

Petroleum Exploration and Production: Past and Present Environmental Issues in the Nigeria's Niger Delta

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Abstract Petroleum exploration and production in the Nigeria's Niger Delta region and export of oil and gas resources by the petroleum sector has substantially improved the nation's economy over the past five decades. However, activities associated with petroleum exploration, development and production operations have local detrimental and significant impacts on the atmosphere, soils and sediments, surface and groundwater, marine environment and terrestrial ecosystems in the Niger Delta. Discharges of petroleum hydrocarbon and petroleum-derived waste streams have caused environmental pollution, adverse human health effects, socio-economic problems and degradation of host communities in the 9 oil-producing states in the Niger Delta region. Many approaches have been developed for the management of environmental impacts of petroleum production-related activities and several environmental laws have been institutionalized to regulate the Nigerian petroleum industry. However, the existing statutory laws and regulations for environmental protection appear to be grossly inadequate and some of the multinational oil companies operating in the Niger Delta region have failed to adopt sustainable practices to prevent environmental pollution. This review examines the implications of multinational oil companies operations and further highlights some of the past and present environmental issues associated with petroleum exploitation and production in the Nigeria's Niger Delta. Although effective understanding of petroleum production and associated environmental degradation is importance for developing management strategies, there is a need for more multidisciplinary approaches for sustainable risk mitigation and effective environmental protection of the oil-producing host communities in the Niger Delta.

Keywords: petroleum, exploration, production, environment, pollution, Niger Delta, Nigeria

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1. Introduction

Petroleum exploration and production in the Nigeria's Niger Delta region and export of oil and gas resources by the petroleum sector has substantially improved the nation's economy over the past five decades. However, activities associated with petroleum exploration, development and production operations have local detrimental and significant impacts on the atmosphere, soils and sediments, surface and groundwater, marine environment, biological diversity and sustainability of terrestrial ecosystems in the Niger Delta. Discharges of petroleum hydrocarbon and petroleum-derived waste streams have caused environmental pollution, adverse human health effects, detrimental impact on regional economy, socio-economic problems and degradation of host communities in the 9 oil-producing states in the Niger Delta region. Although there are other potential anthropogenic sources of pollution, some of the major environmental consequences such as air pollution, global

climate change and oil spills in the Niger Delta may be regional or global in scale [1-8]. Apart from other anthropogenic emission sources, atmospheric pollution in the region is associated with emissions from flaring and venting of petroleum associated natural gas by petroleum industries [9,10,11]. Atmospheric contaminants from anthropogenic activities can be categorized into (i) gaseous pollutants, (ii) persistent organic pollutants, (iii) particulate matter and (iv) trace element and/or heavy metals [12]. Release of petroleum hydrocarbons into the environment, whether accidentally or due to anthropogenic activities, is a major cause of controlled water and soil pollution [3,5,13,14] and may also contribute to regional atmospheric pollution [11].

Petroleum is a naturally occurring complex mixture made up predominantly of hydrocarbon compounds and frequently contains significant amounts of nitrogen, sulphur, and oxygen together with smaller amounts of nickel, vanadium, and various elements. Petroleum compounds can occur in solid form as asphalt, liquid form as crude oil and/or gaseous form as natural gas. Petroleum hydrocarbons could be divided into four classes: saturates

(pentane, hexadecane, octacosane, cyclohexane), aromatics (naphthalene, phenanthrene, benzene, pyrene), asphaltenes (phenols, fatty acids, ketones, esters, and porphyrins), and resins (pyridines, quinolines, carbazoles, sulfoxides and amides) [15,16]. Soils and sediments are the ultimate sink for most petroleum contaminants, such as benzene, toluene, ethyl benzene, and xylenes(BTEX), aliphatic and polycyclic aromatic hydrocarbons (PAHs). Petroleum hydrocarbon contamination of soils and sediment is a global concern because of the toxicity [16] and refractory character of the aromatic components in the absence of oxygen [17]. PAHs, which make up about 5% by volume, are a widespread class of environmental chemical contaminants of anthropogenic or natural origin (Block *et al.*, 1991). Although predominant oil pollution in the United Kingdom contains high volumes of aliphatic hydrocarbons [18], petroleum pollution in the tropical region like the Nigeria's Niger Delta contains complex mixtures of both the aliphatic and aromatic hydrocarbons [19,20].

The inadvertent discharges of petroleum hydrocarbons into the environment often pose threats to human health, safety and the environment, and have significant socio-economic consequences. Evidence of acute and chronic toxicity demonstrates the potential toxic and negative impacts of petroleum-derived wastes on the tropical environment [21]. However, some of the

multinational oil companies operating in the Niger Delta region have failed to adopt best practice strategies for risks mitigation and comply with environmental regulations. The poor environmental management practices by the petroleum industries and the failure of Nigeria's environmental regulations contribute towards environmental contamination with direct consequences on the surrounding populations' socio-economic wellbeing, human health and the environment. Environmental contamination, human health risks, safety and the environment, and negative socio-economic consequences of most petroleum pollution in the world depend on the intersection of the event, the geographic setting, the characteristics of the regional population, corporate governance systems and political economy. Environmental contamination and degradation associated with both onshore and offshore petroleum exploration and production operations in the Niger Delta has not yet been properly addressed for the past five decades.

This review examines the implications of past and present contributions of multinational oil companies operations and the Nigerian government towards environmental degradation in the Niger Delta. It will further highlights some of the issues of environmental degradation resulting from unsustainable practices associated with petroleum exploration, exploitation and production in the region.

