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A critical review of oil spills in the Niger Delta aquatic environment: causes, impacts, and bioremediation assessment

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Abstract The Niger Delta region in South-South Nigeria, on Africa's West Coast, is densely populated. The region, which contains a substantial stock of crude oil and natural gas, has been nicknamed "the engine room" for Nigeria's economic development and progress. It is responsible for up to 90% of the country's economic growth (or gross domestic product/GDP). The region has multiple ecosystems, such as the aquatic environment, that are critical to the survival of the area's various habitats and living species. However, the same region has witnessed unjustifiable environmental pollution arising from oil activities over the years of exploration and production which has orchestrated negative consequences on the Niger Delta ecosystem. This has led to extended negative consequences on natural resources, which also have detrimental repercussions psychologically, ecologically, socially, economically, and physically which, in turn, impacts the overall health of the affected individuals. This write-up provides an overview of the major drivers of the oil leakage in Nigeria's Niger Delta ecosystem as well as the major impacts on the environment. It will also analyze numerous means of remediation in use and extend such for a more inclusive and productive option. Moreover, this review offers key measures that may help to maintain long-term policies for reducing adverse implications and increasing the living standard for the Niger Delta area's affected communities.

Keywords Oil spills · Bioremediation · Niger Delta · Aquatic Environment

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Introduction

The aquatic environment refers to the ecosystem that exists within and around a body of water (Izah et al., 2017). Water is required for the continuation of life on Earth, as it is required by all industrial, environmental, and physiological systems, and it is linked to economic development (Bibi et al., 2016; Kumar et al., 2018; Muhammad et al., 2020). Nigeria's Niger Delta is a highly inhabited region in South-South Nigeria on Africa's West Coast (United Nations Environment Program UNEP, 2011; Nazmuz-Sakib, 2021). Crude oil is an unprocessed petroleum product made up of a complex mixture of hydrocarbons, other organic compounds, and certain organometallic components that occurs naturally (Yuniati, 2018; Akpoghelie et al., 2021). Crude oil is a vital strategic resource for which all countries compete ferociously (Xu et al., 2018), and natural resources, such as crude oil, are essential to the economy. It is also one of the most essential sources of energy for a variety of sectors around the world (Xu et al., 2018). Nigeria's petroleum sector which is the backbone that promotes Nigeria's development, contributing to more than 90% of the country's total foreign exchange earnings (Niger Delta Development Commission, NDDC, 2014), relies on components of crude oil explored solely from the Niger Delta region of the country. It also provides a significant portion of the country's energy needs, as well as popular petrochemical intermediates used in the creation of a wide range of products such as solvents, dyes, medicines, polymers, and novel compounds. Crude oil and its numerous products are thus employed in practically all parts of any society ranging from transportation and construction to various sorts of commercial operations (Bashir, 2021). When these items are spilled into the environment, they cause pollution (De-la-Huz et al., 2018).

The exploration of oil in the Niger Delta has culminated in oil pollution and other environmental disasters. Pollution of water, damage to sea life, and agricultural disruption are all examples of such problems (Osuagwu & Olaifa, 2018). The discharge of a liquid petroleum product into the ecosystem during an oil spill, which can happen on land or in the sea, is considered a form of pollution brought on by human activities (Ifelebuegu et al., 2017). Oil spills and seepage pollute the aquatic environment, wreaking havoc on the habitats, the majority of whom are the creek dwellers whose livelihoods are reliant on natural resources from their immediate environment (Adati, 2012; Pete et al., 2021). The effluents of petrochemical devices produce solid waste, which pollutes the aquatic environment (Uzoekwe & Oghosanine, 2011). People are exposed to these effluents indirectly through the food they eat. These put people at risk of serious or moderate health problems as pollution has unquantifiable gastrointestinal and hematological consequences (Okoye & Iteyere, 2014).

The frequency of recorded oil leaks in Nigeria has been rising in lockstep with the increase in petroleum output (Adesipo et al., 2020; Al-Wasify & Hamed, 2014). Contamination of water bodies with petroleum hydrocarbons as a result of oil spills has been a longstanding concern in Nigeria (Adesipo et al., 2020) and has now escalated into a significant environmental issue. Since there have been recent reports of massive contamination, damage, and/or disruption of the ecosystem (i.e., land, water, and atmosphere), this raises concerns about people's health as well as the environment (Adesipo et al., 2020; Anaejionu et al., 2015; Ite et al., 2013; Khalid et al., 2021; Linden & Palsson, 2013). Accidents or leaks from cargo tankers hauling gasoline, diesel, and derivatives could be possible causes of fresh and marine contamination. Petroleum products spill from storage tanks, offshore structures, drilling equipment, and wells and so do spillages of oil products (such as gasoline and diesel) and their by-products, heavyweight fuels used by large ships such as bunker fuel, and spills of any oily refuse or waste oil (Khalid et al., 2021; Muhammad et al., 2020; Xu et al., 2018), all pollute seawater significantly (Haseena et al., 2017).

The environment is immediately threatened by crude oil spills, which necessitates a swift and effective clean-up procedure. Various conventional methods for removing crude oil spill pollution from the aquatic environment have been used around the world such as float devices and hurdles, oil gathering devices, oil collection vessels, absorbent materials, chemical dispersants, and surfactants; however, the majority of these procedures are neither cost-effective nor environmentally beneficial (Anih et al., 2019; Lim et al., 2016). Bioremediation is a potential treatment strategy that investigates the ability of microorganisms and plants to remove organic contaminants like hydrocarbons from contaminated locations. This is an alternate treatment technique that is successful, low-risk, cost-effective, adaptable, and environmentally friendly (Cai et al., 2021; Pete et al., 2021; Sayed et al., 2021). In today's world, using biological methods to clean petroleum hydrocarbon contaminants is a top priority in the push to build green technologies (Cai et al., 2021; Sayed et al., 2021). Microbial remediation (microbes), phytoremediation (plants), and mycoremediation (fungi) are all examples of bioremediation (Dell-Anno et al., 2021; Khalid et al., 2021; Nnaji, 2017; Yarima et al., 2020). In the Niger Delta region of Nigeria, oil spills have occurred for decades, but regrettably, cleanup methods such as the use of skimmers and booms, straws, and non-assisted bioremediation have remained mostly unaltered (Pete et al., 2021). Overall, existing information implies that using microorganisms for bioremediation of petroleum hydrocarbon-contaminated aquatic habitats could be a promising bioremediation technique (Dell-Anno et al., 2021). As a result, the goal of this article is to review oil spills in the Niger Delta aquatic environment, as well as their causes, impacts, and bioremediation assessment.

The Niger Delta Region

Nigeria's Niger Delta is a highly inhabited region in South–South Nigeria on Africa's West Coast (United Nations Environment Programme, UNEP, 2011; Nazmuz-Sakib, 2021). It is located on the Atlantic Ocean, directly at the tip of the Gulf of Guinea. It is a huge low-lying region through which the Niger River divides into various tributaries and drains into the Gulf of Guinea (Ogeleka et al., 2017; Akpoghelie et al., 2021). The region stretches along the coastline spanning the west bank of the Benin River to the east bank of the Imo River (Akpoghelie et al., 2021). Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers are the nine states which form the Niger Delta, and Fig. 1 displays these nine Nigerian states that are now generating significant amounts of oil products for the Nigerian economy (Lindén & Palsson, 2013; Wizor & Wali, 2020; Bashir, 2021; Sanchez et al., 2021). Within the Niger Delta region is the faunal zone, a region where the global tertiary Delta basins and abundant hydrocarbon provinces are found (Akpoghelie et al., 2021), as well as the wealthiest part of Nigeria in terms of hydrocarbon reserves and varied natural surroundings (Sanchez et al., 2021).

The majority of Nigeria's energy resources are located in the Niger Delta and on the country's coastal waters (Lindén & Palsson, 2013; Bashir, 2021). Nigeria was ranked as the fifth exporter of liquefied natural gas exporter in the year 2018. Nigeria's crude oil is often known as "sweet oil" due to its low sulfur content. The term "sweet" originates from the fact that a low level of sulfur provides the oil with a

