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Petroleum Hydrocarbons Contamination of Surface Water and Groundwater in the Niger Delta Region of Nigeria

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Abstract Petroleum hydrocarbons contamination of the environment associated with exploration, development and production operations is a common feature in oil producing nations around the world, especially in a developing country like Nigeria where the incidence of facilities sabotage, operational failures, accidental discharges, pipeline vandalization and leakages, bunkering and artisanal refining is very common. Apart from poor governance systems, poor corporate social responsibility (CSR) of multinational oil companies (MOCs), poor environmental regulation of the petroleum industry, the inability of the political elite to effectively manage petroleum hydrocarbon-derived revenue, loss of petroleum hydrocarbons resource revenue to corruption and theft, petroleum hydrocarbons contamination of the total environment (air, soil, water and biota) have impacted negatively on the human health and wellbeing of oil producing communities in the Nigeria's Niger Delta region. Findings from several studies have revealed variable negative impacts of petroleum hydrocarbons toxicity on the human health (including exposed populations), the natural environment and other ecological receptors. Over the past fifty–five years, the oil producing host communities in the Nigeria's Niger Delta region have experienced a wide range of environmental pollution, degradation, human health risks, deterioration of our cultural heritage items and socio–economic problems as a result of various activities associated with petroleum exploration, development and production. Petroleum hydrocarbons contamination of surface water and groundwater is a notable environmental and human health problem in the oil producing communities and there are several water quality issues in the Nigeria's Niger Delta region. This review examines some of the water quality issues and human health implications of petroleum hydrocarbons contamination of controlled water sources (surface-water and groundwater) in the oil producing host communities in the Nigeria's Niger Delta region. It will further highlight some of the problems of petroleum hydrocarbons contamination and/or pollution of marine environments associated with unsustainable practices of petroleum industry in the region.

Keywords: *petroleum hydrocarbons, contamination, drinking water, Nigeria, Niger delta region*

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1. Introduction

Petroleum resources have contributed enormously to the global energy demand and economic development of oil producing nations, e.g. Nigeria, over the past fifty–five years [1]. The petroleum industry has a lot of influence in the world today and petroleum hydrocarbons are essential commodity that could be regarded as the backbone of today's global economy [2,3]. Since 1956, the discovery of petroleum resources in commercial quantities in Oloibiri (Ogbia Local Government Area of Bayelsa State) placed Nigeria among the group of oil producing nations, which today remains among many of Africa's largest oil producing countries. Apart from poor governance systems in the Niger Delta region of Nigeria, poor corporate social responsibility (CSR) of multinational oil companies (MOCs), poor environmental regulation of the petroleum industry, the inability of the political elite to effectively manage petroleum hydrocarbon–derived revenue, loss of petroleum hydrocarbons resource revenue to corruption and theft, inadvertent discharges of petroleum hydrocarbons and its products have equally contributed to severe environmental degradation, deterioration of our cultural heritage items as well as complex socio–economic problems over the past fifty–five years [1,4-10]. According to Ite et al. [5], the inadvertent discharges of petroleum hydrocarbons and chemical–derived waste streams associated with petroleum exploration and production have caused environmental

pollution, adverse environmental and/or human health problems, negative impacts on the terrestrial ecosystems, detrimental impacts on regional economy, socio–economic problems and degradation of oil producing host communities in the Niger Delta region. Some of the consequences associated with the inadvertent release of petroleum hydrocarbons into the environment are as follows: (i) atmospheric pollution associated with natural gas flaring and venting which may contribute to global climate change [4,11,12]; (ii) pollution of marine ecosystem which may result in adverse impacts on wildlife and negative impact on tourism, fishing and other related businesses; (iii) pollution of soil and controlled water sources (surface and ground water) [1,7,8,13-17], (iv) socio–economic problems and deterioration of our cultural heritage items in the impacted oil producing host communities in the region [1,5,6,18,19,20,21], and (v) contaminated land, food quality issues and reduction in agricultural produce [8,22,23,24].