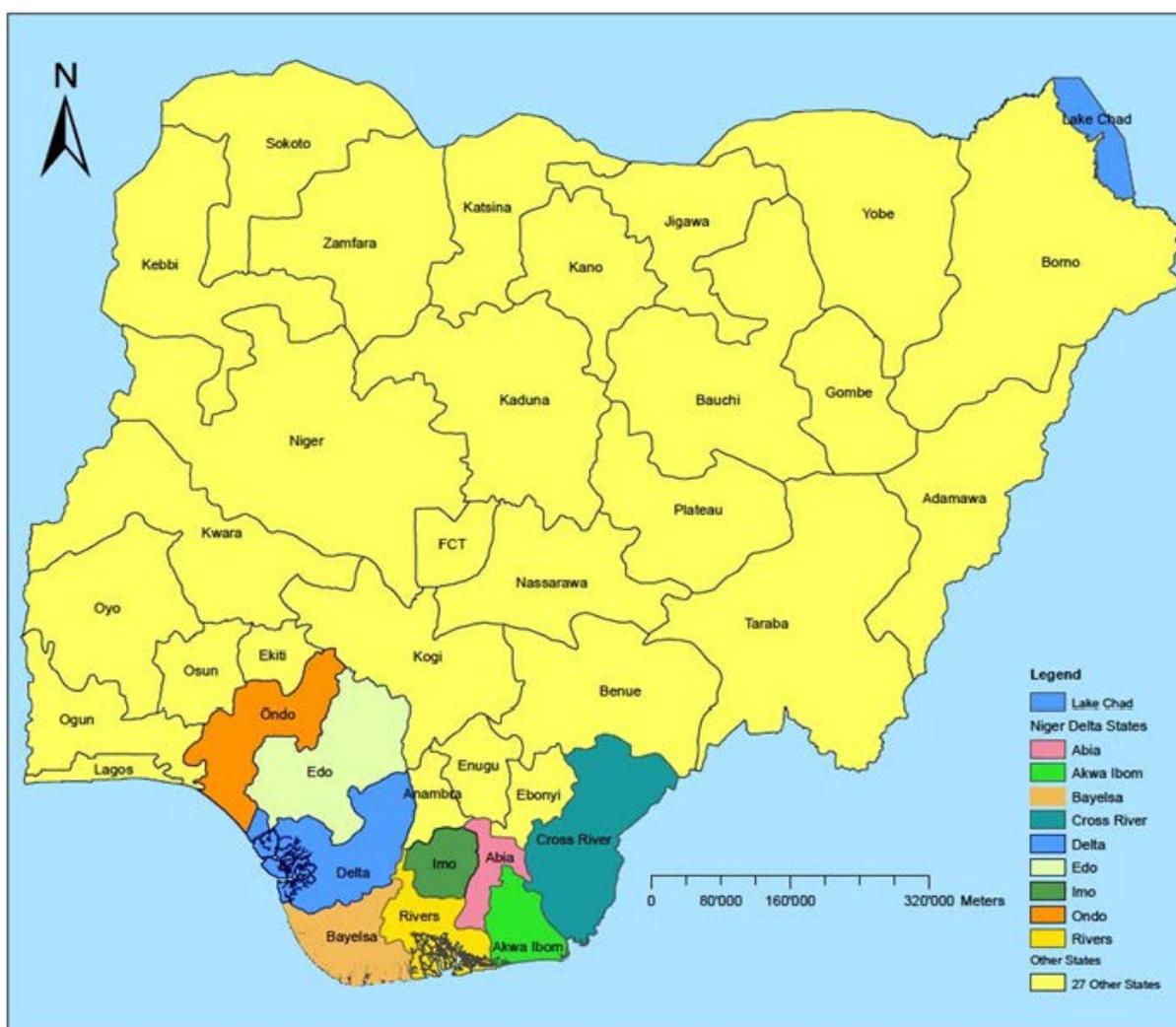


Figure 1. Map of Nigeria showing the Oil Producing States in Niger Delta Region (excluding offshore production beyond the lower limit of the continental shelf)

2. The Niger Delta Region of Nigeria

The Niger Delta region is situated at the apex of the Gulf of Guinea on the west coast of Africa [22,23] and on the Nigeria's South-South geopolitical zone (Figure 1). The Niger Delta, which is home to some 31 million people [24], occupies a total area of about 75,000 km² and makes up 7.5% of Nigeria's land mass. The Niger Delta region consists of 9 oil-producing states (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo and Rivers) and 185 local government areas. This region cuts across over 800 oil-producing communities with an extensive network of over 900 producing oil wells and several petroleum production-related facilities [25]. The ecological zones in the Niger Delta region can be broadly grouped into tropical rainforest in the northern part of the Delta and mangrove forest in the warm coastlines of Nigeria. Mangrove forests and swamps, which are characterized by regular salt-water inundation, lie at the centre of a complex and sensitive ecosystem which is vital to the local economy and accommodates important flora and fauna [26]. The Niger Delta, which is the largest mangrove forests in Africa and the third largest in the world, is the richest part of Nigeria in terms of petroleum resources and diverse natural ecosystems supportive of numerous species of terrestrial and aquatic fauna.

The Niger Delta is one of the world's largest tertiary delta systems and extremely prolific hydrocarbon provinces globally. The Niger Delta basin has been one of the most studied basins because of the occurrence of vast deposits of petroleum resources and the current production of all Nigeria's oil and gas is derived from this region [27]. According to Curtis [28], a large portion of the world's oil and gas reserves are in tertiary terrigenous fill on passive continental margins and the most significant hydrocarbon deposits of this type could be found in the U.S. Gulf of Mexico, Canadian Beaufort-Mackenzie Delta and Nigeria's Niger Delta. Advances in evaluation and improved seismic technology showed that the Niger Delta petroleum systems consist of Lower Cretaceous (lacustrine), Upper Cretaceous-lower Paleocene (marine) and Tertiary (deltaic) [22]. The geological assessment of the source material has shown that the principal source for oil and gas in the Niger Delta belonging to the tertiary deltaic petroleum system [22,23]. Over the past five decades, a total of about 1,182 exploration wells have been drilled to date in the delta basin, and about 400 oil and gas fields of varying sizes have been documented [27].