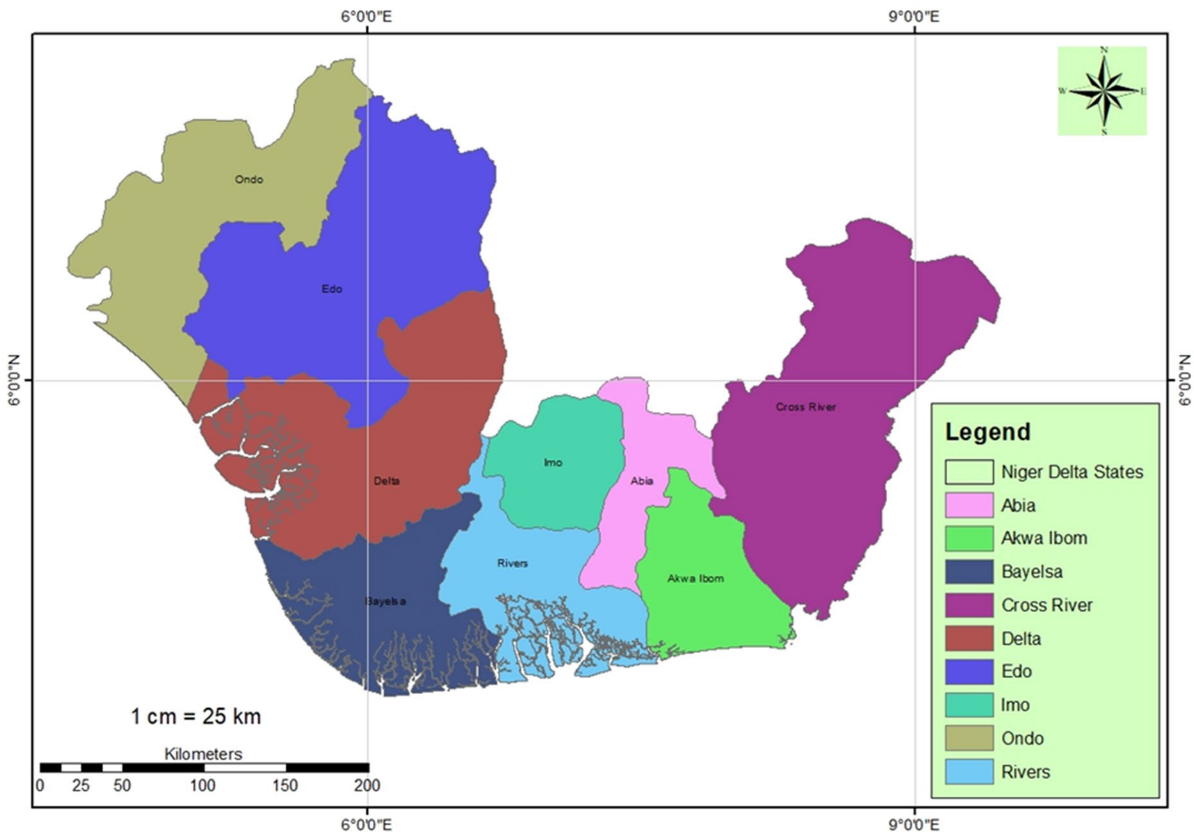

Fig. 1 Map of Niger Delta Region showing the nine states. Source: Department of Geography, Federal University of Technology, Minna, Nigeria (2022)

relatively sweet taste and pleasant smell, compared to sulfurous oil. In the delta region, 1,182 exploratory wells have been drilled, and approximately 400 oilfields of various sizes are identified. This region features a vast network of over 900 active oil wells as well as a number of petroleum-related infrastructure (Nazmuz-Sakib, 2021). The area is Africa's largest and most significant oil-producing area, according to experts and, without a doubt, Nigeria's most appealing investment zone. It is brimming with life and natural riches, as well as a rich cultural and historical history. It is the driving force behind Nigeria's economic development (Akpoghelie et al., 2021). Nigeria's Niger Delta vast oilfields have been mined for ages. Despite their socioeconomic and cultural differences, the Niger Delta states are all affected by the detrimental consequences of petroleum extraction (Agbaji et al., 2020; Yakubu, 2017), as crude oil explorations, exploitation, and operations exert specific unfavorable and serious effects on the entire environment, including biological diversity (Aniefiok et al., 2018; Nazmuz-Sakib, 2021). So, from 1956, when the very first economically viable oilfields were found in Oloibiri, Nigeria's Niger Delta, to today, the problem of petroleum and its environmental impact have always been a subject of continuing friction among oil corporations and their host communities, as the area has really been overlooked in Nigeria's development projects despite its remunerative benefits to the entire nation (Ekpo et al., 2018). In other words, the Nigerian authorities have invested years focusing on petroleum exploration while ignoring the progress of the Niger Delta region, which is where the oil exploration is taking place (NDDC, 2014). Because the waters, ponds, and adjacent Atlantic Ocean offer great and favorable fishing conditions, residents of the Niger Delta region where crude oil is produced mainly engage in basic sustenance agriculture (Ofoegbu et al., 2014), and more than 70% of the inhabitants fall back on the natural habitat for their survival (Ebegbulem et al., 2013; Osuagwu & Olaifa, 2018).

Crude oil

Crude oil is a flammable, usually dark brown or black in color, viscous liquid that is found in nature, and it is made up of a variety of organic molecules, the vast majority of which are hydrocarbons. Based on their solubility in organic solvents, petroleum components are divided into four classes (Sayed et al., 2021). Crude oil has four primary constituents saturated, aromatics, resins, and asphaltenes in its chemical composition (Al-Hawash et al., 2018) which impacts negatively the ecosystems and humans when spilled. Since the discovery of oil in the region more than 50 years ago, environmental contamination, primarily from oil exploration and exploitation, has ravaged the Niger Delta region of Nigeria. The pollutant migration from oil spill-affected regions of the Niger Delta poses major dangers to soil and groundwater, affects agricultural output, and exposes people to a variety of health problems. They are considered to have a negative impact on the region's economy as well (Nazmuz-Sakib, 2021).

Oil spills

Oil spills are a type of pollution that occurs when petroleum products are discharged into the environment as a result of anthropogenic activity, particularly in coastal environments (Samhan et al., 2017). Oil spills can happen in the sea or along the coast, as well as on the ground (Muhammad et al., 2020). Oil contamination has become a worldwide public health issue, particularly in developing nations such as Nigeria where oil is drilled (Adesipo et al., 2020; Samhan et al., 2017). Oil leakage, both onshore and offshore, is the most serious environmental issue linked with Nigerian crude exploratory drilling (Ifelebuegu et al., 2017). The number of leakages reported in the nation has been increasing in tandem with the rise in petroleum product output (Adesipo et al., 2020). Oil spilling onto the water surface could be the result of a mishap or a spill from a vessel delivering refined petroleum products. Spills of oil products from ships, offshore structures, drilling equipment, as well as refined petroleum products (such as petrol and diesel) and by-products, bulkier fuels required by big vessels, like bunker fuel, and spillage of any greasy garbage or waste oil (Muhammad et al., 2020), pollute seawater to a large extent (Haseena et al., 2017). Offshore drilling exploration has also led to water contamination. On the water's surface, the residual hydrocarbons produce a thin layer of water-in-oil emulsion

(Khan et al., 2013; Akpoghelie et al., 2021; Nazmuz-Sakib, 2021).

Oil spills and contamination in the aquatic ecosystems have posed a significant hazard to the environment and public health by introducing harmful organic compounds, particularly polycyclic aromatic hydrocarbons (PAHs), into the food chain (Al-Wasify & Hamed, 2014; Bashir, 2021). Polycyclic aromatic hydrocarbons (PAHs) in terrestrial and aquatic ecosystems are a serious problem as an environmental contaminant, as the majority of these compounds are recalcitrant. Petroleum hydrocarbons are vital energy sources for business and everyday life (Ekpo et al., 2018). It is critical to understand that hauling petroleum into the environment using trucks and ships does not confine petroleum products leakage to oil-producing states alone, but to surrounding states that are vulnerable to oil spillage due to shipping, mishaps, and broken pipe systems that traverse through these places (Al-Wasify & Hamed, 2014; Bashir, 2021).

Causes of oil spills in Nigeria's Niger Delta

Tens of thousands of barrels of crude oil have spilled into the Nigerian environment as a result of leaks from pipelines and storage tanks. The pipelines and storage tanks are not properly maintained, resulting in spillage. Some of these structures have been in operation for decades without being replaced (Bashir, 2021; Cai et al., 2021; Ifelebuegu et al., 2017). Another cause of oil spills in the Niger Delta is the vandalism of oil and gas pipelines by the residents of host communities. People are thought to sabotage pipelines in order to gain access to their goods or to file claims for damages and maintenance services. Oil bunkering is a practice that spills oil into the environment, and it is usually carried out by some individuals in Nigeria in cooperation with persons from other countries. In an attempt to steal oil, individuals sabotage and destroy oil pipelines (Cai et al., 2021; Muhammad et al., 2020). Pirates steal Nigeria's crude oil at an incredible rate, siphoning roughly 300 million barrels each day from the country and illegally selling it in the worldwide oil trade arena (Ifelebuegu et al., 2017). The selling of refined petroleum products, pipeline spills and bursts, storage tanks (Al-Wasify & Hamed, 2014; Cai et al., 2021), tanker accidents, well blowout from flow stations, roadside mechanics' discharge of leftover oil into drains, ballast water discharge, corrosion of over-aged oil facilities (pipelines), and cleaning of oil tankers are other causes of the oil spill (Bashir, 2021; Ekpo et al., 2018; Nnaji, 2017). The most affected are the host communities in Nigeria's Niger Delta region (Aniefiok et al., 2018).

