of wastewater due to oil spills and pollution in the Niger Delta region, the following policy recommendations are proposed:

Strengthening regulatory frameworks

1. *Improve enforcement* Strengthen the capacity of regulatory agencies, such as NOSDRA, DPR, and NESREA, to enforce existing laws and regulations. This can be achieved through increased funding, personnel training, and the provision of advanced monitoring and enforcement tools.
2. *Streamline and harmonize regulations* Address overlapping responsibilities and conflicting mandates among various regulatory agencies by streamlining and harmonizing their roles and functions. This will help reduce bureaucratic bottlenecks and improve the overall effectiveness of the regulatory framework.
3. *Update and revise legislation* Periodically review and update existing laws and regulations to ensure their relevance and effectiveness in addressing current and emerging challenges related to oil spills and pollution. This can include incorporating international best practices, addressing gaps and inconsistencies, and enhancing penalties for non-compliance.

Enhancing transparency and accountability

1. *Improve reporting and disclosure* Require oil companies to regularly report on their environmental performance, including data on oil spills, waste management, and remediation efforts. These reports should be publicly accessible, independently verified, and adhere to international reporting standards.

2. *Establish independent oversight bodies* Create independent oversight bodies responsible for monitoring and evaluating the performance of regulatory agencies and oil companies in relation to oil spills and pollution. These bodies should have the authority to conduct investigations, issue penalties, and make recommendations for improvements.
3. *Promote public participation* Encourage public participation in decision-making processes related to oil production and waste management, such as the development of new policies and regulations, the review of environmental impact assessments, and the allocation of compensation and remediation funds.

Promoting community participation and empowerment

1. *Strengthen community engagement* Enhance the capacity of local communities to engage with oil companies and regulatory agencies in a meaningful and constructive manner. This can include providing training and resources for community leaders, establishing community-based monitoring and response systems, and creating forums for dialogue and collaboration.
2. *Enhance access to information* Ensure that local communities have timely and accurate information about oil spills, pollution incidents, and related issues. This can be achieved through the establishment of information centers, the use of local media and communication channels, and the provision of regular updates and reports.
3. *Empower communities through education and training* Promote education and training initiatives aimed at building the capacity of local communities to understand and address the challenges posed by oil spills and pollution. This can include environmental education, technical and vocational training, and the development of entrepreneurial skills.

Encouraging investment in sustainable development and clean technologies

1. *Provide financial incentives* Develop financial incentives, such as tax breaks, grants, and low-interest loans, to encourage investment in sustainable development and clean technologies. This can include support for renewable energy projects, energy efficiency improvements, and innovative waste management solutions.
2. *Foster research and development* Promote research and development in sustainable development and

clean technologies by providing funding, resources, and partnerships for universities, research institutions, and technology companies.

3. *Encourage international cooperation* Collaborate with international partners, such as the United Nations, the World Bank, and other donor agencies, to mobilize financial and technical support for sustainable development and clean technology initiatives in the Niger Delta region.
4. *Support local innovation* Encourage and support local entrepreneurs, innovators, and businesses in developing and implementing sustainable solutions to oil spills and pollution in the Niger Delta region. This can be achieved through the establishment of innovation hubs, business incubators, and mentorship programs.
5. *Implement sustainable procurement policies* Adopt sustainable procurement policies for government agencies and public-sector enterprises, requiring them to prioritize environmentally friendly products and services, including those related to oil production and waste management.
6. *Raise public awareness* Develop and implement public awareness campaigns to inform and educate the public about the environmental and socioeconomic impacts of oil spills and pollution, as well as the importance of sustainable development and clean technologies. These campaigns can use various communication channels, such as radio, television, print media, and social media, to reach a wide audience.
7. *Promote international best practices* Encourage the adoption of international best practices and standards in oil production and waste management, such as the use of advanced technologies, proper maintenance and monitoring of infrastructure, and the implementation of comprehensive environmental management systems.
8. *Strengthen international partnerships* Foster international partnerships and collaborations to exchange knowledge, expertise, and technology related to sustainable development and clean technologies. This can include participation in international forums and conferences, the establishment of joint research and development projects, and the signing of bilateral and multilateral agreements.

By implementing these policy recommendations, Nigeria can make significant progress in addressing the issue of wastewater due to oil spills and pollution in the Niger Delta region. This will not only protect the environment and local communities but also contribute to the long-term sustainability and resilience of the Nigerian economy. Ultimately, a comprehensive and collaborative

approach involving various stakeholders is necessary to achieve meaningful and lasting change.

Conclusions

This study has comprehensively analyzed the severe impact of oil spills and pollution in the Niger Delta region, highlighting significant environmental and socio-economic repercussions on local communities. Current regulations and remediation measures have proven insufficient due to weak enforcement, inadequate resources, and overlapping agency responsibilities. We found that innovative methods such as advanced oil spill detection, bioremediation, and renewable energy hold promise for augmenting mitigation efforts, and we emphasize the essential role of collaboration between diverse stakeholders like government agencies, oil firms, local communities, civil societies, and global partners. Policies should strengthen the regulatory framework, enhance transparency and accountability, foster community participation, and encourage investments in sustainable development and clean technologies. Recommendations for future research include assessing the effectiveness of specific regulations and enforcement mechanisms, conducting longitudinal studies to understand the long-term impacts of oil spills, examining the potential of emerging technologies like nanotechnology and AI, scrutinizing the role of corporate social responsibility initiatives, evaluating the impact of public awareness campaigns, and investigating the effectiveness of international collaborations. This research adds to ongoing efforts to address the issue of wastewater due to oil spills and pollution in the Niger Delta and provides insights to guide policymakers, practitioners, researchers, and stakeholders toward developing and implementing strategies to mitigate and remediate these adverse impacts on the environment, communities, and the Nigerian economy.

Abbreviations

CSR	Corporate social responsibility
DPR	Department of Petroleum Resources
EIA	Environmental impact assessment
EGASPIN	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria
EMP	Environmental Management Plan
FEPA	Federal Environmental Protection Agency
IOC	International oil companies
JIV	Joint Investigation Visit
MNOCs	Multinational oil companies
NDDC	Niger Delta Development Commission
NESREA	National Environmental Standards and Regulations Enforcement Agency
NOSDRA	National Oil Spill Detection and Response Agency
NSS	Non-spill sites
PIA	Petroleum Industry Act
SAR Images	Synthetic Aperture Radar Images
SS	Spill sites
UNEP	United Nations Environment Programme

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Author contributions

DREE was a principal investigator made substantial contributions to the conception and design of the study, as well as the interpretation of the findings from the reviewed literature. OFO played a significant role in the identification, acquisition, and analysis of the relevant literature. TOS contributed to the critical revision of the manuscript for important intellectual content. CNO was involved in drafting the manuscript and revising it for important intellectual content. AOO provided substantial support in synthesizing the findings from the reviewed literature, as well as in drafting and revising the manuscript for important intellectual content. CGU was involved in drafting the manuscript and revising it for important intellectual content. CO provided technical guidance, proofread the manuscript for intellectual merit, and participated in the internal review process. All authors gave final approval of the version to be published and agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Competing interests

The authors declare that they have no competing interests, financial or non-financial, that could be perceived as influencing the content or conclusions of this paper.

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