3. The Petroleum Exploration and Production in the Nigeria's Niger Delta

3.1. Historical Perspective of Oil and Gas Exploration and Production

Petroleum resources exploration in Nigeria dates back to 1908, when German surveyors for the Nigerian Bitumen Corporation, began prospecting for Tar Sand deposit in the South-Western Nigeria. These pioneering efforts ended abruptly with the outbreak of the World War I in 1914. Exploration of petroleum resources did not begin until 1938, when Shell D'Arcy (a consortium of

Iranian Oil Company (later British Petroleum) and Royal Dutch Shell) was granted a sole concessionary right over the whole country. However, World War II (1939-1945) terminated the initial oil exploration activities by Shell D'Arcy. Oil exploration in the Nigeria's Niger Delta resumed in 1946 after World War II and Shell D'Arcy drilled a number of oil exploratory wells in 1951. At the initial stage, Shell D'Arcy (later Shell-British Petroleum) enjoyed a complete monopoly of oil exploration for a considerable long time (1938-1955). Thereafter, Mobil Producing (Nigeria) Ltd, a subsidiary of American Socony-Mobil Oil Company, obtained license to explore for oil and began operations in Nigeria in 1955 under the name Mobil Exploration Nigeria Incorporated (which was later incorporated as Mobil Producing Nigeria on June 16, 1969). The first commercial oil discovery in the Tertiary delta was confirmed at Oloibiri field in January 1956 by Shell D'Arcy (later Shell-British Petroleum) and a second oil field was later discovered at Afam [22,29, 0]. In February 1958, Shell British Petroleum (now Royal Dutch Shell) started exporting crude oil produced from Oloibiri and Afam oil field at Port Harcourt [30]. The giant Bomu oil field, which has estimated ultimate recovery (EUR) of 0.311 billion of barrels (BB) of oil and a total of 0.608 billion of barrels of oil equivalent (BBOE) including gas, was discovered southeast of Port Harcourt-Rivers State in 1958 [29].

The petroleum sector began to play a vital role in shaping the Nigerian economy and political destiny of the country in the early 1960s. When Nigeria became an independent nation on 1 October 1960, Shell-BP began to relinquish its acreage and its exploration licenses were converted into prospecting licenses that allowed development and production [29,31]. Following the increase dominance of the Nigerian economy by petroleum sector, the sole concession policy was abandoned and exclusive exploration right was introduced to encourage other multinational oil companies aimed at accelerating petroleum exploration and production. Other multinational oil companies joined oil and gas exploration in Nigeria and these include Texaco Overseas Nigeria Petroleum Company Unlimited in 1961, Amoseas in 1961, Gulf Oil Company in 1961 (now Chevron), Société Africaine des Pétroles (SAFRAP) in 1962 (which later later became Elf Nigeria Limited in 1974), Tennessee Nigeria Limited (Tenneco) in 1962, Azienda Generale Italiana Petroli (AGIP) in 1962, ENI in 1964, Phillips Oil Company in 1964 and Pan Ocean Oil Corporation in 1972. Most of these multinational oil companies recorded considerable successes in oil and gas exploration and production in both onshore and offshore fields in the Niger Delta.

The Federal Government of Nigeria started its Department of Petroleum Resources (DPR) Inspectorate in 1970 and Nigeria joined the Organization of the Petroleum Exporting Countries (OPEC) in 1971. The first national oil company, the Nigerian National Oil Corporation (NNOC), was created in 1971 and it later became the Nigerian National Petroleum Corporation (NNPC) in 1977. In order to take control of the country's petroleum industry, Nigeria nationalized BP's holding completely in 1979, and Shell-BP became Shell Petroleum Development Company of Nigeria (SPDC) [32]. Although several other oil companies have joined in exploration and production

over the past decades, SPDC has the largest acreage in the country from which it produces some 39 per cent of the nation's oil and remains the major producer in the Nigeria's petroleum industry. The Niger Delta region is richly endowed with 31 giant oil and gas fields and each has an estimated ultimate recoverable oil of more than 500 million barrels and produces in excess of 1 million barrels a day out of the nation's total production of about 2.1 million barrels per day [27]. According to Vassiliou [29], 17 of giant oil and gas production fields are located offshore and some of the examples include Bomu, Oso, Ubit, Assan, Meren, Abo, Bonga, Bonga Southwest and Agbami, etc. Bonga and Bonga Southwest were discovered in 1996 and 2001, respectively and are operated by a joint venture led by SPDC [29]. Currently, there are over 18 multinational oil companies which are involved in oil and gas exploration and production in the Niger Delta [33] and the major players include Dutch Shell, ExxonMobil, ENI/Agip, Total Fina Elf and US-based Chevron Texaco.

3.2. Environmental Regulation of Oil and Gas Exploration and Production in Nigeria

There are many approaches that have been developed for the safety and management of environmental impact of oil and natural gas exploration and production operations in the Niger Delta. The emergence of Niger Delta as one of the most ecologically sensitive regions in Nigeria has led to the institutionalization of several statutory laws and environmental regulations to regulate the Nigerian petroleum industry. Over the past years, the Nigerian Federal Government has promulgated laws and regulations so that oil and gas exploration and production operations, on both onshore and offshore oilfields, could be controlled by systems of limits which aim at minimizing the associated environmental impacts. Some of the related environmental laws and regulations in the oil and gas sector include Oil Pipelines Act 1956 (amended in 1965); Mineral Oils (Safety) Regulations (1963); Oil in Navigable Waters acts (1968); Petroleum Acts (1969); Associated Gas Re-injection Act (1979); the Federal Environmental Protection Agency (FEPA) Act (1988); the National Policy on the Environment, 1989 (revised in 1999); National Environmental Protection (Effluent Limitations) Regulations (1991); Environmental Protection (Pollution Abatement in Industries Generating Wastes) Regulations (1991); Environmental Impact Assessment (EIA) Act (1992), and Department of Petroleum Resources (DPR) Environmental Guidelines and Standard for the Petroleum Industry in Nigeria (EGASPIN) (2002). According to Salu [34], most of these statutory laws and regulations provide the framework for petroleum resources exploration and exploitation in Nigeria and only some of these environmental regulations give guidelines on issues of petroleum pollution. Although the environmental laws and regulations in Nigeria have been poorly implemented, numerous environmental agencies have regulations that affect the exploration, development and production operations in the petroleum industry in Nigeria.

