Prospects ofOil Spill Remediation in the Niger Delta, Nigeria; the Case Study ofBodoCreek

Abstract

Remediation of oil spill contaminated sites is very important in the actualization of the goals of the United Nations Decade on Ecosystem Restoration (UNDER) project. Conventional and artisanal oil exploration have resulted in several oil spill incidence within the Niger Delta.The volume of spilled oil in Bodo Creek was estimated to be 103,000 - 311,000 barrels. Shoreline flushing and artificial mangrove revegetation are key aspects of the remediation process.This review was done to assess the effect of the oil spill remediation on the recovery of flora and fauna in Bodo Creek.The data was mined from literature on pre-spill, post-spill and post-remediation studies from the same study Stations in Bodo Creek.This review reported oil exploration and oil spill in the study area.The study reviewed oil spill remediation approaches as well ashighlights on the recovery trend of macroinvertebrate following oil spill remediation. Prospects of oil spill remediationincluding; oil degradation, improved economy, carbon sequestration and coastal protection are reported in this study.What is the correlation between oil spill remediation and the recovery of flora and fauna?We hypothesized that the remediation would result in faster recovery of macroinvertebrate.The study found that remediation results in faster recovery of macroinvertebrate.This paper concludes that further research is necessary in order to develop unique oil spill remediation approaches to serve as template for oil spill remediation in other parts of the Niger Delta asproper oil spill remediation effortsare necessary to tackle the severe consequences of oil spill in the environment.There is need for collaboration between the oilspill remediation agency and researchers. It is also important to publish findings from empirical study on remediation.

Keywords: Oil exploration, remediation, macroinvertebrate, mangrove and environmental restoration.

INTRODUCTION

Crude petroleum oil is an expression used to describe what is left after living matter have been buried and subsequently decomposed to a state in which carbon and hydrogen are the basic elements. This might be one of the very complex mixtures occurring naturally on earth which is made up of compounds that vary in their basic constituent parts and physical characteristics that are toxic to freshwater and marine species when they are exposed to them (Owate and Okujagu, 1995; Afolabi *et al*., 1985).The importance of the exploration of crude petroleum oil has come at a great cost (Orisakwe, 2021). Severalcountries (example; USA and UK) have come up with approaches and adequate policies in order to restore the oil spill contaminated sites. There is a shift from mere policy formulation to implementation of such policies in most developed countries including, the UK, Netherlands and the USA. Conversely, in the developing countries there is yet to be a reflection of this worldwide response to contaminated land (Zabbey*et al*., 2017).According to a U.S Government report, an estimated 4.9 million barrels of oil was released for over 87 days, starting from 20th April and ending on 15th July, 2010, into the Gulf of Mexico from the Deepwater Horizon spill(Rohal *et al*., 2020; McNut*et al*., 2011a; McNut*et al*., 2011b). After the oil spill, some of the oil was recovered directly from the wellhead. Others were contained, skimmed offshore, burning in-situ under controlled condition, dispersion (naturally and chemically, both on the surface and subsea), as well as other pathways, such as stranding on the shoreline.

The exploration of crude oil is the main source of income for Nigeria; although agriculture to some extent forms a substantial part of the country's income (Akankali and Nkeeh, 2022).For over 50 years, the exploration and exploitation of crude oil has been the major contributor to the Nigerian economy. There is a substantial oil reserve and natural gas, estimated at 37.4 billion barrels (OPEC, 2017) and 192 trillion standard cubic feet, respectively, in the Niger Delta region, which produces the oil. In Nigeria, there have been adverse pressures on the ecosystem, due to several decades of reliance of the country's economy on the exploration and extraction of crude oil; accidental and incidental release of hydrocarbon and its products into the environment is the main cause of the pressure (UNEP, 2011; Zabbey*et al*., 2017). Globally, Nigeria is ranked the 11th largest producer of oil. The Niger Delta region is the hub for oil and gas in Nigeria. The region also has the highest concentration of mangroves and uncommon biodiversity (Sam *et al*., 2016).Although oil exploration can lead to increased revenue earning, employment opportunities and general improvement in the wellbeing of citizens, uncontrolled release of crude oil into the environment would have adverse effect on the ecosystem flora and fauna. Oil spillage is the uncontrolled and unintentional release of hydrocarbon into the environment; the discharged hydrocarbon could range from almost negligible volumes to massive spills in thousands of barrels. The release of large volumes of oil into the environment could come from natural seeps; oil tankers and vessels; offshore oil platforms and pipelines. Negligible volume of crude oil into the aquatic environment could be from recreational boats, commercial boats and ships.

Nigeria's Niger Delta region is a hub for the exploration and production of oil, attracting multinationals from all over the globe. The Niger Delta region is home to several multinational companies engaged in oil exploration and production. Companies such as Shell, Chevron, ExxonMobil, TotalEnergies, NAOC, Addax Petroleum, Conoil, and Seplat Petroleum have significant operational footprints in various states of the Niger Delta, including Rivers, Bayelsa, Delta, Akwa Ibom, Imo, and Edo (Watts and Zalik, 2020; Ite *et al.*, 2013; Nwankwo, 2017; Manby, 1999; Mamudu*et al*., 2021; Nwoke, 2021; International Crisis Group, 2015; Achebe *et al*., 2012).