Petroleum hydrocarbons contamination of the total environment (air, soil, water and biota) in the Nigeria's Niger Delta region has become a paramount interest and several studies have revealed various negative impacts of oil toxicity on the environment and exposed populations [1,4,5,6,7,22,25,26]. According to Ite et al. [5], the poor environmental management practices by the petroleum industries and the failure of Nigeria's environmental regulations contribute to environmental contamination with direct consequences on the surrounding populations' socio-economic wellbeing, human health and the environment. Nigeria is a country with insufficient investments in infrastructure and weak environmental governance, as such, oil leakage from pipelines often occurs as a result of poor management and maintenance as well as significant cases of sabotage and/or deliberate attacks ('interdictions') on oil facilities and pipelines [27]. Therefore, the Niger Delta region is plagued with petroleum hydrocarbons contamination and the region has been rated as one of the most crude oil spill vulnerable areas in the world [28]. It is widely known that environmental contamination, human health risks, and negative socio–economic consequences of most petroleum hydrocarbons 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 [1,5,6,27]. Over the past fifty–five years, it has been reported that an estimated 10 m to 13 m tons of petroleum hydrocarbons have been spilled into the Niger Delta regions and about 77 % of spilled petroleum hydrocarbons have not been recovered [29,30]. Apart from accidental discharges, part of these could be attributed to facilities and/or pipeline sabotage (interdiction) associated with social and political unrest in the Niger Delta region which has long been regarded as being responsible for low foreign exchange earnings from Nigeria's oil and gas resources [31]. However, petroleum hydrocarbons contamination of surface water and groundwater is a significant environmental and human health problem in the oil producing host communities in the Niger Delta region.

This review examines some of the water quality problems and human health implications of petroleum hydrocarbons contamination of controlled water sources (surface-water and groundwater) in the oil producing host communities in the Niger Delta region. It will further highlight some of the problems associated with petroleum hydrocarbons contamination and/or pollution of the marine environment associated with unsustainable practices by the petroleum industry in the region.

2. The Niger Delta Region of Nigeria and Petroleum Hydrocarbons Contamination

The Niger Delta Basin, which lies within latitudes 3° and 6° N and longitudes 5° and 8° E (Figure 1), occupies the Gulf of Guinea continental margin in equatorial West Africa [32,33,34]. The Niger Delta basin has a total area of about 75,000 km^2 and occupies the coastal and part of the ocean-ward of the Benue trough that makes up 7.5% of Nigeria's land mass [1]. The Niger Delta Basin, which is home to over 40 different ethnic groups, is a low–lying floodplain that was initially built over an older transgressive Paleocene prodelta. The basin is the youngest of the three large sediment bodies that filled the aulacogen formed after the separation of the African and South American plates [34,35]. The Niger Delta region is an extremely prolific hydrocarbon province and a concise description of the region has been previously discussed [1,4,5]. 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. According to Osuji and Onojake [36], the Niger Delta region cuts across over 800 oil producing communities with an extensive network of over 900 producing oil wells and several petroleum production–related facilities. 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 [37]. However, it has been reported that six states out of the nine oil producing states of the Niger Delta region (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers) are also the epicentre of an ongoing insurgency and civil unrest in the Niger Delta region of Nigeria [38]. From the geological perspective, the Niger Delta region is a hydrocarbon rich province with ultimate recovery currently estimated at nearly 40 billion barrels of oil. This accounts for more than 70 % of the overall hydrocarbon reserves of sub-Saharan Africa [34,37]. Although the Niger Delta region is one of the most petroleum hydrocarbons resource–rich regions in the world, it remains mired in cycles of conflicts that have perpetuated underdevelopment, threaten human security [21,39], habitat destruction [40], bunkering/artisanal refining and petroleum contamination of the natural environment [1,5,17,31,41,42]. Overall, a brief history of petroleum exploration and production in the Niger Delta region has been extensively reviewed by few researchers [1,5,43].

Apart from the negative impacts on the natural resources, some of the environmental problems associated with petroleum hydrocarbons exploration and production include oil spills, gas flaring and venting, improper discharges of petroleum hydrocarbon–derived chemical wastes, contamination of controlled water sources, contamination of soil and sediments, and destruction of the farmland and