The establishment of FEPA in 1988 significantly changed the legal status quo of environmental regulation in the Nigeria petroleum industry. Under the 1988 FEPA

Act, penalties and enforcement mechanisms were imposed, multinational oil companies could be held liable for costs of clean-up, restoration and multinational oil companies could pay compensation to parties injured by their illegal practices. However, the existing statutory laws and regulations for environmental protection applicable to the Nigerian petroleum industry appear to be grossly inadequate and ineffective [7,9,35,36]. For example, Eaton [36] has extensively discussed the five major statutory defects which seriously prevent effective environmental regulation and non-legal explanations for Nigeria's failure to effectively regulate the activities of multinational oil companies. The government's environmental regulations are often affected by the limitations of technology, the need to support industry and the influence of public opinion [37]. In the Nigeria's Niger Delta, the participation of communities in the environmental decision-making process is a relatively new process and often ineffective with little or no sustainable development goals [38]. Over the past fifty years, the multinational oil companies operating in the Niger Delta region have failed to adopt sustainable exploration and production practices due to increased costs of complying with environmental regulations. Although comprehensive system of environmental regulations is now in place, environmental pollution associated with oil and gas exploration and production operations has continued to persist under these laws for several reasons. Therefore, unsustainable petroleum exploration and production practices and poor environmental management practices has impacted on the atmosphere, controlled waters, soils and sediments, biological diversity and sustainability of the natural ecosystem in the Niger Delta region for several decades.

3.3. Petroleum Resources and the Nigerian Economy

The dominance of the Nigeria's economy by the petroleum sector in the early 1970s resulted in declined economic contribution of agricultural sector in the country's economy and there was an overwhelming prominence of petroleum resources in the Nigerian economy, especially from 1973 onwards [39]. According to Graf [39], there is evidence to indicate that crude oil sales income as a proportion of foreign exchange earnings escalated from 2.5% to 58.1% in 1970, to 93.6% in 1975 greater than 98% through the first half of the 1980s. Production of oil and gas resources, which have been on-going for the past five decades, account for over 85 % of the Nigeria's gross domestic product (GDP), represents over 95 % of nation's foreign exchange revenues and contributes over 80 % of the government revenues [40]. Overall, oil and gas production from the Niger Delta region by the Nigerian government and multinational oil companies has generated an estimated \$600 billion since the 1960s [41]. Therefore, effective understanding of unsustainable exploitation of natural resources has helped shape our views of economic development from narrow economic interest to one that comprehensively embraces human, social and environmental factors in recent years.

Poor management of the petroleum resources has led to socio-economic, socio-political and complex interaction

problems involving the people, economic development and the environment. Despite massive influxes of oil revenues, Nigeria seems to suffer from the “oil curse” or the “natural resource curse” due to poor governance, lack of effective environmental and sustainability awareness. The development of a sustainable society is vital in any nation’s economic development both in the short and long term. Presently, the petroleum industry in Nigeria is battling against rising oil theft and oil bunkering has become a major cost to the nation’s treasury, which depends on oil for over 80 % of its earnings. In spite of the enormous contributions of the petroleum resources in the nation’s economy, the past and present petroleum exploration and production operations by the multinational oil companies has led to environmental contamination with associated adverse human health effects and socio-economic consequences in the Niger Delta.

4. Environmental Issues, Human Health Risks and Socio-economic Problems Associated with Petroleum Exploration and Production

There are several environmental impacts associated with the disturbance of forest and ground surface from related activities such as site clearance, construction of roads, tank farms, brine pits and pipelines, and other land

modifications necessary for the drilling of exploration and production wells and construction of production facilities [42,43]. For example, some of the environmental problems associated with oil exploration and production include oil spills, gas flaring and venting, discharges of petroleum-derived chemical wastes, contamination of controlled water sources, contamination of soil and sediments, the destruction of the farmland and the marine environment (Table 1). The major environmental issues arose primarily from the improper disposal of large volumes of petroleum-derived hazardous waste streams, such as oily and toxic sludge [10], equipment failure, oil spills/operational discharges and sabotage of petroleum facilities [25,33,44]. In addition, accidental discharges from abandoned oil wells that were orphaned or not correctly plugged and spills from oil bunkering (hacking into the pipeline to steal crude oil for illegal trade or ‘artisanal refining’) pose serious environmental threats in the Niger Delta. Although there are several impacts from other petrochemical industries in the Niger Delta, the adverse environmental condition in many parts of the oil-producing host communities has affected human right to a healthy environment [36] and makes the people vulnerable to environmental and health hazards. Therefore, this section will discuss some of the environmental issues, human health risks and socio-economic problems associated with oil and gas exploration for and production in the Niger Delta.

Table 1. Environmental impacts associated with upstream and downstream petroleum operations