OIL EXPLORATIONAND OIL SPILL IN NIGERIA

Sola (2005), reported that crude oil and gas exploration and production is amongst the largest and very profitable businesses in the world, just as it is the backbone and primary energy source for developing and developed economies across the world. Oil production is the primary driver of Nigeria's economy, with about 80 percent of the country's revenue coming from the oil sector.Nigeria experienced an oil production boom in the 1970s, driven by high prices of oil globally and increased foreign investments. This period experienced the rapid development of oil fields including Bonny, Escravos and Forcados, resulting in a surge in government revenue and economic growth (Tamuno and Felix, 2006). Nigeria's oil industry has had numerous environmental and social challenges. Oil spills, flaring of gas and degradation of the environment have impacted local communities, resulting in conflicts and social unrest (Bello andNwaeke, 2023).In the later part of 1990s and early 2000s, there was a shift towards deepwater exploration in Nigeria, as onshore and shallow-water reserves became depleted.Major deepwater discoveries in fields such as Bonga, Erha and Agbami expanded Nigeria's oil reserves and capacity of production, further solidifying her position as a significant oil-producing nation (Nkem *et al*., 2022; Orisakwe, 2021; Nriagu*et al*., 2016).The journey of oil production in Nigeria has been marked by challenges and successes. From the first discovery at Oloibiri to becoming Africa's largest producer of oil, Nigeria has experienced significant economic and social transformations. Nevertheless, environmental concerns, management of revenue, and the need for economic diversification remain critical areas to address for sustainable development of oil industry of Nigeria.

In-spite-of the high energy and economic potential coming from the oil sector, crude oil exploration and production has brought about a huge environmental pollution resulting in serious impact on the environment.Oil spill is amongst the serious environmental problems linked with crude oil production.This is due to the fact that crude oil as well as other petroleum hydrocarbons are toxic to every form of life and harmful to aquatic and terrestrial ecosystems (Zunaira *et al*., 2022).Many factors have been held responsible for oil spill such as error from human, sabotage as well as failure of equipment.Achunike*et al.*(2020) stated that a 2015 SPDC report estimated that around 85% of oil leak events from SPDC-JV facilities were due to unauthorized interference by third-party with pipelines and other infrastructure. Oil exploration and underdevelopment has also been reported in the Niger Delta (Ezuma and Sunday, 2020).The

adverse effect of oil spill on the environment is enormous. Oil spill impacts the environment as it causes physical changes, ecological changes, and chemical toxicity.The deleterious effect of the impacts depends on the extent of the pollution, the chemical and physical properties of the spilled oil, the immediate environmental condition, and the sensitivity of the fauna and flora and their habitats to the extraneous factors.The toxicity may range from chronic to acute on living flora and fauna depending on exposure period and oil spill concentration (Ehizonomhen*et al*., 2023; Onyechi*et al*., 2016). Soil quality and fertility are affected by the oil spill contamination. As oil has the propensity to force soil particle together, it affects soil porosity. Carbon dioxide availability for the respiration of living organisms is depleted since oil spill forms coats on soil surface (Linden and Palsson, 2013). The effect of oil on aquatic animals could include change in their reproductive, feeding behavior and resulting in tainting and loss of habitat. Tainting happens when an organism takes in sufficient hydrocarbon to the extent of causing an off flavor in seafood making it unsuitable for consumption by humans until the tainting disappears (Ehizonomhen*et al*., 2023; Lake *et al*., 1985). The effects of oil on marine larvae significantly damages the structure and value of wetland, destroying the insulating ability of mammals with fur including sea otter and the water propelling ability of bird feeders thereby exposing these faunas to harsh elements. Nigeria in Western Africa has a rich history of oil exploration and production. The exploration of oil in Nigeria dates back to the colonial period(Adeola *et al*., 2022; Frynas, 2000). The British colonial government in 1908 established the Nigerian Bitumen Corporation, which started oil exploration(Steyn, 2009). Nevertheless, it was in 1956 that significant oil reserves were discovered at Oloibiri in Bayelsa State. After the independence of Nigeria in 1960, the Nigerian National Oil Corporation (NNOC)was established in 1971 in order to oversee the country's oil operations. The NNOC thereafter transformed into the Nigerian National Petroleum Corporation (NNPC), becoming the state oil company saddled with the responsibility of exploration, production, and marketing of petroleum products (Ogbuigwe, 2018).

NIGER DELTA OIL SPILL

The Niger Delta covers a landmass of 112,000 square kilometers and is made up of several ecologically sensitive regions (for example coastal barrier islands, freshwater swamps and mangroves) (NDDC, 2014). The region comprises 9 states, having a population of approximately 31 million individuals whose main source of living include fisheries and agriculture (Pegg and Zabbey, 2013; Sam *et al*., 2017; UNEP, 2011; Sam and Zabbey, 2018). The exploration of oil in the Niger Delta goes back to as far as the 1950s following the discovery of significant oil reserves in the region (Okonkwo andEtemire, 2017; Ordinioha and Brisibe, 2013). The discovery of crude oil in marketable quantity was first made in Oloibiri, Bayelsa State, Nigeria in the year 1956 (Okonta, 2008).Shell-BP drilled the first oil well known as Oloibiri-1 in 1956, marking an important time in the history of Nigeria since it marked the starting of commercial oil production in the country.Oil discovery in the Niger Delta brought tremendous opportunities and challenges.The region thus without delay became the center of the country's oil industry,