Oil spill incidence in Nigeria

Oil spills have happened along the shore in various locations and at various times. According to records acquired from Nigerian Department of Petroleum Resources (DPR), approximately 31,121,909.80 barrels of oil were spilled in the ecosystem in around 9,107 events between 1976 and 2005 (Anaejionu et al., 2015; Adesipo et al., 2020). The amount of contamination in Ogoniland, as per a United Nations Environment Programme (UNEP) analysis from 2011, is the worst-affected region in Nigeria. The extent of contamination in rivers, creeks, and groundwater was disclosed by their studies. Extractable petroleum hydrocarbons were around 7420 gL^{-1} in surface water, 42 200 gL^{-1} in drinking water wells, and 9000 gL^{-1} in benzene, and this was 900 times higher than the WHO standards. It was around 17,900 mg kg^{-1} in sediments, whereas the concentration of polycyclic aromatic hydrocarbons in the majority of the polluted areas was around 8.0 mg kg^{-1} (Adesipo et al., 2020). Table 1 shows some major oil spill incidence in Nigeria.

The impacts of oil spillage in the Niger Delta

Oil spillage is acknowledged as a severe hazard to ecosystems, and many environmental problems take years or decades to recover from after a spill (Al-Zaban et al., 2020). Oil spills have had disastrous implications in Nigeria, particularly within and around the Niger Delta states now recognized as among the world's most vulnerable areas to oil spills (Könnet, 2014). Oil drilling and exploration operations in the area had contaminated approximately 2000 locations (Ite et al., 2013), resulting in a wide range of negative consequences, among such are environmental, public health, ecological, and socioeconomic consequences (Bashir, 2021). Crude

Table 1 Oil spill incidence in Nigeria

Year	Quantity of oil spilled (barrels)	Place	References
1970	250	The Bomu 11 oil	Adesipo et al. (2020)
1978	500,000	GOCON's Escravos oil spill	Adesipo et al. (2020)
1979	570,000	Shell Petroleum Development Company's (SPDC) Forcados Terminal tank failure	Adesipo et al. (2020)
1980	600,000	Texaco Funiwa-5 Field blowout and Oyakama pipeline spill	Bashir (2021)
1982	18,818 5,000	Abudu pipeline spill and Ebocha-Brass pipeline	Adesipo et al. (2020)
1984	54,000	Ikata pipeline spill	Bashir (2021)
1998	40,000	Idoho oil spill MOBIL/QUA IBOE oil spillage Jones Creek oil disaster	Adesipo et al. (2020)
2021	2,000,000	Aiteo's OML29 Well 1 oil blowout	Retrieved from https://homef.org/2021/12/22/aietos-oml-29-well-01-blowout-an-ecological-horror-tale/

oil causes health problems like cancer, birth defects, gene abnormalities, and infertility in people since it is a carcinogenic material that is also mutagenic and contains teratogenic complex compounds (Agbaji et al., 2020; Zabbey et al., 2017). The presence of hydrocarbon and its components in the environment is a severe problem since it damages wetlands and tropical rainforests by eroding soil over time and, in some circumstances, permanently (Al-Zaban et al., 2020; Halanych et al., 2021; John et al., 2016). The black gold's oil drilling activities have turned the region's previously green vegetation and stunning blue streams black; consequently, people are losing their jobs because of the disruption of commercial activities in agriculture and fishing, leading to reduced food production and rising health problems for the inhabitants of this region (Ekpo et al., 2018).

Environmental impacts of oil spillage

The environmental repercussions of oil spillage in the Niger Delta region are possibly the most catastrophic (Ofoegbu et al., 2014). Toxins in hydrocarbons cause mortality in fauna and flora straight away and several other sublethal repercussions. Toxicity is determined by the nature and type of hydrocarbons, the concentration of oil spills, the situation of the environment, and the degree of sensitivity of individual species present in such an environment (Nazmuz-Sakib, 2021). The Niger Delta's varied environments include mangroves, freshwater wetlands, and rainforests. It is one of Africa's biggest marshes and one of the world's top ten most important wetlands in marine ecosystems. It is because most of the oil and gas production and exploration location is inside the 700,000 hectares of delta marshland that contamination from oil spills has contributed significantly to the transformation of the area into a desolate wasteland (Ofoegbu et al., 2014). These are Nigeria's last forested biome, as well as approximately two-thirds of Africa's remaining mangroves, and they are a vital ecosystem for both local inhabitants and fishermen (Ekpo et al., 2018). Oil spills affect the ecosystem by damaging flora, mangrove forests (Fig. 2), food/cash crops, fishing grounds/marine life, lowering soil nutritional value, fragmenting land, and, in rare cases, lighting communities on fire, forcing internal displacement (Ekpo et al., 2018). Indeed, the area has gotten so polluted that it now has poisonous waters, and also biodiversity depletion as well as forest damage (Bashir, 2021).

When oil spills on farmland or when spilled oil in the water habitats is washed into the shoreline by flooding, the soil is unable to absorb water, depriving plants of oxygen. It could have a negative impact on soil nutrients as well as richness, resulting in land deterioration thus, lowering crop production (Akpoghelie et al., 2021). The discharge of petroleum products into arable land has been documented in the Niger Delta region of Nigeria (Nazmuz-Sakib,

Fig. 2 Vegetation damage from an oil spill in Okerenkoko community, in Jones Creek, Warri South West LGA, Delta State, Nigeria (Field Photograph)

2021). Oyedeji et al. (2012), for example, studied the influence associated with oil soil on the growth and production of *Abelmoschus esculentus*, an extensively farmed agricultural plant in Nigeria. Petroleum hydrocarbon contamination of agricultural soil inhibited germination, harmed *Abelmoschus esculentus* L. agronomic growth performance, and resulted in low crop yield. The effects of various types of crude oil on soil characteristics and microorganisms might be immediate or long-term. When oil spills on land, it affects plant growth by making essential nutrients like nitrogen and oxygen unavailable to them (Stakeholder Democracy Network, 2019).

Ecological impacts

Oil spills pollute the environment and have negative consequences on the ecosystem (Akpoghelie, 2017). The ecosystem has a complicated structure, as evidenced by various co-existing creatures. Whenever the environment is subjected to pollution from spillage or other factors, the chemical makeup of the environment, as well as the amount of petroleum exposed to species, are both critical variables in determining how populations react to leaked hydrocarbons. Some biological and chemical features, particularly the habitat and depth of the species, make certain lifeforms better susceptible to being exposed to hydrocarbons than another (Chang et al., 2014). The oil spill depletes oxygen levels in both the land and aquatic environments, decreasing the amount of oxygen available to living organisms and ultimately in their death (Peterson et al., 2003; Akpoghelie et al., 2021). These species' deaths reduce their population size, which has an impact on the food chain. The inference is that there will be a food shortage, followed by famine and possibly malnutrition (Akpoghelie et al., 2021). Toxicity pathways in the aquatic habitat include intake of crude oil or its refined products; accumulation of toxins in body tissue; damage to DNA; immune dysfunction; organ failure; widespread death of eggs and larvae, e.g., in fishes; destruction of momentum and coating for birds, and inhalation of vapors (Major, 2012).

When oil spills on farmland or when spilled oil in the water habitats is washed into the shoreline by flooding, the soil is unable to absorb water, depriving plants of oxygen. It could have a negative impact on soil nutrients as well as richness, resulting in land deterioration, thus lowering crop production (Akpoghelie et al., 2021). In Nigeria's

Niger-Delta region, the effects of oil spillage on freshwater resources are growing more common (Zabbey & Olsson, 2017). Oil spills (Fig. 3), are a common cause of pollution from oil fields, contaminating drinking water supplies and contaminating fishing creeks, resulting in the mass killing of fish and other aquatic life. Oil contaminates surface water, ambient air, and groundwater with hydrocarbons. For instance, total petroleum hydrocarbons (TPHs), ejected from the soil enter the ground via the top. As most of these substances are unstable, they can vaporize quickly into the atmosphere. Just a small percentage dissolves in the aquifer and moves away from the polluted site (Zhang et al., 2019). Most chemicals bond to particulate matter and thus stay on the earth for an extended amount of time, whereas certain hydrocarbons are broken down by soil bacteria.

Hydrocarbon leak has had an impact on the maritime ecology and ecosystem because the environmental implications of an oil spill are manifold (Kim et al., 2019). Once the oil is spilled directly into bodies of water, it extends over long distances; pollutants float mostly on the water's surface and form a slender greasy film. It attaches to each and every stone, a particle of soil, and even a tree stem along the river's edge. This technique may hinder natural aeration, resulting in the death of confined marine species (Akpoghelie et al., 2021). Spongy vegetation and grass absorb oil when it leaks into coastal habitats, mangrove swamps, or other marshes, causing plant damage and making the area hazardous for wildlife. The pollution ultimately sinks into the marine environment when it ceases floating on the surface (Kim et al., 2019). It has a corresponding negative impact on ocean life, resulting in the death of fish and other lower species which are integral to the marine food chain worldwide (Environmental Pollution Center, 2017). The component of an oil spill poisons and kills fish. Missing fish as well as other sea life are usually caught and kept by smoking before being marketed as foodstuff to the public at large. Alteration and/or long-term destruction of species are some of the most environmental consequences caused by oil pollution (UNEP, 2011).