| Activities | Potential associated risks | Environmental, health and safety issues |
|--|--|---|
| Exploration operations | | |
| <ul style="list-style-type: none"> • Geological survey • Aerial survey • Seismic survey • Gravimetric and magnetic survey • Exploratory drilling • Appraisal | <ul style="list-style-type: none"> a. Noise pollution b. Habitat destruction and acoustic emission c. Drilling discharges e.g. drilling fluids (water based and oil based muds) and drill cuttings d. Atmospheric emission e. Accidental spills/ blowout f. Solid waste disposal | Ecosystem destruction and interference with land use to access onshore sites and marines resource areas; environmental pollution (air, soil and controlled water) and safety problems associated with the use of explosives; land pollution which affects plants and pose human health risks; groundwater contamination and adverse effects on ecological biodiversity. |
| Development and production | | |
| <ul style="list-style-type: none"> • Development drilling • Processing: separation and treatment • Initial storage | <ul style="list-style-type: none"> a. Discharges of effluents (solids, liquids and gases) b. Operation discharges c. Atmospheric emission d. Accidental oil spills e. Deck drainage f. Sanitary waste disposal g. Noise pollution h. Transportation problems i. Socio-economic/ cultural issues | Ecosystem destruction and interference; contamination of soils and sediments with petroleum-derived wastes; atmospheric emissions from fuel combustion and gas flaring/venting; environmental pollution (air, soil and sediments, controlled waters) and groundwater contamination; ecological problems in the host communities, adverse human health risks; safety related risks and interference with socio-cultural systems. |
| Decommissioning and rehabilitation | | |
| <ul style="list-style-type: none"> • Well plugging • Removal of installations and equipment • Site restoration | <ul style="list-style-type: none"> a. Physical closure/removal b. Petroleum-contaminated waste disposal c. Leave in situ (partial or total) d. Dumping at sea | Environmental pollution and human safety; pollution related to onshore and offshore operations; hazard to other human activities such as fishing and navigation; marine pollution, fishing and navigation hazards |
| Refining of petroleum products | | |
| | <ul style="list-style-type: none"> a. Atmospheric emissions and air pollution b. Discharges of petroleum-derived wastes | Atmospheric emissions and air pollution; oil spillages; water effluents and production discharges. |
| Transportation and distribution | | |
| <ul style="list-style-type: none"> • Pipelines • Barges, ships, tankers and FPSOs • Road tankers and trucks | <ul style="list-style-type: none"> a. Emissions and accidental discharges b. Discharges from transporting vessels e.g. ballast, bilge and cleaning waters | Air emissions (hydrocarbons from loading racks and oil spills); accidental discharges and operational failures; disposal of sanitary wastes; contamination of soils and sediments. |
| Marketing operations | | |
| <ul style="list-style-type: none"> • Product importation • Storage | <ul style="list-style-type: none"> a. Operational discharges b. Wastes disposal | Spillage; contamination of soils and sediments; emission of organic contaminants and environmental pollution. |

4.1. Gas Flaring and Venting in the Niger Delta

Gas flaring and venting are widely used in the oil and natural gas industry to dispose of associated natural gases for safety reasons during petroleum development operations and/or where no infrastructure exists to bring it to market. The process of flaring (burning) and venting (releasing into the atmosphere without burning) of petroleum associated gas has been dramatically curbed in developed countries [45]. Although Norway has adopted flaring reduction measures and introduced a carbon tax, gas flaring and venting reduction strategies in Nigeria seems ineffective over the past years [11]. The extent of economic loss due to gas flaring and venting is estimated at \$2.5 billion annually [46] and enormous economic benefits would have accrued to the Nigerian government from harnessing this energy resource [47]. According to Ite and Ibok [11], gas flaring and venting associated with petroleum exploration and production in the Nigeria's Niger Delta has continue to generate complex consequences in terms of energy, human health, natural environment, socio-economic environment and sustainable development over the past fifty years.

Flaring of associated gas mainly emits carbon dioxide (CO₂), carbon monoxide (CO) and a variety of air pollutants, such as VOCs (which include carcinogens and air toxics), nitrogen oxides (NO_x), sulphur dioxide (SO₂), toxic heavy metals, and black carbon soot. Gas flaring and venting in the oil-producing areas of Niger Delta and vehicular traffic emissions (CO_x, HC, NO_x, SO₂ and particulate matters) contribute to atmospheric pollution in the South-South geopolitical zone of Nigeria [10,48]. According to Ologunorisa [49], empirical studies on the impact of gas flaring on the physical, chemical, soil, biological, atmospheric and social environment have not been adequately documented. In spite of decree 99, which bans unauthorized flaring, Nigeria flares over 75 % of the associated gas it produces and this represents a pollution equivalent to 45 million tons of CO₂ per day. Currently,

Nigeria has over 123 flaring sites in the Niger Delta region and has been regarded as one of the highest emitter of greenhouse gases in Africa [50]. Some 45.8 billion kilowatts of heat are discharged into the atmosphere of the Niger Delta from combustion of 1.8 billion cubic feet of gas everyday [51] and this is a major contributing factor to the global warming crises. Further, it is known that incomplete combustion of petroleum associated gases produces a variety of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) [52,53].

Flaring of associated gas from oil and gas exploration and production operations has several consequences on the environment. Some studies have suggested links between gas flaring and health problems in the communities [54,55,56] and others have established relationships between gas flaring and poor agricultural yields [57]. In a study, Dung et al. [57] investigated the spatial variability effects of gas flaring on the growth and development of cassava (*Manihot esculenta*), waterleaf (*Talinum triangulare*), and pepper (*Piper* spp.) crops commonly cultivated in the Niger Delta, Nigeria. The results suggest that a spatial gradient exists in the effects of gas flares on crop development [57]. Further, assessment of the PAH compound ratios, phenanthrene/anthracene and fluoranthene/pyrene, suggested that predominant present of PAHs of pyrogenic sources in surface soils is an indication that oil leakage and/or gas flaring contributes to soil contamination [58]. According to Edino et al. [59], it has been found that the residents perceive gas flaring as hazardous to health, environment, and general well-being of the oil-producing host communities. Few studies have shown that gas flaring have effects on corrosion of zinc roofs in the Niger Delta [55,60]. There are several consequences associated with flaring and venting of associated gas from petroleum resources exploitation and production [11,49]. Therefore, there is urgent need for more research on the effect of gas flaring on the different environmental compartments in the Niger Delta.