attracting multinational oil companies and transforming Nigeria's economy (Olujobi, 2021).As a result of the success of the Oloibiri-1 well, there was an intensification of exploration efforts throughout the Niger Delta.Niger Delta was found to be rich in hydrocarbon resources, having vast reserves of oil and gas located offshore and onshore (Pitkin, 2013).Nevertheless, this fast expansion of oil exploration and production also came with diverse challenges and negative consequences for the Niger Delta and its communities (Adeola *et al*., 2022); degradation of the environment, such as oil spills, gas flaring and ecosystem destruction became common in the region (Onyena and Sam, 2020; Ite *et al*., 2013). Two decades after (1958), the discovery of crude oil in second commercial quantity was made, at the Bomu oil field in Ogoni, Rivers State. This later discovery made tangible contribution to the 1st oil export from Nigeria to overseas. There was an expansion on this, leading to Fifty-seven oil wells associated with five flow stations in Ogoni (UNEP, 2011; Linden and Palsson, 2013; Zabbey and Uyi, 2014).

Oil spill is the accidental or deliberate release of oil into the environment either on land or water (Dhaka and Chattopadhyay, 2021).Oil spill in the Deepwater Horizon affected the marine species in the Gulf of Mexico, flora and the population of human along the coast (Nyankson*et al*., 2016).The spill of hydrocarbons into the Niger Delta environment from the start of the oil sector in Nigeria is put at 13m tones resulting in some levels of terrestrial and aquatic environment contamination. This relatively long history of oil development and associated impact on the environment (e.g oil spill) notwithstanding, different governments in Nigeria have neither been effective or in a hurry to come up with governance structures and strategies for the prevention and remediation of oil spill contaminated land. As a result, contamination from oil has always been highest within the region compared to other parts of Nigeria, having land-based site that are oil contaminated, estimated at over 2000 sites (Sam and Zabbey, 2018).Most of the documented oil spill incidents in Nigeria take place in the mangrove swamp forest and the offshore areas within the Niger Delta, which accounts for the most productive area (Nwankwo and Ifeadi, 1988). There were 377 reported cases of oil spill incidents in the Niger Delta, out of 784 reported cases in Nigeria between 1976 and 1980. The actual volume of spilled oil within the period under review in the estuary coastal waters was estimated at 1, 337, 820 barrels; out of this, 796, 453 barrels (60 percent) took place in the Niger Delta (Awobajo, 1981). The Niger Delta has experienced several disasters resulting from oil blowouts; it is estimated that, over 2,567,960 barrels of crude oil have contaminated the Niger Delta in 5733 incidents from 1976-2000 549,060 barrels were recovered,on the other hand, 1,820 barrels were lost to the environment (Denny and Jacob, 2022).

From the time that petroleum oil was discovered at Oloibiri in the Niger Delta, the exploration of crude oil has been ongoing (Otobo, 1995). The continued exploration of crude oil in addition to other allied activities in the petroleum sector, have been the backbone of the economy of Nigeria since 1970s. In Nigeria, there are reports of different oil spills. Between 1976 and 1997, 5334 cases of oil spills were reported to have released around 2.8 million barrels of oil into the environment (coastal waters, swamp, land and estuaries). Other points of crude oil entry into the

environment apart from oil spills include discharges from industries, accidents by tankers, natural seepages, sabotage and effluents emanating from the refinery processes (Dublin-Green *et al*., 1988).Apart from crude oil exploration, the release of other chemicals such as; paraquat poses a serious challenge to fauna in the Niger Delta (Nkeeh and Jamabo, 2019). However, the effect of the spill of hydrocarbon into the environment is common and worse than the pollution from other sources.

CASE STUDIES OF OIL SPILL IN THE NIGER DELTA

The incidence of oil spills has caused a devastating impact on the Niger Delta region in Nigeria, resulting in a widespread environmental degradation and affecting the lives of the local communities. This section examines the case studies of significant oil spill incidents in various states within the Niger Delta, providing the dates of the spills and their duration. In 2008, Bodo community located in Rivers State of the Niger Delta experienced two major oil spills resulting from a ruptured pipeline operated by Shell. The first oil spill took place in August 2008 and continued for about three weeks, while the second oil spill took place in December 2008 and continued for a period of ten days. An estimated 60,000 barrels of oil was released into the environment from the spill, causing extensive ecological damage (Watts and Zalik, 2020).In addition to aquatic fauna, physicochemical parameters of Bodo Creek have been reported to be affectedby the oil spill (Nkeeh*et al*., 2021b; Nkeeh*et al*., 2021c; Nkeeh*et al*., 2021d).

In 2011, there was an oil spill incidence in the Ikarama community of Bayelsa State following equipment failure at an oil well operated by Agip(Nigerian Agip Oil Company). The spill continued for many days, thus leading to farmland contamination, contamination of water bodies and fishing areas. The duration of the spill varied, however the spill had a significant impact on the ecosystem and livelihoods.There was an oil spill incidence in the Koluama community of Delta State, in 2020, resulting from an equipment failure at an offshore oilfield under the operation of Chevron Nigeria Limited. The oil spill persisted for many days, resulting in the release of oil into the marine environment and thus affecting the shoreline, mangrove forests as well as fishing areas. The length of time of the oil spill impacted the recovery efforts and the environmental consequences in the long-term (Adesioye and Owoh, 2023).Oil spill incidence was recorded in Brass community of Bayelsa State, in 2019, resulting from a pipeline leak operated by Shell Petroleum Development Company (SPDC).The oil spill continued for a significant period, thus affecting the marine ecosystem, mangrove forests as well as activities.The length of time of the oil spill and the clean-up efforts thereafter had a lasting impact on the socio-economic well-being of the community (Wizor andWali, 2020; Wizor and Eludonyi, 2020). An offshore oil spill close to the Ibeno community in Akwa Ibom State, occurred in 2012, resulting from a ruptured pipeline owned by ExxonMobil. The oil spill continued for many days, leading to a discharge of reasonable amount of crude oil into the Atlantic Ocean. The oil spill had impact on coastal areas, beaches as well as fishing grounds, resulting in significant ecological and socio-economic implications (Udoh and Ekanem, 2011).