the marine environment [1,5]. According to Ite et al. [1], every stage of petroleum resources exploration, development and production, decommissioning and rehabilitation, transportation and distribution often results in some considerable environmental impacts, human health risks and deterioration of our cultural heritage items as well as socio–economic problems within the oil producing host communities in the region. The major sources of environmental pollution in the Niger Delta region include oil spillage, pipeline explosion, gas flaring and venting, improper disposal of large volumes of petroleum–derived hazardous waste streams, such as drilling mud, oily and toxic sludge [12], equipment failure/oil spills associated with ageing facilities, sabotage of petroleum facilities, illegal oil bunkering and artisanal refining [1,5,27,31], oil well blowout, oil blast discharges and other operational discharges [1,4,5,9,10,36,44,45,46]. Historically, the two largest individual spills in Nigeria include the Royal Dutch Shell's Forcados oil export terminal tank failure in 1978 (a spillage of approximately 580,000 barrels or 92,000 m^3 of oil) and the blowout of a Texaco Funiwa-5 offshore station in 1980 (a spillage of approximately 400,000 barrels or 64,000 m^3 of oil) [47,48]. It has been estimated that from 1958 to 2010 approximately 546 million gallons (10.8 million barrels per year) of crude oil have been spilled into the environment [49], enough to cause significant damage to human health, community well-being and the environment [22,23]. Over the years, oil and gas industries operating in the Niger Delta region have created huge pollution problems with over 4,000 oil spills since 1991 [50,51]. Analysis of the oil spill data from 2007 to 2015 reveals that a total of over 90 million litres of crude oil had been spilled into the Niger Delta region [42]. According to Ordinioha and Brisibe [23], an average of 240,000 barrels of crude oil are spilled in the Nigeria's Niger delta region every year and the spillage may be attributed to unknown causes (31.85 %), third party activity (20.74 %), and accidental and/or equipment failure (17.04 %). Although many of the largest oil spills in the world have been caused by accidental terrestrial blow outs, leakages from pipelines due to sabotage, operational failures and neglected maintenance may account for most of petroleum contamination of terrestrial environment in the Niger delta region [5,42,52,53].