In the estuary region, oil damages vegetation and wildlife. Crude oil and its products get washed up on the beach, killing the species that dwell there. Immediate toxicity occurs when an organism's cell is filled with pollutants oil and mortality by suffocation occurs (Sayed et al., 2021). Also, it accumulates on the sea bottom, killing species that live at the bottom, such as crabs (Emuedo et al., 2014). Oil pollutes algae, disrupts critical food cycles, and lowers edible crustacean production. Deep coral reefs, which

Fig. 3 Visible Hydrocarbon pollution on surface water and vegetation in Okerenkoko community, in Jones Creek, Warri South West LGA, Delta State, Nigeria (field photograph)

constitute vital habitats, have been devastated by oil spills (Zhang et al., 2019). The resilience of mammals and birds to other environmental stressors like temperature variations, infectious diseases, and other toxins has weakened as a result of the petroleum oil that covers them (Sayed et al., 2021). Seabirds' ability to fly is damaged by oil contact, rendering them particularly vulnerable. Ingestion of contaminated meal, inhaling, and recurrent exposure to the oil–water combination cause severe poisoning and high mortality rates (Zhang et al., 2019). In aquatic creatures, consumed or absorbed petroleum in the system either through membranes such as gill covers causes immediate deadly toxicity, sublethal consequences, and even reproductive failure (Sayed et al., 2021). Animals exposed to crude oil have been observed to suffer from blood poisoning and also damage to their liver cells, as well as suffering infertility and cancer (UNEP, 2011). Public health is impacted both long and short term by oil spillage in the Niger Delta region (Bashir, 2021; Ordinioha & Brisibe, 2013). Furthermore, sea animals are typically the first to be affected by oil spills, resulting in the loss of numerous aquatic lives. The death of aquatic species causes pollution, and eating tainted marine food is dangerous to one's health (Anih et al., 2019).

Turtles stranded in oil spills are exposed both to flowing hydrocarbons and excessive hydrocarbon-saturated breathing atmosphere, as well as food contaminated with oil or tarballs. Petroleum hydrocarbons had plugged the esophagus of old and young tortoises, leading them to starve to death (Zhang et al., 2019). The loss of economic capital caused by direct mortality, habitat destruction, harvesting limits, and fishing closures has an impact on commercial and aquaculture operations (Zhang et al., 2019; Nazmuz-Sakib, 2021).

Farm fish are rendered unmarketable due to high levels of petroleum oil components in the products that are detrimental to human health (Sayed et al., 2021). The fishing industry is crucial to Nigeria's long-term viability since it provides people with much-needed protein and nutrition. Fish populations are dwindling as a result of the growing demand for fish, as they are reduced faster than they can be regenerated (Samhan et al., 2017). Fish populations and fishermen who rely on fishing for a living are both affected by oil contamination. Spills in densely populated areas are usually scattered over a wide area (He et al., 2017). Microorganisms that feed on spilled hydrocarbons use dissolved oxygen, which contributes to fish death (Ekpo et al., 2018; Nazmuz-Sakib, 2021). Oil spills in the Niger Delta have resulted in catastrophic fish extinctions, according to Olujimi et al. (2011), posing a threat to the social and economic well-being of people whose livelihoods rely on the contaminated rivers. Larger areas of the Niger Delta's mangrove habitat have also been destroyed. The mangrove, which provided indigenous people with firewood and served as a refuge for the region's fauna, is now unable to withstand the oil's toxicity (Ekpo et al., 2018).

There is no reason for continuing to discharge petroleum effluents into the environmentally fragile Niger Delta region of Nigeria because pollutants in oil-contaminated produced effluents are harmful to a variety of water and estuarine creatures in the marine environment including microorganisms (Nazmuz-Sakib, 2021). The population of microorganisms reduces when oil is initially introduced into the environment. As these contaminants enter the environment, microbes will proliferate selectively, slowing growth until they have the essential enzymes, at which point normal growth will resume (Hassanshahian, 2014). When nitrogen-fixing organisms are harmed, nitrogen fixation in the ecosystem will suffer (land or sea). Photosynthetic organisms may also be harmed because the oil will coat the water surface, preventing organisms that come to the surface to tap light (photosynthetic organisms) from presenting themselves to sunlight. This will reduce the environment's primary productivity, affecting the food chain and web (Ekpo et al., 2018). Also, because there would be no exchange of oxygen between the air and the water, the *pneumatophores* that allow for oxygen exchange will be difficult to find, causing aerobic bacteria to suffer and the population to decline. Microbe-microbe interactions will also be impacted (Hassanshahian, 2014).

Impacts of oil spillage on public health

It's also critical to avoid, where possible, as well as reduce human tragedy including the negative impacts on the emergency and cleanup crews, as well as any local individuals and human communities, in every disaster episode of hydrocarbon spills in the water environment (Sayed et al., 2021; Zhang et al., 2019).

Contact with petroleum hydrocarbons may come about through cutaneous continuous contact, breathing, and ingestion (Zhang et al., 2019), which can induce cancer, be transient, or be permanently noncancerous (Altomare et al., 2021). Toxic chemicals capable of causing cancer, such as benxo[a]pyrene and polycyclic aromatic hydrocarbon, as well as naturally occurring radioactive elements and trace metals, which can bioaccumulate in food crops and consumption of these polluted consumables or inhalation of crude vapor or mist, could have harmful consequences on humans (Bashir, 2021), exacerbating the region's health problems (UNEP, 2011). According to research by the United Nations Environment Programme (UNEP), water consumption in Ogoniland has a reported carcinogen at a concentration level around 900 times higher than WHO standards (UNEP, 2011; Adekola et al., 2017). From rainwater as well as from hand-dug water sources to drilled aquifer's locations, oil pollutants have now been identified in practically all aquatic sources utilized by humans for various reasons (Zabbey & Olsson, 2017).

Various chemicals employed in dispersants and crude oils are known to cause health problems (Ferguson et al., 2020; Zhang et al., 2019). TPH compounds of varying fractions have varied effects on the body. TPH chemicals, particularly smaller molecules like toluene, benzene, as well as xylene (found in petroleum), can cause nervous system damage (Sayed et al., 2021; Zhang et al., 2019). If exposure levels are high enough, death may result. For more than a few hours, inhaling toluene in amounts of over than hundred parts per million (100 ppm) for more than a few hours can cause fatigue, headache, nausea, and sleepiness. The symptoms will fade away once the exposure has ended. If someone is exposed for an extended period of time, however, the central nervous system can suffer irremediable injury (Ferguson et al., 2020). A single molecule of n-hexane, can even have a unique impact on the central nervous framework, causing "peripheral neuropathy," which is a nerve disorder characterized by numbing sensation inside the legs and, in severe circumstances, can paralyze these areas. Swallowing hydrocarbons compounds like diesel and paraffin induce mouth and stomach problems, as well as central nervous system weakness, respiratory problems, and bronchitis from inhaling the liquid's gases into the lungs. The bloodstream, immunological function, hepatic function, spleen, renal, maturing fetuses, and even airways may all be affected by compounds found in particular TPH fractions. TPH compounds can also be toxic to the skin and impact vision also in large amounts (Sayed et al., 2021).

Barium, a metallic compound used in drilling mud by the petroleum sector, is subsequently discharged offshore or left in mud pits surrounding wellheads. Groundwater quality in the central part of Nigeria's Niger Delta was investigated, but significant levels of barium were found in all of the water samples tested, exceeding WHO permitted limits (WHO, 2011; Nwankwoala et al., 2016). The elevated barium concentration in groundwater aquifers was linked with the drilling waste outflows and eroded stone rock erosion that drained downwards from the subsurface into groundwater resources. Vomiting, gastrointestinal cramps, diarrhea, breathing difficulties, raised or lowered blood tension, numbing in the face area, and muscle aches may occur as a result of over absorption of water-soluble barium (Zabbey & Olsson, 2017). The big-fingered swimmer crab, *Callinectes Amnicola*, is among the most frequently widely caught and consumed inside the marshes of the Niger Delta. With the increase in concentrations of such, up as to 5,727 mg kg^{-1}, *Callinectes Amnicola* subjected to drilling fluids (EDC-99-DW) displayed progressive tissue barium buildup. The drilling mud had histological effects on the crabs, including abnormal body form, macrophage, immune cytokines, and basaloid patches. Some heavy metals are reported to be present in high concentrations in Nigerian crude oil brands. The related heavy metals in Nigeria's presiding sweet crude oil, Bonny Light, will be in the sequence nickel > vanadium > cadmium > copper > lead (Zabbey & Olsson, 2017). Barium, lead, and cadmium concentrations in drilled and exposed hand-dug wells within the Western parts of the Niger Delta (Owamah, 2013) were found to be over WHO permitted limits of 0.7 mg/L, 0.01 mg/L, and 0.003 mg/L, respectively (WHO, 2011), and as per the investigators, oil drilling and production operations are to blame. Heavy metals like cadmium, chromium, copper, iron, nickel, and lead were identified throughout the river Ijana, which obtains petrochemical wastewaters from Warri Refinery in the Western part of the Niger Delta region. They found amounts that were generally higher than WHO surface water limits. According to another study, oil spills can cause a 60% decrease in household food security, as well as a 36% and 40% decrease in the amount of vitamin C in greens and total protein concentrations in *tapioca*, respectively (Adekola et al., 2017; Bashir, 2021). As a result, the rate of childhood malnutrition could increase by 24%.