The release of crude oil in the Niger Delta has resulted in severe and lasting consequences for the communities and environment in the region.The case studies presented below (Table 1), highlights the dates as well as the durations of significant oil spill in different states in the Niger Delta.The spills ranged from a few days to many weeks, however their impacts were felt long time after the spills have taken place. These oil spill incidences serve as reminders of the importance of effective preventive measures, quick response and long-lasting restoration efforts to counter the environmental damage and thus protect the livelihoods of the impacted communities.

Table 1: Highlights of some oil spill incidence in the Niger Delta

Date of oil spill	**Location of oil spill**	**Volume of spill/surface area of land contaminated/comment on the oil spill**
11th July, 1970	SHELL BOMU-11 oil well	607 hectares of farmlands
1971	Forcados terminal storage tanks	570,000 (measure of volume not reported)
January 17th, 1980	Funiwa-5 oil well	146,000 barrels
May 10th, 1980	Nigeria Agip Company (NAOC) pipeline	30,000 barrels
August 13th, 1993	Nigeria Agip Company (NAOC) pipeline	10,000 barrels
October, 1984	lgL4 oil spill at Ikata pipeline	Spill was regarded as almost negligible, as only some part of the stream channel was contaminated by it.
July, 1985	the lg85 oil spill at Okoma pipeline (Ahoada)	Community structure of the fishery in the oil spill contaminated areas was affected by the spill.

(Developed from Hart, 1997 and Awobajo, 1981)

OILSPILL IN OGONILAND

History of oil spill in Ogoni as well as government's neglect of the Ogoni people despite their contribution to Nigeria's economy has been reported (Adeola *et al*., 2022; Okonkwo and Etemire, 2017; Lindén and Pålsson, 2013; Osaghae, 1995; Pegg and Zabbey, 2013).The impact of past oil exploration activities lingers, and the remediation efforts have been slow and insufficient. The Ogoni cleanup project, launched in 2016, aims to restore the polluted sites, but its implementation has faced delays and obstacles (Yakubu, 2017). The history of oil exploration in the Ogoni region serves as a reminder of the complex dynamics between resource extraction, development, and environmental and social justice. It highlights the importance of sustainable practices, community participation, and the protection of human rights in the pursuit of natural resource wealth.

Apart from recorded oil spill incidence resulting from the activities of multinational companies within the Niger Delta, there are cases of oil spill attributedto artisanal refining of crude oil, locally called "oil bunkering". According to a study by Nkeeh (2022), oil bunkering otherwise known as artisanal refining of oil is the illegal exploration of oil, usually by unlicensed operators or non-professionals; by tampering with oil pipelines and stealing crude, which is later heated or boiled locally in metal drums to certain temperatures. The study also reported that artisanal refining of oil usually has uncountable negative impacts on the aquatic plants and animals; illegal refining of oil also leads to the release of black soot into the environment, resulting in respiratory illnesses or aggravating the extent/level of respiratory diseases in already infected patientsin addition to economic loss of great magnitude suffered by multinationals and government.According to Bonte *et al*. (2019), unauthorized activities leading to oil spill include tapping of pipeline, connecting leaking hoses from the tap, transporting stolen crude oil through different open-hulled large (e.g. >30 m) and small wooden vessels, as well as refining at shore side. Post 2010, oil spills resulting from illegal activities increased drastically (over 30 in 2010-2011). Their study also reported that these unauthorized activities and the spillages associated with it have persisted into 2018, just as remediation as well as the SCAT/chemistry programs were going on; the recovery of mangrove plant after the primary loss in 2008 is very marginal and there is the need to plant.

OIL SPILL REMEDIATION TECHNIQUES

All oil spills are unique condition combinations that have to be considered while developing the effective treatment guidelines (Michel *et al*., 2013). The process of Shoreline Cleanup Assessment Technique (SCAT) is an established and globally recognized component of oil spill response in operation since the Exxon Valdez spill, where a standard method of documentation, terminology and decision making for the assessment and treatment of shoreline was initially

applied (Owens and Teal, 1990).Different techniques and methods (Dave and Ghaly, 2011;Al-Majed *et al*., 2012;Ivshina*et al*., 2015; Kumari *et al*., 2019; Ossai *et al*., 2020) have been reported in literatures for the cleanup and remediation of sites impacted by oil spill.Nevertheless, it is pertinent to have a proper knowledge of the extent of the oil spill so as to find an effective way to remediate the environment. Remediation techniques can be grouped into four, namely; physical remediation, chemical remediation, biological remediation as well as thermal remediation. These are the four categories of the present division of remediation techniques. Before restoration and post-restoration data are important in the understanding of how a system responds to remediation efforts (Koebel and Bousquin, 2014). Information on pre-disturbance is very important for the effectiveness of any remediation program (Vinson *et al*., 2008).