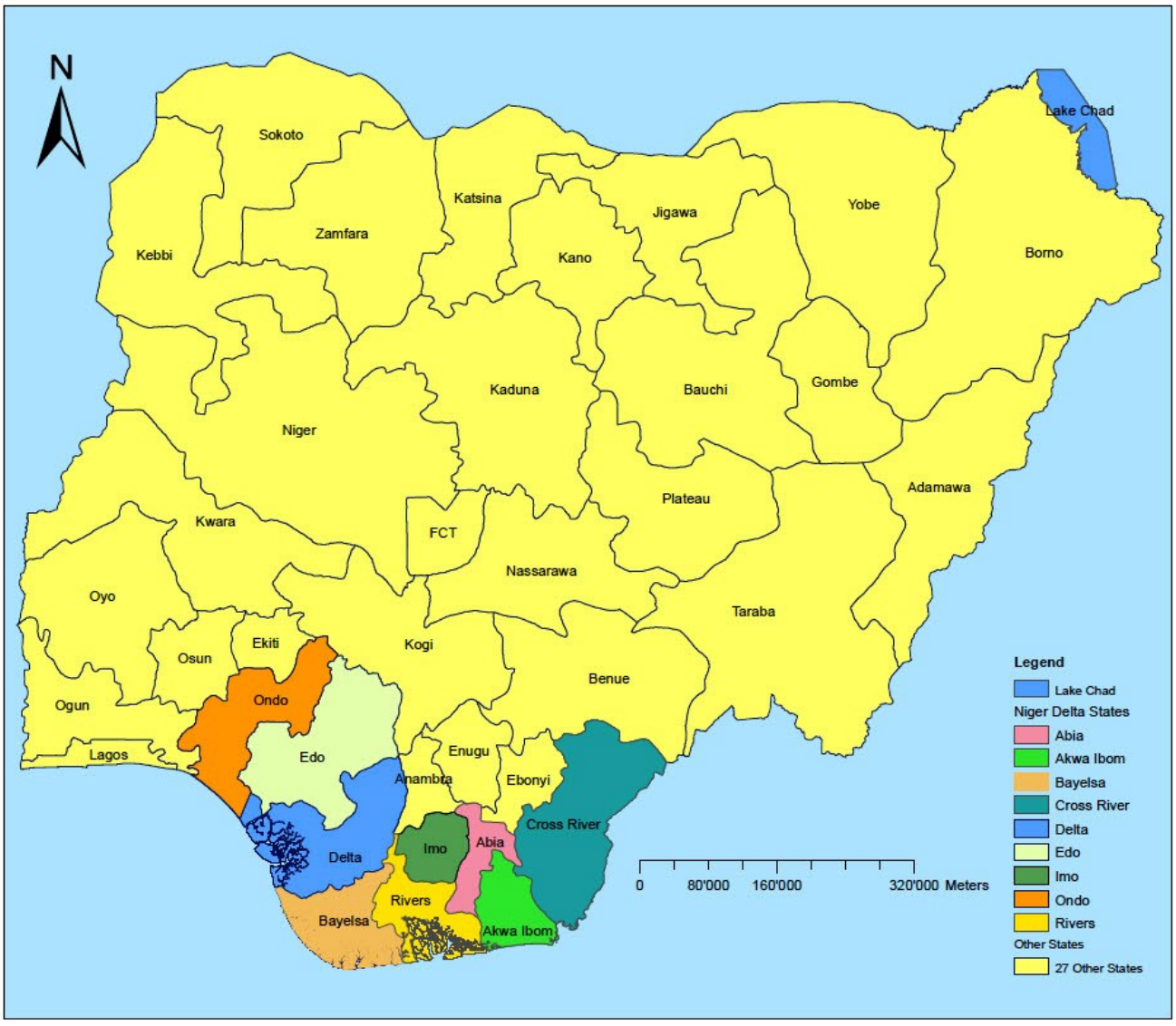

Figure 1. Map of Nigeria showing the Oil Producing States in Niger Delta Region (Source: Ite et al. [1])

The unsustainable activities of petroleum industries in the oil–rich region like the Niger Delta region reflect the inadequate effective statutory laws and regulations as well as lack of regulatory enforcements for environmental protection [1,11,19,40,54,55,56]. As such, the exploration and production activities of the petroleum industry have resulted in severe negative impacts on the Niger Delta region and its people over the past decades [1,4,5,6,7,8,17,21,28,57]. Some specific major disasters include the death of 180 people as a result of the extensive 1980 Texaco spill that contaminated streams which served as drinking water sources, and those that have killed children, leading to the hospitalization of more than one hundred residents due to the consumption of petroleum hydrocarbon–contaminated water [58]. Over the past fifty–five years, petroleum hydrocarbon contamination of soil and water resources has become a serious environmental concerns and human health risks because of the carcinogenic and mutagenic properties of some of the various hydrocarbon compounds [5].

3. Water Quality Problems in the Nigeria's Niger Delta Region

Contamination of surface water and groundwater by organic and inorganic chemicals, radionuclides, and/or microorganisms has occurred in most oil producing host communities in the Niger Delta region. However, the majority of petroleum hydrocarbon contamination and/or pollution incidences have not been properly documented over the years. Detailed quantitative estimates of the extent and effects of petroleum hydrocarbons contamination of surface water and groundwater contamination in the entire Niger Delta region are not available. Considering time and cost implications of the research work, it might probably take several years to acquire the detailed quantitative estimates of the extent and effects of petroleum hydrocarbons contamination of controlled water sources in the region. The time, costs, and technical requirements to develop the regional petroleum hydrocarbons contamination estimates would not be cost effective and information necessary for predicting future petroleum hydrocarbons contamination of controlled water sources cannot be easily predicted. This section of the review presents an improved attempt at a scientific discourse of water quality issues in the Niger Delta of Nigeria based on the petroleum hydrocarbons contamination levels in surface water and groundwater in view of the hitherto dearth of scientific data.

Petroleum pollutants in the tropical region like the Nigeria's Niger Delta region consist of complex mixtures of both the aliphatic and aromatic hydrocarbons [59,60]. The major pollutants in drinking water supplies fall into three general classes: petroleum hydrocarbons, halogenated hydrocarbons, and taste–and–odour compounds (which comprise of algae and bacteria). Petroleum hydrocarbons consist of the most ubiquitous pollutants and apart from polycyclic aromatic hydrocarbons (PAHs) [5], the most prevalent are the volatile organic compounds (VOCs): benzene, toluene, ethylbenzene, and xylenes (BTEX) [61,62]. It is known that BTEX are often found in water supplies, but certainly not exclusively in groundwaters because of the widespread use of petroleum hydrocarbons and their relatively high-water solubility (130 – 1780 mg l^{-1} at 20°C) [61]. According to Ite and Semple [6], polycyclic aromatic hydrocarbons (PAHs) containing from two to five fused aromatic rings are of serious concern because of their persistence in nature due to their lipophilic character and electrochemical stability. It is known that PAHs are relatively recalcitrant in soils [7] and some PAHs have been identified as carcinogens, mutagens, or teratogens. Apart from crude oil spills, improper discharges and/or disposal of petroleum–derived hazardous wastes such as produced water, poorly treated wastewater from oil refineries and petrochemical effluents have become another potential source of surface water and marine environment pollution. However, such improper discharges and/or disposal of petroleum–derived hazardous wastes have not yet received proper attention from the Nigerian government and the public over the years.