Spills in the Niger Delta could cause cancer and infertility in humans since Nigerian crude oil is both hemotoxic and hepatotoxic (Ordinioha & Brisibe, 2013). Long-term exposure can cause reproductive toxicity, immunotoxicity, genotoxicity, and carcinogenicity, with effects ranging from low to high concentrations. Excessive exposure causes weariness, headaches, nausea, vomiting, self-limiting diarrhea, breathing difficulties, drowsiness, and neuron damage, such as neuropathy of the peripheral nerves. It can as well cause irritation of the throat and stomach, skin irritation, plasma immune system defects, and damage to vital organs or lead to the growth of malignant cells (Anih et al., 2019; Akpoghelie et al., 2021).

Conventional methods for remediation

The removal or transformation of toxins in environmental media (groundwater, surface water, sediments, soil, and air) into less dangerous compounds is known as environmental cleanup (Lim et al., 2016). It is the process of restoring the functionality of the ecosystem that existed previous to contamination (Sayed et al., 2021). The decomposition or sequestration of hazardous hydrocarbons, heavy metals, and other volatile organic compounds contained in fossil fuels is a process known as petroleum remediation (Pete et al., 2021). Environmental restoration efforts can use a variety of remediation approaches, which can be categorized in a number of ways, including in situ or ex situ, for soil, surface, or groundwater remediation, or depending on the physics or chemistry of the treatment. Only one method, biodegradation, falls under the category of biological therapies, with the bulk of approaches being classified as physical treatments. Physical therapies entail removing the hazard physically, whereas chemical treatments apply chemicals to encourage the extraction of dangerous substances (Anih et al., 2019). The relative efficacy of different remediation techniques depends on their broad applicability and total cost.

Traditional cleanup methods can be categorized into four categories: chemical, physical, thermal, and biological remediation. The fatal concentration of contaminants and the damage they do to the ecosystem must be taken into account before any of these methods can be employed successfully. As a result, a technique that reduces pollutant levels well below the regulatory dangerous threshold is selected (Anih et al., 2019). The most prevalent technologies and strategies for oil confinement and elimination from the water include float devices and hurdles, oil gathering devices, oil collection vessels, absorbent materials, chemical dispersants, surfactants, physical degradation, biological breakdown, and on-site oil burning (Sayed et al., 2021). Mechanical/physical methods (sorbent booms and skimmers), thermal treatment technologies (in situ combustions), chemical treatments (distribution), and biological techniques are all used to clean up polluted water and soil (Jayaswal et al., 2018; Pete et al., 2021).

Chemical remediation method

Chemical treatment entails using reagents to remove toxic compounds from impacted media, such as solvent extraction to remove PCBs from soil and in situ chemical oxidation to break pollutants down into less hazardous or harmless compounds (Anih et al., 2019). Soil vapor extraction, ozone and O_2 gas infusion, surfactant enhanced recovery, chemical precipitation, chemisorption, membrane separation, and aqueous chemical oxidation are some of the chemical technologies available (Giadom, 2015).

Physical remediation

This may entail physically removing contaminated media, treating it, and returning it to its original location; for example, contaminated groundwater can be pumped out, treated to remove contaminants, and returned to its original location (Alazaiza et al., 2021; Lim et al., 2016). Soil washing and adsorption are examples of physical remediation technologies. Physical cleanup options include the use of skimmers, booms, pumps, and mechanical separators to remove oil (Anih et al., 2019).

Thermal remediation

This is when heat is used to clean up tainted material. Thermal desorption, incineration, steam heat injection, and thermal conduction are all examples. Heat is used in thermal desorption to evaporate substances (such as oil and hydrocarbons), which are then collected and eliminated in a treatment system (Giadom, 2015).

Biological remediation

Microbial bioremediation, mycoremediation, and phytoremediation are examples of biological treatment approaches (Lim et al., 2016). These techniques can sometimes be used in tandem.

Physical, chemical, and photo-degradation approaches have all been developed for the remediation of contaminated environments. However, because the success of each approach is largely dependent on extraneous conditions such as properties of the oil, thickness, quantity, as well as position and weather changes, most treatments have some difficulties in entirely remediating the contaminated media (Pete et al., 2021). The advantages and disadvantages of application of various technologies in remediation are stated in Table 2. Chemical approaches for environmental remediation frequently generate by-products that are toxic to biota, necessitating additional treatment, and disposal (Alazaiza et al., 2021; Chauhan et al., 2020). Numerous hydrocarbon contamination removal strategies have been tried in Nigeria's oil-rich Niger Delta with hardly any progress (UNEP, 2011) because they're either unsuitable for the ecosystem and therefore do not achieve total remediation (Giadom, 2015) or because they all have a negative impact on the ecosystem (e.g., uncontrolled dump burn), culminating in air pollution. According to UNEP, continued use of enhanced natural attenuation (RENA) treatment is proven to fail for the Niger Delta area (UNEP, 2011). Regulatory authorities and commercial companies in the Niger Delta often use RENA – the do-nothing approach – to clean up polluted land (UNEP, 2011). However, the bulk of the places in this area is unsuitable for RENA since the spilled oil has seeped through the soil for far more than 5 m, polluting groundwater aquifers in several locations (Orji et al., 2012). Due to the soils' constrained capacity to digest, break down, and mitigate the toxicity of the pollutants (Bierkens & Geerts, 2014). As a result, the development of unique methodologies and environmentally friendly technologies for the restoration of petroleum hydrocarbon-contaminated landscapes is receiving increased attention (Al-Wasify & Hamed, 2014).

Bioremediation

Bioremediation is described as the employment of biological agents such as bacteria, fungi, algae, plants, protists, or their enzymes, as well as engineered microbes, to detoxify or eliminate organic and inorganic toxins from the environment due to their wide metabolic capacities (Agu et al., 2015; Dell-Anno et al., 2021; Giwa & Ibitoye, 2017; Khalid et al., 2021; Yarima et al., 2020). It is used in the modification or elimination of any impurities in an environment, including petroleum industry products (Agu et al., 2015; Giwa & Ibitoye, 2017), and it can be used in oil operation facilities owing to its capacity to transform toxins into less dangerous forms (Agbaji et al., 2020) through biological processes (Ahmed & Fakhruddin, 2018). The goal of bioremediation is to convert toxic substances like petroleum hydrocarbons to safe compounds like CO_2, H_2O, as well as essential fats; it has been widely used in hydrocarbon mitigation (De-la-Huz et al., 2018; Ojha et al., 2019). Microorganisms, like all living organisms, require nutrients (such as phosphorus, nitrogen, as well as micronutrients). They also require energy and carbon to thrive; hence, bacterial species may employ hydrocarbon (Al-Khalid & El-Naas, 2018; Karlapudi et al., 2018; Speight, 2018).

The following are the most popular bioremediation procedures (processes): bioventing (Chauhan et al., 2020), bioleaching (Baniasadi et al., 2019), bioaugmentation (Villaverde et al., 2019), bioreactor (Narayanan & Narayanan, 2019), composting, biostimulation, land farming (Chauhan et al., 2020), phytoremediation, and mycoremediation (Clay & Pichtel, 2019). Mycoremediation is a method of employing fungus to restore a contaminated environment to a less contaminated condition by channeling heavy metals and hydrocarbons to the fruit bodies for removal (Afzal et al., 2019; Yosef & Melkamu, 2016). Phytoremediation involves the process

Table 2 Advantages and disadvantages of different conventional techniques for remediation

Methods	Advantages	Disadvantages	References
Physical methods a. **Volatilization and photooxidation** b. **Soil washing** c. **Surfactant-enhanced remediation (SER)** d. **Thermal remediation (incineration)**	Easy to implement and does not produce massive quantities of hazardous materials This process can be used to treat numerous organic and inorganic contaminants and can be applied independently or in combination with other treatment technologies. Soil washing is more appropriate for soils containing at least 50% sand and gravel, given its higher permeability Successful in groundwater and soil contaminated with organic pollutants in the form of dense nonaqueous phase liquids (DNAPLs) Thermal technologies can remediate sites quickly and efficiently (hours to months), often removing over 99% of a wide range of hydrocarbon fractions	They are rarely successful in removing and cleaning up contaminants like PAHs, and they are also less safe and cost-efficient It is ineffective on dense nonaqueous phase liquids (DNAPLS), as it typically produces an aqueous effluent that requires further treatment or disposal Technology comes with hazards; as the interfacial force of DNAPLs decreases, uncontrolled vertical movement may occur It is usually done at high temperatures (750–1200 °C), making it a costly process that can also produce unwanted by-products, add to unwanted air quality, which if combined with a combustor, degrade the quality of the air, as well as increased susceptibility to toxins for site employees and local neighbors. Furthermore, while many individuals manually collect oil, shoreline flora deteriorates, and only 10–15% of oil is recovered following a significant disaster	Al-Wasify and Hamed (2014) Sonawdekar (2012) Yang et al. (2021) Lim et al. (2016), Umeojiakor et al. (2019) Zafirakou et al. (2018)
Chemical methods **Mechanical skimming, reducing agents, dispersants**	Faster than the physical method for oil removal Mechanical skimming, reducing agents, dispersants, regulated combustion, elevated hosing, and other spilled oil cleaning procedures all are effective at removing the optimum quantity of oil off the sea	Employs harmful chemicals; in most cases, surfactants, which are employed to clean up oil spills, are frequently more harmful than the oil itself. Persons employed onshore in the post-emergency phase to clean up the oil leak are exposed to oil spill response workers (OSRWs). These OSRWs could come in contact with oil spill contaminants through cutaneous and inhalation routes when they're not safeguarded and precautions are not followed They cannot remove emulsified oil that persists when physicochemical techniques have been used. Physical and chemical treatments cannot completely remove the oil, and there remains residual oil	Alazaiza et al. (2021) Sayed et al. (2021) Sayed et al. (2021)