In petroleum effluent remediation, several traditional and common techniques including biological, physicochemical, and chemical approaches are utilized. Gravity-based separation - flotation, filtration-based separation method, as well as biological process remediation are important (Mokfi*et al*., 2022).The replacement of soil and thermal desorption are the principal components of physical remediation approach, otherwise known as mechanical remediation approach. This system of remediation is very laborious, cost-effective and appropriate for small contaminated sites (Khan *et al*., 2004). Physical remediation is a main remediation stage that utilizes sedimentation to takeaway or separate immiscible liquids, solid particles, suspended solids (SS), and suspended contaminants from petroleum wastewater (Mokfi*et al*., 2022).In chemical methods, clean water, reagents and solvents which possess the ability to leach the contaminants from the soil are used (Lim *et al*., 2016). Some chemicals used for oil spill remediation are; dispersants and solidifiers. The use of chemicals in oil spill remediation is mostly applicable in tropical region.Biological remediation involves the use of plants and microbes (Ibañez *et al*., 2015a). Flora has the ability to absorb, accumulate, and metabolize a range of toxins, such as PAH (Mackova*et al*., 2006). In phytoremediation, green plants are used in the process of fixing or absorbing contaminants from the soil. In this method, enzymes that are present in the roots of plants are used to facilitate contaminant degradation process. This helps to reduce the concentration of contaminant in soil and thus reduce the human health and environmental risk from such contaminants (Zabbey*et al*., 2017). Examples of plants used for oil spill remediation are; Willow (*Salix species*), poplar tree (*populous detoides*) and Indian grass (*Sorghastrumnutans*).Bioremediation approach enhances the natural hydrocarbon biodegradation process by providing nutrients and oxygen needed for microbial activities. These approaches are expensive and also conserve resource (Lim *et al*., 2016). Biodegradation mechanisms involve the use of the ability inherent in microorganisms to breakdown hydrocarbons as a means of energy (Lawniczak *et al*., 2020). This oil spill remediation approach could further be divided into two categories, namely; bioaugmentation and biostimulation. Bioaugmentation is the process of enhancing microbial population performance by adding bacteria that possess specific ability for catabolism, in addition to straining or enrichment consortia in order to increase the rate at which contaminants are degraded (Lim *et al*., 2016). Biostimulation is a term used to describe how environmental parameters including nutrients, biosurfactants and biopolymers are adjusted. The

process of adding oxygen to the soil pore spaces for the purpose of stimulating microbial growths is known as bioventilation (Zabbey*et al*., 2017).Oil spill remediation could also be achieved through natural dispersal (natural breakdown of oil) and the use of floating booms.

OILSPILL REMEDIATION AND MACROINVERTEBRATE RECOVERY, THE CASE STUDY OF BODO CREEK

Upon request from the government of Nigeria, the United Nations Environment Programme (UNEP) was saddled with the responsibility of conducting environmental assessment in some parts of the Niger Delta-Ogoniland; this was a consequence of the protests and anger expressed by the local communities, non-governmental organizations and the media (UNEP, 2011).The establishment of the Hydrocarbon Pollution Remediation Project, HYPREP is a direct consequence of the UNEP report. HYPREP which is directly under the Federal Ministry of Environment, Nigeria, is responsible for the oil spill remediation in Bodo Creek and other oil spill impacted sites in Ogoni. Shoreline flushing and artificial mangrove revegetation are key aspects of the remediation process.Shoreline Cleanup Assessment Technique (SCAT) and chemical sampling have been used to assess the remediation of Bodo Creek (Nkeeh, 2022). Bonte *et al.* (2019) reported exhaustively on the SCAT process and chemical sampling in Bodo Creek. According to their study, SCAT relies so much on the direct visual examination for the assessment of the severity of oil contamination and help to guide remediation efforts. Their study compared SCAT observations of oil type, total surface area covered by the oil as well as pit oiling to collected surface and subsurface sediment samples collected at the same time and analyzed for hydrocarbon constituents. Their findings showed that while the contamination can be chemically characterized through limited sampling and analysis, observations through SCAT can be measured using limited sediment sampling and is enough to steer physical remediation methods.

Macroinvertebrates are fauna >0.5mm in diameter that live in the bottom substrates such as sediments, rocks, snags and aquatic flora, of aquatic ecosystems for at least an aspect of their life cycle (Sengupta and Dalwani, 2008). They can as well live on substrates (Nupur *et al.*, 2013). These aquatic organisms are a diverse array of fauna with or without backbones, retained by sieve or mesh having pore size of 0.5mm, often used in the devices for sampling of stream (Winterbourn *et al*., 1999; Basyuni*et al*., 2022). They are usually greater than 0.5millimeter (pencil dot size). At times they can be found on sediments, although they can also be found partially/completely buried within the sediment of the sea bottom. Macroinvertebrate include different assemblage of organisms across almost all the animal phyla. They are aquatic fauna inhabiting the bottom of marine and fresh waters (Nkwoji*et al*., 2010). They dwell on rocks, logs, sediment, debris and aquatic flora throughout or some aspects of their lifespan.Bottom dwelling macroinvertebratecould be littoral or profundal (Mann, 1980).