Petroleum hydrocarbons contamination of the controlled water sources is becoming a global environmental problem and over the past thirty (30) years, several studies have been carried out to evaluate the extent of surface water and groundwater contamination in the Niger Delta region [26,28,63-74]. In a study, Nduka and Orisakwe [70] investigated water quality problems in the Niger Delta of Nigeria focusing on polyaromatic and straight chain hydrocarbons in some selected surface waters collected from mid-Niger Delta (Bayelsa, Delta and Rivers States). From the results obtained, the concentration of six (6) PAHs were measured in samples from Anieze River in Port Harcourt. Their concentrations of PAHs were as follows acenaphthene (0.015 mg/l), 1,2-benzanthracene (0.004 mg/l), benzo(b)fluoranthene (0.064 mg/l), benzo(g,h,i)perylene (0.009 mg/l), dibenzo(a, h)anthracene (0.040 mg/l) and chrysene (0.015 mg/l). The concentration of PAHs in water samples from Orash River were chrysene (0.017 mg/l) and fluorene (0.109 mg/l). However, the only concentration of PAH in water samples from Ifie-Kporo River in Delta State was dibenzo(a, h)anthracene (4.350 mg/l), while none of the 16 PAHs prioritized by the United States Environmental Protection Agency (US EPA) was measured in water samples from Bayelsa State. According to Nduka and Orisakwe [70], straight chain aliphatic hydrocarbons of the order $C_8 – C_{14}$ were not detected in the majority of the water samples, whereas $C_{15} – C_{40}$ were detected in most of the samples with highest to lowest concentrations in water samples from Rivers, Delta and Bayelsa States, respectively. In another study, Ezekwe and Edoghotu [72] investigated the indicators of water quality in open coasts, estuaries, and inlets including nutrients, water clarity, and contaminants in the Andoni River estuary in the eastern Niger Delta of Nigeria. According to Ezekwe and Edoghotu [72], the findings of their study revealed that the estuary is polluted from immediate petroleum hydrocarbon pollution sources and local pollution from eroded contaminated sediments, discharged domestic and human wastes, and long distance river pollutants.

In a related study, Lindén and Pålsson [71] investigated the extensive petroleum hydrocarbons contamination of rivers, creeks, and ground waters in Ogoniland, Nigeria. The levels of pollutants in the more contaminated sites are high enough to cause severe impacts on the ecosystem and human health. For example, the concentration of extractable

petroleum hydrocarbons (EPHs) (>C_{10} – C_{40}) in surface waters was up to 7420 µg l^{-1} in these communities [71]. EPH concentrations in sediments were up to 17 900 mg kg l^{-1}. In most contaminated sites in Ogoniland, polycyclic aromatic hydrocarbons concentrations of up to 8.0 mg kg^{-1} have been reported. However, it is known that that petroleum hydrocarbons spills of varying magnitude often originate from aged facilities and pipelines, leaks from dilapidated and abandoned infrastructure, spills during transport, bunkering and artisanal refining of stolen oil under very primitive conditions [5,10,71]. In another study, assessment of petroleum hydrocarbon pollution associated with produced water discharges in seawater and sediments in offshore platform in the Nigeria's Niger Delta region was carried out by Okogbue et al. [75]. From the results obtained, it was found that the offshore waters were contaminated with total petroleum hydrocarbon (TPH), nitrite, sulphate, phosphate, nickel and zinc in the dry season, whereas benzene, toluene, ethyl benzene, xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs), cobalt, nitrite, total nitrogen, sulphate, phosphate and zinc were the major contaminants in the wet season [75]. According to Okogbue et al. [75], the sediments were also contaminated by barium, chromium, copper, iron, nickel, lead, vanadium, zinc, petroleum hydrocarbons in the dry season and by benzene, toluene, ethyl benzene, xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs), phenols, arsenic, cadmium, chromium, copper, iron, nickel, lead, vanadium, zinc and TPH in the wet season. Apart from PAHs and VOCs, petroleum hydrocarbons contain heavy metals [62,76,77] and radioactive isotopes that can have various potential effects on human health.