Figure 2. Oil spill on the coastal water at Ogonicommunity, Rivers State, Nigeria

4.2. Petroleum Hydrocarbon Spills and Accidental Discharges in the Niger Delta

Oil spillage, which often results from accidental or operational discharges of petroleum hydrocarbon into the environment, is a global issue that has been occurring since the discovery of crude oil. Oil spill incidents associated with petroleum exploration and production operations are common in the Nigeria's Niger Delta [61] and have plagued various oil-producing host communities since 1956 (Figure 2). The Niger Delta has experienced a number of disasters from oil blowouts and examples of oil pollution include blowouts and pipeline leakages from the Shell-BP Bomu II well blowout of 1970, the SAFRAP (now Elf) Obagi 21 well blowout of 1972, the Texaco Faniwa oil well blowout of 1980, and the Agip Oyakama pipeline leakage of 1980 [6]. According to estimates, over 2,567,966 barrels of crude oil has been spilled in 5733 incidents in the Niger Delta from 1976-2000 and about 549,060 barrels were recovered while 1,820,411 barrels were lost to the environment [62]. The cumulative spill volume within the period is nearly 10 times more than the total quantity that was spilled in the Exxon Valdez disaster. However, multinational oil companies operating in the Nigeria's Niger Delta often underestimate the quantity of oil spilt and a large number of other spills are not frequently reported, the total volume of oil spilt may be 10 times higher than the officially reported figure [63]. Further, the cases of unreported spills by some oil exploration and production companies could be related to the Nigerian National Petroleum Corporation (NNPC) inspectorate classification guidelines whereby spillage are classify into minor, medium, major and disaster.

In past years, major oil spills has attracted a global attention and created awareness due to the associated ecological, human health and environmental risks and/or damages that result from such spillages. The main sources of oil spill and pollution in the Niger Delta are equipment failure, oil blowouts from the flow stations, leakages from aged and corroded network of the pipelines, operational mishap, sabotage and vandalization of the oil pipelines by the local militant groups. However, oil spill resulting from the vandalization of pipelines either as a result of civil disaffection with the political process or as a criminal activity causes a serious contamination of the environment [8,64]. Although the Department of Petroleum Resources contends that 88% of the oil spill incidences are traceable to equipment failure [8,64], recent causes of oil spills in the Niger Delta are attributed to sabotage, militancy, bunkering and oil theft operations. In general, oil spills and production discharges in the Niger Delta have resulted in disastrous effects on land, freshwater swamps and the marine environment as well as potential threats to human health in the affected host communities.

The immediate effects of large scale spills and oil pollution in the coastal areas are well documented [65] and most of the terrestrial ecosystems and shorelines in the oil producing communities are often impacted. Defoliation and mortality of the mangroves have been observed in swamps affected by oil spills [66]. The effects of oil pollution on the diversity and functioning of fish and turtle communities in the Niger Delta have been reported [67]. According to Incardona et al. [68], the chemical complexity of petroleum hydrocarbon and

organic contaminants poses many important challenges for exposure science in marine ecosystems that support productive fisheries throughout the world. Important toxic effects associated with petroleum contamination in the shoreline could be difficult to identify which specific chemicals in complex oil mixtures are causing early life stage toxicity in fish [68,69,70]. In the aquatic environment, the oil slick sometimes floats on the water surface where it is dispersed to shorelines by wind and wave actions and invariably affecting the soil. When oil spillage occurs onshore or near shore, the soil and other components of the terrestrial ecosystem are inevitably affected [71]. Contamination of the marine environment associated with oil spills and accidental discharges of petroleum, if not effectively checked, can led to degradation of the Delta's mangrove forests, destruction of ecosystems, drastic decline in the fish and agricultural yields that are central to the livelihoods of local communities.

A large portion of the terrestrial ecosystems and shorelines in the oil producing communities in the Niger Delta region are important agricultural lands which are under continuous cultivation and support peasant farming. Spillage of crude oil into agricultural lands in the Niger Delta has been reported since 1971 [72] and early studies on the impact of crude oil on the environment has been reported by few researchers [2,72]. It is known that various types of crude oil can exert acute or chronic toxicity or both on soil properties and microflora [2,3,4,61,72,73,74,75]. The presence of high concentrations of petroleum hydrocarbon in soil may cause oxygen deprivation and subsequent death of soil fauna due to asphyxiation [76]. Several studies have investigated the effect of crude oil contamination of soil on the germination and growth performance of some agricultural crops [77,78]. The effect of crude oil-contaminated soil on the germination and growth performance of *Abelmoschus esculentus*, a widely cultivated vegetable crop in Nigeria, have been reported [77,78]. According to Oyedeji [77], petroleum hydrocarbon contamination of agricultural soil hindered germination, affects the crop agronomic growth performance of *Abelmoschus esculentus* L. and subsequently result in poor crop yield. As such, oil spillages may have far reaching implications on the agricultural productivity of an affected area and multiplier effects on the socio-economic well-being of the people of the Niger Delta [79].

4.3. Drilling Discharges and Petroleum-derived Chemical Wastes in the Niger Delta

Prior to the institution of statutory laws and regulations in the 1970s, the major petroleum-derived wastes such as produced water, spent drilling muds, drilling cuttings and wastes that require handling during site abandonment were commonly discharged into coastal waters, swamps, and unlined evaporation ponds. In particular, produced water is the largest volume waste stream associated with oil and gas exploration and production processes. The chemical composition of the oil field produced water is complex, including large amounts of dissolved salts, hydrocarbons, heavy metals, organic and inorganic components, naturally occurring radioactive materials

(NORMs) and chemicals added in the oil extraction and separation steps [43,80]. Produced water is either discharged into above ground storage facilities or re-injected into a subsurface formation as a permanent disposal/secondary recovery process during onshore operations, whilst it is either discharged through shore side outfalls or coastal rim releases (within 4 miles from shore)during offshore or coastal operations [81]. In many cases, the past and current disposal practices such as these have caused severe environmental contamination of coastal waters, groundwater water, soils and sediments, and marine ecosystems in the Niger Delta. The improper disposal of produced water on the ground is associated with salt scars and potentially contaminated land that is difficult to remediate.