Ogoni, located in Rivers State, Niger Delta in Nigeria, comprises four Local Government Areas, namely; Khana, Gokana, Tai and Eleme. Bodo is a community in Gokana Local Government Area.Bodo is a coastal, traditional and rural community in Ogoni which occupies (latitude 4836′ N, longitude 7821′ E) the upper reaches of the Andoni-Bonny estuarine system. More than sixty five percent of Bodo is made up of mangrove swamps, pockets of island forests as well as

brackish water creeks that are generally referred to as Bodo Creek (Onwughuta-Enyi*et al.*, 2008). On a daily basis, several of the creeks in Bodo are submerged and exposed due to semi-diurnal ebb and flood tides. (Pegg and Zabbey, 2013).The flow station known as Bodo West field is situated in Bodo Creek mangrove midland. The Trans Niger Pipeline (TNP), responsible for the daily transportation of 120,000 to 150,000 barrels of oil from the region's heartlands to the oil terminal at Bonny passes through the Bodo Creek. Despite the suspension of oil production as a result of the impacts of the 1990s Ogoni struggle led by MOSOP, the TNP is still very active thus making the environment that it passes on vulnerable to oil spill. Wellheads and flow stations without caps, pipeline leakage, oil spills resulting from the tapping of wells illegally, artisanal refining of oil and transportation of stolen oil further compounds the threats and oil spill incidents in Ogoni (UNEP, 2011; Linden and Palsson, 2013; Zabbey and Uyi, 2014).Two major oil spills occurred in Bodo Creek in 2008 and the environmental impact on the immediate and adjoining communities are properly reported (Pegg and Zabbey, 2013). For Bodo Creek oil spill, the volume of spilled oil was estimated at 1640 barrels during the 1st spill;another account estimates the volume of the spilled oil to be between 103,000 to 311,000 barrels (Pegg and Zabbey, 2013; Vidal, 2012).Prior to the two primary 2008 oil spills in Bodo Creek, there was relatively uncommon reported spills in the area (17 between 1986 and 2008), 10 of which resulted from illegal activities (Gundlach, 2018).Scientific research also exists, which evaluates and shows the significant negative impact of the oils on the creek's faunal resources. A study after the impact carried out by Zabbey and Uyi (2014) reevaluated intertidal flats previously evaluated before the spills (Fentiman and Zabbey, 2015).

Recovery trend of macroinvertebrate pre-spill, post-spill and cleanup study in Bodo Creek