In another study, Tongo et al. [74] investigated the distribution, characterization, and human health risks of polycyclic aromatic hydrocarbons (PAHs) in Ovia River, Southern Nigeria. The results obtained showed that naphthalene, acenaphthylene, and fluoranthene were the most dominant contaminants in water, sediment, and fish, respectively, with mean concentrations (µg l^{-1}) of 3.08, 45.4, and 90.7. According to Tongo et al. [74], the mean concentration (µg l^{-1}) of individual PAHs in water ranged from 0.83 – 5.33 for naphthalene, 0.00 – 2.33 for 2-methylnaphthalene, 0.50 – 5.33 for acenaphthylene, 0.00 – 3.33 for acenaphthene, 0.17 – 2.83 for fluorene, 0.50 – 2.83 for phenanthrene, 0.00 – 2.50 for anthracene, below detection limit (BDL) – 3.83 for fluoranthene, BDL – 1.83 for pyrene, 0.00 – 0.50 for benzo(a)anthracene, and BDL – 0.33 for chrysene. In comparison, the mean concentrations of PAHs in water samples from Ovia River reported by Tongo et al. [74], were higher than those reported by other researchers [57,78,79]. In general, the concentrations of individual PAHs obtained in the study by Tongo et al. [74], were generally higher than the permissible concentration of 0.05 µg l^{-1} recommended by World Health Organization (WHO) guidelines concentration for PAHs in drinking water [80]., Alinnor et al. [81] in their study investigated the concentrations of total petroleum hydrocarbons in soil and groundwater of crude oil impacted areas of five communities in the Nigeria's Niger Delta region. The results obtained showed that water samples collected from all the stations in these communities were contaminated with TPH and at a depth 0 – 0.5 m the mean concentrations of TPH at Stations I, II, III, IV and V in water samples were 8186.67, 12110.00, 1351.67, 4137.00 and 9020.67 µg l^{-1}, respectively [81].

Apart from discharges of petroleum hydrocarbon–derived waste waters, crude oil spills have also significantly contributed to the pollution of marine environment. Some of the adverse impacts associated with marine pollution include contamination of fishing areas and drinking water sources, and percolation of petroleum hydrocarbons into the soil may cause contamination of groundwater aquifers [5]. According to Anyakora and Coker [69], the assessment of the petroleum contamination threat on groundwater showed that PAHs concentrations ranged from 1.92 – 40.47 µg l^{-1} and BDL for high molecular weight PAHs which have been attributed to their low water solubility. The discharges of petroleum hydrocarbons and petroleum hydrocarbon–derived chemical wastes into freshwater environments and overflowing of oily wastes in burrow pits during heavy rains have had deleterious effects on soil and several sources of controlled waters [82]. According to Ayotamuno et al. [83], 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. Over the past years, it is known that ageing oil and gas production facilities often discharge significant volumes of petroleum hydrocarbons into the agricultural land and marine environment. For example, there have been several cases of crude oil spillages on farmlands in Ikot Ada Udo in Akwa Ibom State resulting from leakages of aged and corroded wellhead 'Ibibio 1' established in 1954 by Shell Petroleum Development Company of Nigeria (SPDC) [5]. Over the past years (1993 – 2009), similar petroleum hydrocarbons contamination of the environment due to leakages from aged oil production equipment and infrastructures has been witnessed in Ogoniland in Rivers State [5,10]. Although inadvertent discharges of petroleum hydrocarbons constitute environmental problems and human health risks, the local residents in Ogoni community attempted to deal with petroleum hydrocarbons contamination in order to use the contaminated land for agriculture and residential purposes [5]. Considering the fact that about 22 % of petroleum hydrocarbon–contaminated land area is arable land with a significant exposure route to humans [42], petroleum hydrocarbons contamination can have both short and long term adverse effects on the environment and human health.

In 2006, the Federal Government of Nigeria invited the United Nations Environmental Programme (UNEP) to undertake a comprehensive environmental assessment of petroleum hydrocarbons–impacted sites in Ogoni communities in the Nigeria's Niger Delta region. The aim of the assessment was to identify, evaluate and minimize the immediate and long–term environmental, human health and socio–economic impacts of petroleum hydrocarbons contamination in Ogoni community. In 2011, the United Nations Environment Programme (UNEP) sampled Ogale drinking water wells and detected numerous petroleum hydrocarbons in water samples from individual borehole drinking water wells, notably benzene at concentrations as high as 9280 µg l^{-1}. From the results obtained, the concentration of benzene was approximately 1800 times higher than the United States Environmental Protection Agency (US EPA) drinking water tolerable limit [26,28]

and over 900 times higher than the World Health Organization (WHO) drinking water guidelines acceptable limit [28]. Consequently, the UNEP recommended immediate provision of clean drinking water for the residents [84], medical surveillance, and a prospective cohort study. Although the Nigerian government has provided emergency drinking water [9], other UNEP's recommendations have not been fully implemented due to the lack of political will on the part of the Nigerian government and the nonchalant attitude by SPDC [8]. Recently, the Federal Government of Nigeria has put in place financial and legislative framework in order to begin implementation of the recommendations made by the United Nations Environment Programme (UNEP) [41]. According to Ite et al. [5], effective management and remediation of petroleum hydrocarbons contaminated land are essential for effective risks mitigation and significant risks that are not currently controlled in the case of petroleum hydrocarbons contaminated land in Ogoni community need to be properly mitigated to avoid long–term human health effects. In practice, adoption of the UNEP's recommendations for addressing environmental health problems requires implementation of effective environmental management strategies and/or environmental management system models [8].