of using species of plants to degrade and remove toxins from the soil (Nnaji, 2017). Rhizoremediation is a well-developed bioremediation approach that involves the symbiotic relationship of host plants with microorganisms to eliminate particular toxins from contaminated locations (Agu et al., 2015). One of the principal processes for removing hydrocarbon contaminants from our surroundings is microbial degradation using bioaugmentation, which would be less expensive than alternative remediation strategies (Das & Chandran, 2011). Petroleum hydrocarbon biodegradation in the environment is a complicated process. The kind and amount of oil or hydrocarbon present, as well as the composition of the autochthonous microbial population, influence the quantitative and qualitative features (Ichor et al., 2014). Because of its economic and environmental efficacy, bioremediation of oil-contaminated water is a promising technique (Samhan et al., 2017).

Microorganisms used in remediation

Microbes are microscopic organisms that live in the environment but are not visible to the naked eye

(Anih et al., 2019). Microbial taxa which could be relevant in the bioremediation of polluted soils could be identified in the same spot or from other contaminated sites (Dacco et al., 2020). Despite the difficulty of treating oil pollution, microorganisms that degrade petroleum hydrocarbons may have emerged because of living in very close contact with preexisting hydrocarbon compounds with naturally occurring petroleum hydrocarbons in an environmental media. These creatures could be used to clean up oil pollution (Lea-Smith et al., 2015).

Indigenous microbial species have been projected to be more useful and benign environmentally compared to allochthonous bacteria, which might need modification to their native habitat in order to enhance their productivity such as changes in O_2 or food concentration as well as pH (Dell-Anno et al., 2021).

Biodegradation of oils is the basic premise underpinning microbial bioremediation: using microbial species to degrade petroleum spills as well as transform the composition of the hydrocarbon from massive, toxic components to lesser, innocuous compounds like fatty acids or carbon dioxide (Anih et al., 2019). Microbial degradation plays an important role in the final removal of organic compounds such as oil from the soil, freshwater, brackish water, and marine habitats (Kumar & Gopal, 2015). Degradation or biotransformation of pollutants is not restricted to the action of a few diverse microorganisms, according to several findings; it occurs widely within bacteria, mycelia fungus, and yeasts (Ogbonna et al., 2012). In addition, inorganic contaminants can be transformed by microorganisms into chemicals with reduced solubility, mobility, and toxicity, though not always completely (Adriano et al., 2018). Microorganisms that degrade petroleum hydrocarbons such as polyaromatic hydrocarbons (PAHs), naphthalene, mono aromatic hydrocarbons like toluene, or aliphatic hydrocarbons like the n-alkanes can be easily separated from the environment, especially from petroleum-contaminated locations (Geetha et al., 2013). The catabolic capacities of autochthonous microbes to digest petroleum products have been described in several studies (Badr-El-Din et al., 2014; Clay & Pichtel, 2019; Dell-Anno et al., 2021). These bacteria, which have evolved in contaminated environments, have enzymatic structures which allow species to utilize petroleum as their sole source of carbon. In petroleum-contaminated environments, many such oil-utilizing organisms have now been discovered such as bacteria and archaea (Fowler et al., 2016).

Bacterial remediation, degradation, and/or utilization of hazardous pollutants is gaining popularity (Badr-El-Din et al., 2014). Bacterial species are the most effective agents in the breakdown of hydrocarbons since they are key decomposers of oil pollution in the ecosystem, as certain bacterial species have been shown to survive solely on hydrocarbon molecules (Das & Chandran, 2011). Bacteria can be isolated from a variety of substrates or from creatures that share a symbiotic connection with them (Guerra et al., 2018). As a result, there is a good chance of isolating bacteria capable of degrading and/or utilizing contaminants in its environment (Kumar & Gopal, 2015). Bacteria are being employed to tolerate toxins in the environment, degrade or change them into less hazardous chemicals, and eventually synthesize molecules that can be used to address the environmental pollution challenge (Chen et al., 2013).

The degrading capacities of indigenous or external microbes utilized as starter cultures are critical to the effectiveness of remediation techniques used in petroleum-contaminated settings (Al-Wasify & Hamed, 2014). The most critical need for microbial oil removal is the existence of microorganisms equipped with proper metabolism (Al-Wasify & Hamed, 2014). Dvorák et al. (2017) found that populations exposed to hydrocarbons became acclimated, including selective enrichment and genetic alterations. Microbes that have developed can adapt to pollutant concentrations in just a few hours (Xu et al., 2018) and have higher biodegradation rates than communities that have never been exposed to hydrocarbons (Al-Wasify & Hamed, 2014). As a result, the possibility to isolate a large number of specific hydrocarbon microbes off an ecosystem is commonly interpreted as proof that those microbes are by far the most energetic petroleum degraders in those surroundings (Al-Wasify & Hamed, 2014) and could be utilized in the environmental remediation of petroleum oil-polluted sites. Hydrocarbon-degrading species have been found in a variety of taxa, including *Vibrio*, *Corynebacterium*, *Arthrobacter*, *Brevibacterium*, *Flavobacterium*, *Burkholderia*, *Enterobacter*, *Flavobacterium*, as well as in *Sporobolomyces*, *Acinetobacter*, *Alteromonas*, *Achromobacter*, *Bacillus*, *Aeromonas*, *Thiobacillus*, *Lactobacter*, *Staphylococcus*, *Penicillium*, *Articulosporium*, *Pseudomonas*, and

Alcaligenes (Dell-Anno et al., 2021; Fahid et al., 2020; Xu et al., 2018). These organisms have been isolated in huge quantities from a variety of hydrocarbon-polluted water as well as soil, even though they are prevalent in smaller amounts in noncontaminated ecosystems (Agu et al., 2015; Xu et al., 2018). Hydrocarbonoclastic bacteria (OHCB) are found in genera such as *Alcanivorax*, *Marinobacter*, *Thallassolituus*, *Cycloclasticus*, and *Oleispira*, which are known for their capacity to breakdown hydrocarbons (Dell-Anno et al., 2021). Bacterial isolates, such as *Acinetobacter haemolyticus*, *Mycobacterium* sp., *Pseudomonas aeruginosa* (Khalid et al., 2021), *Bacillus subtilis*, *Klebsiella* sp., *Acinetobacter junii*, *Acinetobacter* sp. (Rehman et al., 2018), *Rhodococcus* sp., *Azotobacter vinelandii*, *Bacillus megaterium*, and *Acinetobacter lwoffii* (Fahid et al., 2020), have all been isolated from the hydrocarbon-contaminated environment. The capacity of microorganisms to use hydrocarbons to meet their cell development and energy demands is the driving factor behind petroleum biodegradation. For the isolation of such hydrocarbon emulsifying and degrading bacteria, hydrocarbon-contaminated soil and marine sources have been the most prevalent choices. The capacity to emulsify hydrocarbons in solution is one of the most essential features of hydrocarbon-degrading bacteria (Gupte & Sonawdekar, 2015).

Bioremediation techniques

The restoration of contaminated areas utilizing microbial activity (bioremediation) has shown to be efficient and dependable due to its environmental features. An effective bioremediation operation, however, depends on choosing the appropriate bioremediation method that can efficiently reduce concentrations of pollutants to an unharmful state. Biostimulation and bioaugmentation are the two basic strategies for enhancing bioremediation, given that environmental parameters, which impact the efficacy of bioremediation, are kept within an ideal range (Pete et al., 2021).

Bioaugmentation (BA)

It is a bioremediation approach that involves adding bacteria with certain catabolic activities or strain consortia to the microbial population so as to improve the rate of pollutant breakdown (Lim et al., 2016). This entails introducing certain pollutant-degrading microorganisms into the already-existing microbial community at the intervention site in order to accelerate contaminant breakdown (Nnaji, 2017). It is a strategy for boosting the number of chemicals that can be degraded by augmenting indigenous marine ecosystems with hydrocarbonoclastic organisms. In places where native microorganisms are incapable of digesting all petroleum pollutants available, or if indigenous microbes seem to be in a lengthy lag phase owing to pollution ingestion, bioaugmentation may help speed up cleanup efforts (Pete et al., 2021).