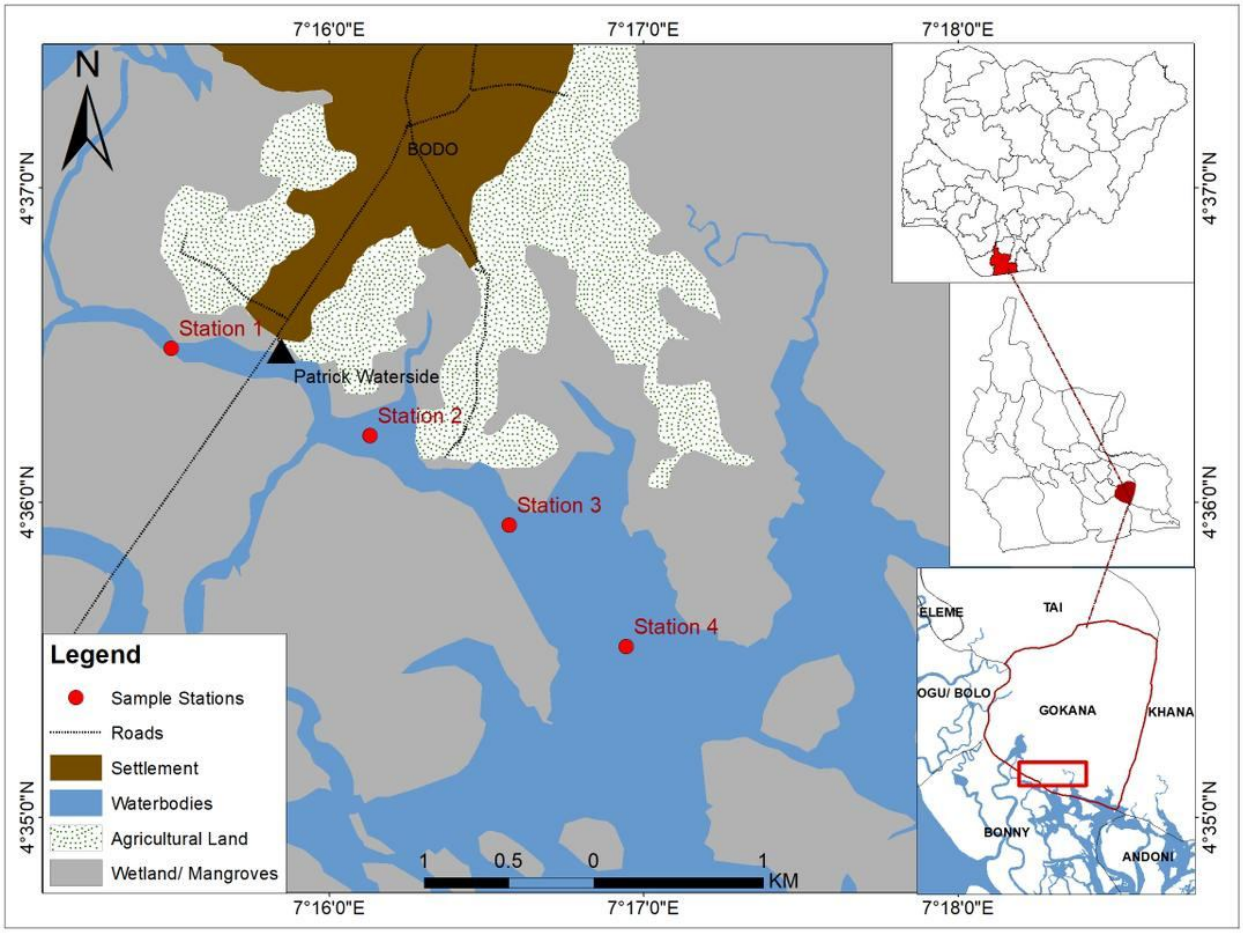

Fig. 1: Map of study area

The four Stations reviewed in this study is shown in Figure 1.The recovery trend of macroinvertebrate before-spill, after-spill and after cleanup in Bodo Creek is presented in Table 2. This recovery trend is developed from the pre-spill, post-spill and after remediation studies conductedon the same, four Stations,in Bodo Creek. The recovery trend covers period of data collection from 2006 to 2020. Data that was collected from 2006 to 2008, are categorized as pre-spill study(2006-2007; 2006-2008). Post-spill studies are the studies that the data collection period was after 2008 to 2016 (2011; 2013; 2015-2016). The post-remediation study is the study that the data was collected in 2020.

Table 2: The recovery trend of macroinvertebrate of Bodo Creek (September 2007-November, 2020)

S/N	Reference (s)	No. of species	Period of data collection
	Pre-spill study		
1	Zabbey and Arimoro (2017)	36	May 2006-April 2007
2	Zabbey and Hart (2014)	47	May 2006-April 2008
	Post-spill study		
6	Zabbey and Uyi (2014)	4	July 2011
7	Isaac (2013)	6	July 2013-October 2013
8	Nwipie*et al*. (2019)	11	September 2015-February 2016
	Clean-up study		
9	Nkeeh (2022)	18	February 2020- November 2020

(Nwipie*et al*., 2019; Nkeeh, 2022)

The recovery trend(Table2) shows that before the 2008 oil spill, thefirst and second pre-spill study reported 36 and 47 species respectively. The first post-spill study showed 4 species. This drastic reduction in species could be attributable to the effect of the oil spill. In the second and third post-spill studies, the macroinvertebrate species increased to 6 and 11 species respectively; this could be attributable to the effect of remediation due to natural attenuation (RENA). However, the post-remediation study showed a sudden rise in macroinvertebrate community, at a rate that could not have been possible only due to RENA. This shows that remediation efforts are necessary in order to achieve the recolonization of previously polluted environment by fauna.

OILSPILL REMEDIATION AND MANGROVE REVEGETATION

Mangroves are very productive trees, herbs, shrubs, ferns and patima hosting a divers and rich associations of flora and fauna which interact with, and depend on, the habitat of the mangrove for their lifecycles. They are adapted to the harsh environment of seas and land-including a multitude of trunks and roots allowing the trees and bushes to stay in place when the tides are falling and rising (Zabbey and Linden, 2023b).The outcome of oil spill remediation includes; soil and water qualityimprovementas well as mangrove regeneration.However, mangrove revegetaion

is also an important aspect of the remediation of oil spill impacted wetlands. This is necessary as mangrove forms an integral and significant part of the coastal environment and relying on natural mangrove regeneration alone will be a slow process of mangrove recovery. Contamination of the aquatic environment by hydrocarbon usually results in the death of mangroves, as it deteriorates the water quality necessary for the growth and survival of the mangroves. Nevertheless, through mangrove revegetation, there is the possibility of restoring lost mangrove. According to Zabbeyand Tanee (2016), soil quality investigations, and under necessary circumstances, accompanied by remedial treatment, especially augmenting important nutrients, are vital precursors in order to achieve artificial mangrove regeneration. Earlier study by Bonte *et al.* (2019), recommended the planting of mangrove, as the recovery of mangrove plant after the primary loss in 2008 is marginal. Biotic responses following oil spill incidence could differ quantitatively than those from restoration, even highly oiled marshes initially denuded of vegetation (Fleeger *et al*., 2020).

Local participation in mangrove revegetation

According to Hendra *et al*. (2017), mangrove revegetation program has been put in place by the local community of Karangsong Village, Indramayu District, West Java, Indonesia, with the support of PT. Pertamina RU VI Indramayu. Also, Gunawan and Anwar (2005) reported that the success of mangrove rehabilitation on the north coast of Central Java Province is dependent largely on the participation of the local community surrounding the mangrove area. Successful mangrove revegetation depends on local people participation, groups within the community and private sector contributions with local and national government support (Hendra *et al.,* 2017).

Empirical reports on mangrove revegetation

In a study on mangrove revegetation by Hendra *et al*.(2017), they reported a dramatic increase in mangrove population, from about 25,000 individuals in 2008 to as high as 690,835 individuals in 2016. They continued that the number of mangrove species planted increased from 3 in 2008 to 9 in 2016. Other studies (Crewz and Lewis, 1991; Luo and Xu, 20210), have reported that a minimum of two decades are required to assess the success of mangrove restoration based on vegetation's structural features and functionality.

Significance of mangrove revegetation

Mangrove revegetation has the potential for improving the quality of the coastal sea water, thus restoring the habitat of biota dwelling in water; mangrove rehabilitation success depends on all stakeholders' involvement (Hendra *et al*., 2017). According to Gunawan *et al*. (2007a), mangrove presence has the ability to improve water quality in fish ponds. Mangrove rehabilitation using a silvofishery program can increase household income (Gunawan *et al*., 2007b). According to Hendra *et al*. (2017), mangrove presence has made available habitat for a variety of fauna, especially for the bird community.