The discharges of petroleum-derived waste streams from oil and gas exploration and productions are toxic to the coastal waters, soils and sediments near the discharge points. For example, disposal of produced water poses several threats to marine ecosystems and local effects have been observed in shallow estuarine or coastal waters [82-87]. According to Roach et al. [86], adverse impacts to mangrove vegetation are the most obvious signs of environmental effects resulting from produced water spills or discharges. The toxicity of produced water is directly related to high salinity (3000 to > 350,000 mg/L total dissolved solids [TDS]) [43] and other parameters such as toxic metals, soluble organics and radionuclides contents [88]. In the marine environment, contaminants with petroleum-contaminated produced water are toxic to a wide variety of aquatic organisms or estuarine organisms [85,86], therefore, there is no justification for the continuous disposal of produced water into ecologically sensitive areas in the Niger Delta. Although oil spills and discharges of petroleum-derived waste have plagued the natural environment for the past five decades, there is an urgent environmental concerns for effective disposal and/or remedial strategies for this highly saline water. Therefore, there is a need to develop sustainable strategies to mitigate the effects of past and present petroleum-derived wastes disposal practices in the Niger Delta.

4.4. Petroleum Contamination of Soil, Sediment and Groundwater

Petroleum hydrocarbon contamination of soil can occur in several ways, from natural seepage of hydrocarbons in areas where petroleum is found in shallow reservoirs, to accidental spillage of crude oil on the ground. In the Niger Delta, activities associated with petroleum exploration and production and subsequent discharges of hydrocarbon-derived chemical wastes have caused contamination of soils, groundwater pollution and ecosystem degradation. Several studies have been carried out to evaluate petroleum contamination of soil, sediments and groundwater in the Niger Delta region [2,3,4,6,71,73,74,75,76,89,90,91,92,93]. Ageing oil and gas production facilities often discharge significant volumes of petroleum hydrocarbon into the agricultural land. For example, there have been several cases of crude oil spillages at farmland in Ikot Ada Udo in Akwa Ibom State resulting from leakages of aged and corroded wellhead 'Ibibio 1' established in 1954 by SPDC. According to Okop et al. [90], the total petroleum

hydrocarbon concentrations levels in soils sampled from petroleum-contaminated farmland varied from 9-289 mg kg⁻¹ topsoil (0-15cm), 11-413 mg kg⁻¹ subsoil (15-30cm) and 13-178 mg kg⁻¹ at the greatest depth measured (30-60cm). Petroleum hydrocarbon contamination of soil is a widespread and well recognized environmental problem associated with oil and gas industries [16]. There are several cases of petroleum contamination of soils and sediments in the Niger Delta area that are linked to accidental or operational discharges of either crude oil and/or petroleum-derived chemical wastes.

Extensive oil spillage was reported near Ebubu-Ochani area (Ogoni community) in Gokana Local Government Area in Rivers State in 1971 from an oil delivery pipeline off a petroleum flow station. The amount of oil spilled could not be quantified because of intra-country civil unrest and incineration of the spill on soil surfaces resulted in the formation of large tar mat within 0.25 km radius of the point source [4]. The impacts of oil exploration and production in most of the oil-producing host communities in the Niger Delta have not been well assessed and managed over the past decades. For example, oil exploration and production (1950-1990) in Ogoni community led to civil unrest and/or conflicts over the environmental contamination associated with petroleum development and the requisite compensation for the impacted communities. In the early 1990's, the Shell Petroleum Development Company of Nigeria (SPDC) diminished oil drilling activities and later stop production operations in Ogoni community without complete decommissioning of their facilities. For the past 15 years, oil related contamination has occurred due leakages from aged oil production equipment and infrastructures. Although new cases of contamination have been witnessed over the past years, the local residents in Ogoni community have attempted to deal with petroleum contamination in order to use contaminated land for agriculture and residential purposes. In 2006, the Federal Government of Nigeria launched the assessment to identify, evaluate and minimize the immediate and long-term environmental, human health, socio-economic impacts of oil contamination in Ogoni community. It is widely known that high concentrations of organic and inorganic contaminants in soil environment often cause contamination of groundwater, degradation of land, pose significant adverse effects on human health and other ecological receptors. Although effective management of contaminated land is essential for risks mitigation, environmental contamination associated with petroleum exploration and production in the Ogoni community has not yet been addressed properly.

Contamination of the controlled water sources by petroleum hydrocarbons and other organic contaminants is a global environmental concern. Several studies have been carried out to evaluate petroleum contamination of groundwater in the Niger Delta region [75,93-99]. According to Anyakora and Coker [99], the assessment of the petroleum contamination threat on groundwater showed that PAHs concentrations ranged from 1.92-40.47 µg l⁻¹ and undetectable levels of high molecular weight PAHs have been attributed to their low water solubility. The discharges of petroleum hydrocarbon and petroleum-contaminated production wastes in freshwater environments and overflowing of oily wastes in burrow

pits during heavy rains has had deleterious effects on soil and several sources of controlled waters [100]. The petroleum hydrocarbon spills have resulted in contamination of marine environment, fishing areas and drinking water sources, and percolation of petroleum hydrocarbon into the soil causes contamination of groundwater aquifers. According to Ayotamuno et al. [101], groundwater contamination resulting from the leakage of crude oil and refined petroleum products during extraction and processing operations is a serious environmental problem in the Niger Delta region.

Groundwater evaluation is increasingly tilting toward a watershed approach due to large-scale contamination, resulting from urban development, rapid population growth, and land use changes [102]. Contamination of controlled water sources in the Niger Delta have made the people to resort to drilling borehole for drinking water, therefore, the protection of groundwater supply is importance to help mitigate potential risks associated with petroleum contamination. Considering the fact that ground water is one of most precious natural resource across Africa [103], there is a need for widespread adoption of sustainable development strategies for risks mitigation, effective understanding of the hydrogeology and adoption of microbial strategies in the management of petroleum contamination of environment.