Bioaugmentation (BA) involves the incorporation of recognized hydrocarbon-degrading microorganisms into the native microbes' community. Petroleum-utilizing bacterial species are introduced to boost the pre-existing microorganism in the bioaugmentation process (Sayed et al., 2021). Bioremediation efforts try to boost naturally occurring degradation rates by introducing foreign microorganisms (BA). Since the consequence of a recently spilled oil is too slow to migrate towards less damaging constituents since the amount of newly oil spilled is originally quite substantial, bioaugmentation is considered a "straightening" or "completing" operation. As allochthonous microorganisms are unveiled to toxic oil pollution, they attempt to let out biosurfactants, as such disperse from the spill to minimize harmful impacts on the spill's toxicity. Bacteria that degrade petroleum hydrocarbons (both native and non-native) employ their intracellular enzymes to convert these compounds into some other source of food. In contaminated water, bioaugmentation methods are used to bioremediate petroleum products and associated chemical compounds (Sayed et al., 2021).

One difficulty with this strategy is that no single microbe is equipped with the power to break down all components of hydrocarbons. As a result, numerous strains of microbes such as bacteria and fungi have been recommended for such cleanup of petroleum pollutants in investigations (Lim et al., 2016). Bioaugmentation involves the introduction of active microorganisms into polluted areas. External addition of these microbes is common, and it has been demonstrated to aid in situ bioremediation of oil-contaminated locations (Sonawdekar, 2012). Bioaugmentation is supplementing bacteria from the outside, whether as a relatively pure culture or even as part of the integrated culture (consortium), in order to boost total metabolism rate and absolute breakdown. Microorganisms are an important tool for the remediation of contaminated soils due to their wide range of adaptation strategies, including the capacity to modify the cellular membrane in order to sustain the required physiological activity, the production of surface-active substances like biosurfactants, and the use of efflux pumps to reduce the concentration of toxic compounds inside the cells (Goswami et al*.,* 2018). Isolates that are promising in bioaugmentation of pollutants include pure cultures of *Pseudomonas*, *Flavobacterium*, *Sphingomonas*, *Achromobacter*, *Bacillus*, and *Rhodococcus*. A heterogeneous bacterial culture is shown to be more favourable than a pure bacterial isolate due to the combined actions amongst species of microbes (Sarkar et al., 2020).

Biostimulation

This entails supplementing native bacteria with nutrients to boost microorganism growth and metabolic capacity (Sarkar et al., 2020), electron acceptors, and donors, adjusting environmental variables like biopolymers, biosurfactants, and fertilizer. The addition of oleophilic fertilizers augments inorganic mineral elements such as potassium, phosphorous, as well as nitrogen (Jiang et al., 2016; Pete et al., 2021; Sayed et al., 2021). It also involves the maintenance of suitable temperature, pH, and moisture conditions to stimulate the catabolic activity of indigenous microorganisms (Esmaeli and Akbar, 2015).

Biostimulation has been shown to be an effective bioremediation method for treating contaminated environments (Umeojiakor et al., 2019). Certain environmental variables may be changed in various scenarios to help the biodegradation process (Sayed et al., 2021). Resident bacterial species are still more effective, despite the rising danger of leakage as well as their presumed capacity to compete with previously adapted local germs (Sayed et al., 2021). As a result, biostimulation is preferable to bioaugmentation. Minerals, like iron, phosphorus, and nitrogen, are required for the successful biodegradation of pollutants in some circumstances. Some of these nutrients may function as an inhibitor, slowing down the biological degradation action. Fertilizers have primarily been employed as biological stimulants by researchers, due to the presence of N, P, and K. Organic sources of carbon (petroleum hydrocarbons), as well as hydrogen and oxygen from water, are all sources of carbon (Umeojiakor et al., 2019).

Organic and inorganic nutrients including iron, oxygen, nitrogen, and phosphorus could be crucial in the bioremediation process since they encourage microbial growth and the breakdown of hydrocarbons. When it is discovered that certain nutrients, particularly nitrogen, phosphorus, and potassium, were lacking, indigenous microbes need to be "encouraged" and "fed." According to Abioye et al. (2012), organic nutrients, particularly nitrogen and phosphorus, utilized as amendments enhanced the capacity of microorganisms, including gram-negative bacteria, to naturally degrade hydrocarbons. The biodegradation process must be initiated with nutrients by detoxifying polluted environments (Alotaibi et al*.,* 2021). Nutrients are necessary for boosting biodegradation through the biomass of microbes. The amount of carbon increases, and phosphorus or nitrogen quality decreases when liquid petroleum hydrocarbons are released into the environment, which has an impact on oil deterioration. Plants need a lot of nutrients because phosphorus and nitrogen in freshwater and the ocean create nutrient-deficient zones. Nutrient levels must be raised for the breakdown of oil contaminants. While the biodegradation process is inhabited by a significant concentration of nutrients. Numerous researchers who study nutrient levels have found that high levels of NPK (nitrogen, potassium, and phosphorus) are a hindrance to breakdown, particularly when aromatic hydrocarbons are present. Most significantly, nutrient type and quality have an impact on how quickly a hydrocarbon degrades (Singh, 2020). Research suggests that food availability affects how quickly petroleum hydrocarbons degrade. Different types of nutrients, including sulfur, manganese, nitrogen, a little amount of phosphorus, and iron, are used by aerobic bacteria throughout the decomposition process. Nitrogen and phosphorus are crucial nutrients for the natural breakdown of hydrocarbons, and their deficiencies can slow down this process. These nutrients are not present in great quantities in seawater. The levels of phosphorus and nitrogen compounds in saltwater depend on temperature, ranging from 0 to 0.7 mg/l and 0.1 to 1 mg/l, respectively. Phosphorus is found in seawater as calcium phosphate. If there are insufficient nutrients for biodegradation, fertilizer is used as a nutrient source (Goveas, 2020).

Biostimulation is mostly used in soil remediation (Al-Dhabi et al., 2020; Bodor et al., 2020; Brzeszcz et al., 2020; Cui et al., 2020). In this natural habitat, indigenous microorganisms are nevertheless short of resources. The availability of nutrients allows these microorganisms to break down contaminants through anabolism and catabolism. It might be difficult to employ nutrients or fertilizers to foster the formation of a hydrocarbon-consuming microbial community in a spill region containing harmful oil. Several species endemic to the spill region is first weakened and/or killed by the toxic nature of the hydrocarbon (Cui et al., 2020). Nourishments can frequently be inhibited from activating the surviving native bacteria due to the toxic nature of petroleum. The bioremediation category BS can be employed efficiently when there is no wave surge and the discharged petroleum location has lowered toxic effects to the point where native bacterial species could be kept (Sayed et al., 2021).

Natural attenuation (NA)

Natural attenuation (NA), also known as natural recovery, involves a series of procedures that inherently change impurities into a lesser hazardous state or contain them such that they pose a lower environmental risk (Zhang et al., 2019). It is fundamentally an application that permits the elimination and spontaneous degradation of hydrocarbons without interference. In the formative stages of an oil leak, evaporation of volatile components is the most important method for spontaneous cleansing and eradication of lightweight material components from hydrocarbons. Within the first 12 h, about 50% of the really dangerous, lightweight oil compositions can disappear, according to the makeup of the spilled oil (Sayed et al., 2021). Photooxidation occurs when sunlight interacts with oil components (Sayed et al., 2021; Zhang et al., 2019). More sophisticated chemical breakdown generates smaller molecules most of which are often light-weight and also hydrophilic in nature, allowing them to be extracted further using alternative techniques.

Phytoremediation

Phytoremediation is the employment of plants (both natural and modified species) to remove aromatic pollutants from polluted environments. Furthermore, it is well suited for the remediation of greater regions of surface pollution, where other approaches may fall short (Zhang et al., 2019). Natural plants and shrubs such as *Agropyron*, *Bouteloua*, *Cyanodon dactylon*, *Elymus*, *Festuca*, and *Melilotus*, as well as leguminous plants, have been commonly employed to breakdown different polycyclic aromatic hydrocarbon molecules. In sandy loam soils, a combination of several species of shrubs has proven to be beneficial for the phytoremediation of diverse polycyclic aromatic hydrocarbons and pesticide compounds (Mohapatra & Phale, 2021). In addition, different metabolic compounds such as amino acids, sugars, and inorganic nutrients as well as enzymes like dehalogenase, reductase, peroxidase, and laccase have been found in crops' root exudates. It aids rhizospheric bacterial growth and metabolic activity, or they engage directly and easily with polycyclic aromatic hydrocarbons to biologically transform it. Numerous research has indicated that combining plants and microorganisms for pollution removal is an emerging cost-effective strategy that achieves maximum effectiveness while causing the least amount of environmental disruption (Perdigo et al., 2021). The employment of such strategies in conjunction with agricultural management techniques such as nutrient management integration, utilization of water, intercropping, and other agricultural approaches may aid total eradication of pesticides and toxins from farm areas and polluted sites (Mohapatra & Phale, 2021).

Factors affecting bioremediation

Understanding the parameters that influence microbial metabolism and hydrocarbon breakdown is critical for the design of an efficient bioremediation approach (Perdigo et al., 2021). Conditions such as nutrient availability, particularly nitrogen and phosphorus (Pete et al., 2021), or carbon sources contribute to the bacteria's performance in utilizing hydrocarbons (Abdulrasheed et al., 2020). Temperature, pH, salinity, supply of O_2, as well as pressure are all factors that influence microbe growth and degradation rates (Mohapatra & Phale, 2021; Sayed et al., 2021).