SIGNIFICANCE OF OILSPILL REMEDIATION

Apart from the recovery of mangrove, macroinvertebrate as well as planktons as a result of oil spill remediation, there are other benefits of remediating an oil spill contaminated site. Although the release of volumes of hydrocarbon into the environment leads to low fish yield and crop production,the eventual remediation of the environment would restore biodiversity (flora and fauna) in the coastal environment, in addition to increasing the crop yield in contaminated lands. Other benefits derivable from oil spill remediation include;oil degradation, improved economy, carbon sequestration, coastal protection and stabilization, nurseries for fish, regulation of nutrient, tourism creation; drinking water, aesthetics, improved health, human capacity development, pharmaceutical and spiritual value.

Oil degradation

Although the removal of oil from an oil spill contaminated environment could occur through natural attenuation, this would be a very slow process. Oil spill remediation therefore helps to speed up the degradation of unrecovered oil. Linden and Zabbey (2023) reported that oil remediation due to natural attenuation involves microbial degradation and tidal flushing.

Improved Economy

Remediating oil spill contaminated sites has the potential to engage some workers from within the community. The oilspill remediation would also bring about increased economic activity around the oil spill remediation areas, as the workers and other professionals around the creek could patronize the traders around some of the remediation sites. Some individuals could also be saddled with the responsibility of cooking for the workers. There could also be an increase in the patronage of transporters, to and from the cleanup site. Ultimately, there would be increased fish yield, resulting in economic boost of the fisherfolk, in coastal environment as well as increased crop production and yield in contaminated land.

Carbon sequestration (storage of carbon)

Carbon sequestration is the long-term storage of carbon in the lithosphere. Mangrove has a great potential for sequestering carbon. Enhanced mangrove revegetaion would help in the storage of carbon, thus contributing to reduction in greenhouse gas emission. According to Linden and Zabbey (2023), mangrove carbon (CO_2) sequestering ability are at least about five times more efficient than ordinary forests.

Coastal protection and stabilization

Mangrove has the potential to protect coastal environment from extreme weather condition such as the effect of strong wind and thus stabilizing the structural integrity of the coastal environment.

Nurseries for fish

Through the contamination of aquatic environment by hydrocarbon, and the resultant loss of mangrove, nursery for fish is lost. However, through mangrove revegetation, nursery for fish can be assured thus improving fishery.

Regulation of nutrient

There is a strong correlation between mangrove and nutrient availability. The more the mangrove, the more the nutrient, as the decomposition of fallen mangrove leaves helps to improve the nutrient quality of the water. Improved nutrient could encourage biodiversity.

Tourism and recreation

Aquatic environment provides quality tourist attraction and recreation. However, oil spill contamination of the aquatic environment defeats this purpose. Through oil spill remediation, the tourist and recreational quality of the aquatic environment can be restored.

Drinking water

The introduction of crude oil into the environment makes potable water undrinkable. Through oil spill remediation, previously polluted water could become potable once again.

Aesthetics

When hydrocarbon is released into the environment, the aesthetic value of the environment is greatly altered. Oil spill remediation efforts would to a large extent help to restore the beauty of the environment hitherto damaged as a result of the oil spill. The creeks would once again become tourist attractions, and if properly harnessed would help to generate revenue.

Improved health

There are several negative health implications usually associated with oil spill. However, the oil spill remediation has the potential to mitigate these challenges. Oil spill remediation would be able to reduce the negative health implications resulting from inhaling hydrocarbon contaminated air, eating contaminated fauna and drinking contaminated water.

Human capacity development

The staff of the oilspill cleanup agency (e.g HYPREP in the case of Ogoni oil spill remediation), skilled workers and other professionals including shoreline cleanup assessment technique(SCAT) team members would be trained.

Pharmaceutical value

Mangrove extracts are important for pharmaceutical purposes. Thus, artificial mangrove revegetation following an oil spill incidence would help enhance the recovery of mangrove useful in pharmaceutical processes.

Spiritual value

Some communities attach religious or spiritual importance to coastal wetlands. It is therefore significant to remediate oil spill contaminated coastal wetlands.

RECOMMENDATION

Scientific publications based on empirical study on remediation should be encouraged.There is need for collaboration between the oilspill remediation agency,undergraduate and post graduate researchers in environment disciplines. Project students could be encouraged to collect sample (data) for their study from cleanup sites in collaboration with the agency responsible for the cleanup. There could be increased timely publication of progress report on rise in fish yield, recolonization of aquatic environment by macroinvertebrate, phytoplankton and zooplankton; reduction in hydrocarbon level (content) and mangrove revegetation from scientific investigation in the oilspill remediation sites in coastal areas; as well as improved crop yield and revegetation of areas hitherto without plants/crops.

CONCLUSION

Oil spill incidence is commonplace in countries where oil exploration contributes significantly to the economy. In Nigeria where oil exploration in the Niger Delta contributes majorly to the economy, oilspill incidence in Ogoni has been on the increase over the past decades.Remediation of oil spill contaminated marine environment has the ability to improve the diversity and population of marine plankton, bottom dwelling marine invertebrates, fish, seabirds, reptiles and mammals. Further research is necessary in order to develop unique oil spill remediation approaches to serve as a template for oil spill remediation in other parts of the Niger Delta, as proper oil spill remediation could tackle the severe consequences of oil spill in the environment.

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1.

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3.

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