4.5. Human Health Risks Associated with Petroleum Contamination and Environmental Degradation

Discharges of petroleum hydrocarbon into the environment often expose human population around the contaminated area to potentially dangerous toxic substances. There have been reported cases of acute health problems among workers involved in the clean-up operation following the *Prestige* oil spill in Asturias and Cantabria, Spain [104]. Although the negative impacts on human health have not been systematically assessed in the host communities in the Niger Delta, Rodríguez-Trigo et al. [105] have reviewed health effects of exposure to oil spills in the aftermath of other accidents involving oil tankers and available data on the *Prestige* oil spill. Acute exposures to aromatic hydrocarbons, which are common constituents of oil, are known to cause respiratory symptoms [106] and high molecular weight PAHs are of significant concern because of the mutagenicity, carcinogenicity and bioaccumulation in organic tissues due to their lipophilic character [16]. Increasing evidence, mainly from the *Prestige* oil spill, suggests that human population exposed to risks may experience long term respiratory effects and chromosomal damage [107,108,109]. It is widely known that exposure to PAHs can cause skin damage, bronchial symptoms in children and has been implicated in the pathogenesis of skin tumours as well as chromosomal disorders. The human health effects for the affected population during the *Prestige* oil spill [107,108,109] may have direct relevance for development of strategies for risks mitigation and lessons learnt may further provide information for environmental management in the Niger Delta.

Evidence of acute exposure to oil spill around the world demonstrate the potential adverse health effects associated with petroleum-contaminated environment. Some host

communities like the Ogoni have suffered from significant environmental degradation and health impacts including increase in respiratory diseases and cancer cases [110]. According to United Nations Environment Programme [75], the health of several Ogoni communities has been severely compromised as a result of surface and groundwater contamination associated with petroleum exploration and production operations. However, there is paucity of information on potential human health risks of exposure to oil pollution in the oil-producing communities in the Niger Delta region over the past five decades. There is high probability for a wide range of toxic responses in many host communities of the Niger Delta including behavioural abnormalities, respiratory diseases, suppressed growth, induced or inhibited enzyme, adverse physiological responses, blood disorders, negative reproductive outcomes, reduced immunity to disease and parasites, and cancers of the various organs [111]. Apart from health concerns and many of the issues raised by the Ogoni people, petroleum exploration and production has impacted directly upon the lives of the Ogoni community with both environmental and social costs [112,113]. Far from benefiting the local people, oil-producing host communities have instead borne the environmental burden, adverse human health risks and socio-economic cost associated with oil and gas development for several decades.

4.6. Socio-economic Costs Associated with Petroleum Contamination and Environmental Degradation

The Niger Delta has suffered all forms of pollution and degradation arising from petroleum exploration and production, and there are currently over 2,000 oil-polluted sites that need to be remediated in this region [114]. From the findings of independent experts, an estimated 9-13 million barrels of oil have been spilled in the Niger Delta since drilling began in 1958 and about 7,000 spills have occurred between 1970 and 2000 [114,115]. Due to the cumulative impacts of past and present petroleum exploration and production operations, the Niger Delta has been seen as one of the most polluted places in the world due to severe contamination associated with the operations of petroleum industries. The activities of the oil multinationals have adversely degraded the ecosystem and reduced the biodiversity of the Niger Delta area for several decades, thereby affecting the general ecology of the area [1]. Although the ecological effects associated with petroleum contamination have only been spot-wise investigated [116], it is obvious that petroleum exploration and production operations have impacted on agricultural soils, terrestrial ecosystem and pose potential human health risks in the oil-producing host communities in the Niger Delta.

The environmental issues and human health risks associated with petroleum resources exploration and production has seriously influenced the interaction of the people of the Niger Delta with their natural environment. According to Aaron [40], the ecological devastation associated with the activities of multinational oil companies have adversely impacted upon the original occupations of the inhabitants of Niger Delta. For example, petroleum contamination has negatively impacts on

agricultural productivity and some people, who originally engaged in farming and fishing, are facing loss of livelihoods through contaminated land and marine environment. Over the past 50 years, the multinational oil companies have failed to swiftly deal with environmental contamination resulting from oil spills, bunkering and discharges of petroleum-contaminated wastes in the Niger Delta. The failure of existing government statutory rules and regulations for environmental protection applicable to the Nigerian oil industry have led to troubling environmental outcomes, failure to implement proper control and effect preventative measures. However, the petroleum industry has influenced important political decisions by the government [9] and most of the environmental issues in the Niger Delta are linked to poor governance (political and corporate) in all its dimension [117]. Therefore, the fundamental sources of environmental degradation are social problems that occur through the failure of societies' institution to deal adequately with a broad range of socio-economic and environmental problems. As a direct consequence, the oil induced environmental issues and socio-economic problems could be attributed to the unsustainable exploitation of petroleum resources, poor governance and ineffective environmental regulations in Nigeria.

5. Conclusions

Petroleum contamination and environmental degradation associated with exploitation and production of petroleum resources has clearly impacted the natural environment, human health and safety, physical and socio-economic environments in the Niger Delta. In addition, unsustainable operational practices by the multinational oil companies and the ineffective government's petroleum development policies has led to more socio-economic problems and complex environmental degradation in the Niger Delta. Although it is becoming increasingly apparent to the multinational oil companies that pollution prevention pays, petroleum exploration and production environmental issues discussed in this review are widespread in oil-producing host communities in the Niger Delta. In order to achieve sustainable development, both the government and the multinational oil companies need to adopt environmental friendly approach and technologically advanced production operations that minimizes the associated environmental pollution. Adoption of effective sustainable reforms will encourage responsible petroleum exploration and production activities in ways that will positively influence economic development of host communities and protect human and environmental health in the near and long term. Considering the past and present petroleum contamination, it is important to understand the short and long term impacts of hydrocarbon contamination and hydrocarbon discharges from petroleum facilities in order to develop effective remediation and management strategies. Environmental remediation is urgently needed in many of the aged petroleum contaminated sites, where land use may be changing from petroleum production to residential, agricultural and recreational uses in the future. Therefore, effective understanding of petroleum production and associated environmental degradation is

importance for developing sustainable strategies for risks mitigation, management and remediation of environmental contamination.

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