Over the past 20 years, 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 [85]. Contamination of controlled water sources in the Niger Delta region has led the people to resort to drilling borehole for drinking water. Consequently, the protection of groundwater supply is important to help mitigate potential risks associated with petroleum contamination. Considering the fact that groundwater is one of most precious natural resource across Africa [86], there is need for a widespread adoption of sustainable development strategies for risks mitigation, effective understanding of the hydrogeology and adoption of microbial strategies in the management of petroleum hydrocarbon–contaminated environment. Over the past fifty-five years, discharges of petroleum hydrocarbons have been witnessed at several sites across the Niger Delta region and few studies have revealed that residents of Ogoniland are often exposed to petroleum hydrocarbons contamination. Human exposure may occur through inhalation of hydrocarbons in ambient air, direct ingestion of contaminated water, indirectly via consumption through bioaccumulation in crop plants, and dermal contact with hydrocarbons in water, soil and sediments [28,71]. In an environmental impact assessment study, Kponee et al. [26] focused on the community of Ogale (part of Ogoniland) located in the Eleme Local Government Area of Rivers State – Nigeria, where UNEP discovered a substantial leakage from an abandoned section of a pipeline carrying refined oil. In this community, it has been reported that the UNEP environmental impact assessment results revealed approximately three inches of refined oil floating on the groundwater that supplies the community's drinking water [28,87]. Based on the UNEP's findings, several petroleum hydrocarbons notably benzene at concentrations as high as 9280 μg l^{-1}, which is approximately 1800 times higher than the United States Environmental Protection Agency (US EPA) drinking water standard and over 900 times higher than the World Health Organization (WHO) drinking water quality guidelines [23] were detected in water from individual borehole drinking water wells. Although UNEP did not complete a detailed chemical characterization of the refined oil in Ogale wells, studies on petroleum exposures may provide some indication of adverse health effects that might occur in the community.

In a related study, Nwaichi and James [88] assessed groundwater quality in some selected communities in the Niger Delta region and the results obtained revealed elevated concentrations of benzene ($P \leq 0.05$) in water samples collected from Ogale communities in Rivers State of Nigeria. Findings from this study further revealed that the residents of Nsisioken Ogale community may be drinking water from groundwater (boreholes and/or wells) that may be contaminated with benzene at concentrations over 11000 μg l^{-1} which is 850 times above the Environmental Guidelines and Standards for Petroleum Resources (EGASPIN) target concentration of 0.2 μg l^{-1} and World Health Organization (WHO) guidelines of 0.2 μg l^{-1}, respectively [88]. In another study, Amangabara and Njoku [89] assessed the vulnerability of groundwater to the activities of artisanal refining in Bolo and Environs, Ogu/Bolo Local Government Area of Rivers State in Nigeria using an empirical method. In this study, an estimated infiltration rate of 1.15 x 10^{-8} cm/s can be expected with a typical superficial soil permeability of 3.6 x 10^{-8} cm/s, depth of ponding of 0.5 m, and a wetting front of 0.4 m. From the concentration of the infiltration rate and the depth to groundwater (between 3m and 8m), Amangabara and Njoku [89] calculated the time for petroleum hydrocarbons plume to intercept the water table by simply re–expressing the equation for velocity as distance/time which results in approximately 4.6 years. The finding from this study further suggests that groundwater from the area studied has been negatively impacted by the activities of artisanal refining since the illegal activities and crude oil theft have been ongoing since 2002 [89]. The land use factor has a dominant effect on groundwater pollution risk mapping and groundwater vulnerability maps could be used as a tool for protecting groundwater resource and land use planning at the regional scale [90,91].