Nutrients

Microorganisms, like all living organisms, have the need for nourishments like phosphorus as well as nitrogen, carbon as an energy source, and other micronutrients to thrive. Availability of nutrients, as well as environmental variables, impact the pace of hydrocarbon breakdown (Dell-Anno et al., 2021). The main limiting variables for bacterial-mediated hydrocarbon breakdown have been identified as nitrogen and phosphorus; however, sulfur and potassium availability can also impact bioremediation rates (Dell-Anno et al., 2021). Nutrient availability, such as N, P, K, and Fe, is critical for efficient bioremediation. As a result, restricted concentrations of these nutrients (referred to as biostimulation) are necessary to encourage the development of indigenous bacteria for successful PAH bioremediation (Sarkar et al., 2020). High/excess nutrient levels, on the other hand, were observed to alter the rate of PAH biodegradation. PAHs have poor solubility in water as well as significant proclivity adsorption to mineral and organic substances in the matrix, which limits their bioavailability in the environment (Mohapatra & Phale, 2021).

Temperature

In warm water, crude oil degradation is accelerated because heat increases the breakdown of spilled petroleum, making it more accessible to oil-degrading bacteria (Dell-Anno et al., 2021). Sub-zero temperatures, on the other hand, cause cell transport channels to close and cytoplasm movement processes to halt, hampered or inactivating microbial metabolism and hence their biodegradation capacity. Furthermore, despite the fact that certain microorganisms are cold-tolerant, seasonal freeze–thaw cycles between winter and summer may restrict the bioavailability of spilled petroleum, reducing microbial biodegradation efficiency (Dell-Anno et al., 2021). In addition, the concentration of dissolved oxygen drops as temperature rises, which has an influence on aerobic microbe metabolism since molecular oxygen is among the precursors for oxygenase that undertake ring-hydroxylating or ring-cleaving reactions. It is well known that rising temperatures convert parent PAHs into more hazardous chemicals, preventing biodegradation (Mohapatra & Phale, 2021).

pH

Because pH affects microbial metabolism, it can have an impact on bioremediation efficacy, which is best at pH values of 6–8 (Dell-Anno et al., 2021). Many PAH-contaminated sites, such as acid mining sump pit sites having a pH of 1–4, as well as alkalinity leachate-affected fuel gasification areas with pH 8–12, have been shown to exhibit severe pH conditions. These circumstances have been proven to have a significant influence on biodegradation processes. As a result, appropriate chemicals (with mild to no oxidoreductase potential) such as ammonium sulfate or ammonium nitrate in alkaline soils as well as the addition of calcium or magnesium carbonate to acidic soil are advised to correct the pH before applying microorganisms for bioremediation (Gupta & Sar, 2020).

Oxygen

Because most petroleum-degrading microorganisms found so far are aerobic, oxygen concentration is another factor impacting bioremediation processes. Reduced oxygen availability in marine benthic systems (e.g., oxygen minimum zones, sediments with high organic matter content in highly eutrophic systems, or subsurface sediments) results in lower hydrocarbon biodegradation rates than fully oxygenated systems (Dell-Anno et al., 2021).

Advantages of bioremediation

Bioremediation is a nonmechanical way of removing oil from an area affected without causing damage to the place because it has been proved to irreversibly breakdown oil pollutants with minimal physical damage and short-term detrimental effects (Giwa & Ibitoye, 2017; Sayed et al., 2021; Spini et al., 2018). Bioremediation is practicable, targeted, and capable of attaining high removal efficiency at low cost (Al-Zaban et al., 2020), as well as extremely effective in converting pollutants to less harmful or nontoxic end products (Al-Zaban et al., 2020; Ojha et al., 2019). However, it also has its limitations. Table 3 highlights advantages and disadvantages of Bioremediation in environmental clean ups.

Table 3 Advantages and disadvantages of bioremediation technologies

Technologies	Advantages	Disadvantages	References
In situ a.**Bioventing** b.**Bioaugmentation** c.**Phytoremediation**	•Methods of in situ bioremediation do not demand for the relocation of the polluted soils. For example, instead of just transporting toxic petroleum hydrocarbon mixtures or combinations to another adjacent environment, bioremediation techniques such as bioaugmentation and biostimulation as well as combining the two procedures eradicate them •Volumetric treatment is provided by this technique, which can handle both liquid and solid pollutants •Enhanced in situ bioremediation can frequently treat subsurface pollutants more quickly than pump and treat procedures •Organic pollutants may be fully converted to harmless elements like carbon dioxide, water, and ethane •Considering how little site interruption there is, it is a cost-effective solution •The breakdown of hydrocarbons produces H_2O, CO_2, as well as fatty acids as the final products. As a result, it is an alternative approach for removing contaminants, as it has no negative impact on the environment	•Bioremediation efficiency is limited at locations with high levels of hazardous pollutants such as heavy metals, polycyclic aromatic hydrocarbons, and salt, which are damaging to bioremediating microorganisms •Some pollutants might not completely be converted into safe compounds based on the location •If a compound undergoes transformation and ceases at an intermediate, the intermediate may be more hazardous and/or mobile than the parent component; also, some stubborn pollutants are incapable of degrading •Also, because each spill site has its own unique collection of native bacterial species, no general bacterium can be used at all leak locations. Microbial degradation is the most important factor in the environmental restoration of PAH-contaminated environments •When improperly administered, the addition of nutrients, electron donors, and electron acceptor may cause injection wells to become plugged by voluminous microbial growth •Local microorganism activity is inhibited by the concentration of heavy metals and organic contaminants •Acclimatization of the microorganisms was typically necessary for in situ bioremediation, which may not occur for spills and resistant substances	Abioye (2011); Gupte and Sonawdekar (2015); Borah and Yadav (2016); Samhan et al. (2017); Hamoudi-Belarbi et al. (2018); Zhang et al. (2019); Kumar and Bharadvaja (2019); Agbaji et al. (2020); Al-Zaban et al. (2020); Chauhan et al. (2020); Yarima et al. (2020); Pete et al. (2021); Sayed et al., (2021)
Ex situ a.**Biopile** b.**Composting** c.**Farming**	•Appropriate for a diverse range of pollutants •Applicability is fairly easy to evaluate using information from the site investigation •You can influence pH, oxygen, nutrition, heat, moisture, and other factors to promote biodegradation •Generates a modest amount of waste •It is also a noninvasive method that can give a cost-effective alternative for ecosystem restoration and healthier groundwater sources	Great length of time required for phytoremediation (usually several seasons) Limited groundwater depth (90–300 cm) possibility of contaminant entering the food chain through the consumption of plants by animals	Nwachukwu (2010); Ogbonna et al. (2012); Rizwan et al. (2014); Spini et al. (2018); Tripathi et al. (2018); Zubairu et al. (2018); Khalid et al. (2021)

Conclusion

Biological diversity abounds in the aquatic environment, notably in the Niger Delta's aquatic ecosystem. Oil spills are a universal concern. Unfortunately, this menace is clearly at an all-time high in petroleum-producing regions like Nigeria's Niger Delta, harming flora and fauna owing to persistent degradation of the region's coastal environment by ongoing oil exploration. While there is no debate about the rewards that the discovery of black gold has brought to Nigeria, the environmental impact of its extraction and refining activities cannot be overlooked in the region. When oil is spilled, it causes environmental damage, contaminating surface and groundwater, as well as contaminating the entire atmosphere including health consequences to humans and the surrounding area. The population's main origin of income, which is based on agriculture, has also been decimated. These disadvantages in the region have far-reaching consequences in terms of unemployment, hunger, malnutrition, chronic illness, and environmental damage. As a result, cleaning up a hydrocarbon-polluted aquatic habitat is crucial. Hydrocarbons may be broken down using a variety of bioremediation techniques, making them easier to remove from aquatic settings. Different microbial taxa, on the other hand, have different metabolic requirements and can demonstrate varying efficiency in the biodegradation of petroleum hydrocarbons, which varies greatly depending on the chemical structure and bioavailability of the hydrocarbons, as well as environmental conditions.

Recommendations

The Nigerian federal government and federal environmental authorities should thus take steps to protect the region from additional environmental disasters by enacting tough environmental laws and imposing severe punishments to prevent oil spills and gas flaring. Partners in the oil and gas business must ensure that regulations are followed. Employment generation, as well as community participation in safeguarding, repairing, and surveillance of pipelines, should also be incorporated into oil corporations' ethical duties, with the goal of improving the quality of life in host villages and towns. Also, adequate and fast compensation should be offered to impacted people, and swift remedial measures should be carried out whenever spills occur in these oil-producing communities. Finally, long-term sustainability necessitates economic diversification, particularly in light of decreasing but irreversible assets and oil reserves now utilized in the region. By dealing with current woes like defective healthcare, shortage of food, pollutants, injustice, and other issues that contribute to the Niger Delta region of Nigeria's low human development indices, oil and gas proceeds must therefore be invested in a variety of ways to provide long-term gains to subsequent generations.

Declarations

Conflict of interest The authors declare no competing interest.

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