It is known that discharged petroleum hydrocarbons often sink into groundwater and the process of remediation of polluted groundwater can take many years [8,92]. In a study, Omo-Irabor et al. [67] investigated the natural and anthropogenic processes that influence the chemistry of surface water and groundwater within the western Niger Delta region using multivariate statistical techniques. The results obtained in this study revealed that proper land use planning and effective implementation of existing environmental laws are imperative in oil producing region in order to achieved effective controlled of water management [67]. In general, findings from several researches has shown that activities of petroleum industries have led to poor water quality in the Niger Delta, negatively impacting the human health and mangrove ecosystem with extensive depletion of fish stock in the region. According to UNEP [28], it has been reported that a significant number of Ogoniland residents have suffered severe health impairment due to contamination of surface

water and underground water sources arising from petroleum industry operations.

4. Human Health Implications of Petroleum Hydrocarbon Contamination of Controlled Water Sources

There are various sources of xenobiotic compounds in controlled water in the Niger Delta region of Nigeria. The most important contaminants from a health perspective are petroleum hydrocarbons. Adequate supply of safe drinking water is very important for a healthy life and the quality of drinking water as well as possible associated human health risks vary throughout different regions of the world [93]. It is widely known that high concentrations of petroleum hydrocarbons in the soils often cause contamination of surface water and groundwater, degradation of land, pose significant adverse effects on human health and other ecological receptors [5]. In the Niger Delta region, there have been very few studies on individual human health problems associated with petroleum hydrocarbons contamination [5,10,23,94]. Discharges of petroleum hydrocarbons into the environment have caused extensive damage to the mangroves, where large areas of vegetations have died. Investigation has shown significant level of contamination of mangroves, creeks, rivers, and groundwater, particularly in Ogoni communities in Rivers State – Nigeria [10]. In 2001, there were fears of a cholera outbreak after a controlled water source was contaminated with petroleum hydrocarbons in Ondo State of Nigeria [50]. There are various human health complications associated with petroleum hydrocarbons contamination. Some of these include carcinogenicity, genotoxicity, deoxyribonucleic acid (DNA) damage, birth defects, childhood leukaemia, infertility and miscarriages in women, sterility, skin rashes and irritation, respiratory system disorders, and cancers of different parts (organs) of the body [3,9,23,72,95-102]. In some parts of the world, research has primarily been focused on high-doses and short-term occupational exposures to crude oil during remediation of oil spills. It has been reported that workers exposed to petroleum hydrocarbons have adverse health symptoms such as headaches, eye and skin irritation and respiratory difficulties [94,99]. From some studies, it has been found that acute exposures to high concentrations of volatile organic compounds (VOCs) such as toluene is often associated with the problem of central nervous system toxicity, resulting in symptoms such as headaches, fatigue and dizziness [103,104,105]. It is known that chronic exposure to VOCs can impair the immune system [106] and exposure to benzene, a known human carcinogen, is often associated with hematopoietic system disorders [107,108]. Polycyclic aromatic hydrocarbons cause symptoms such as nausea, vomiting and skin and eye irritation following acute, high-level exposures [12,13]. Exposures to PAHs during pregnancy have been linked to decreased birth weight and impaired child development [14]. Chronic occupational exposures are associated with dose-dependent increased risks of certain types of cancers, including lung, skin and bladder cancer [15].

In a study, Olawoyin et al. [96] carried out ecotoxicological and epidemiological assessment of human exposure to polycyclic aromatic hydrocarbons in the Niger Delta region of Nigeria. From the results obtained in this study, the concentrations of the 7 potential carcinogenic PAHs in the soils varied from 297.00 – 4080.60 ± 546.30 mg kg^{-1} with a median of 419 mg kg^{-1}, the concentrations for non-carcinogenic PAHs ranged from 315.00 – 1999.00 ± 300 mg kg^{-1} with a median of 497.50 mg kg^{-1}. In addition, the total concentrations of PAHs in water samples varied from 119.80 – 450.00 ± 117.90 mg l^{-1} with a median of 141.90 mg l^{-1}, while the concentrations in sediments ranged from 6.00 –132.00 ± 28.70 mg l^{-1} with a median of 62.73 mg l^{-1}. According to Olawoyin et al. [96], concentrations of benzo(a) pyrene (BaP) of 66.95 ± 73.47 mg l^{-1} measured in in soil samples were attributed to crude oil spillage in the study area. Based on the evaluation of human exposure to PAHs sources in this study, the ecotoxicological assessments indicate long term exposures to PAHs contamination of environmental media in the Niger Delta region have high potential of acute toxicity sufficient to induce carcinogenic and chronic effects [96]. It is known that naphthalene, a low molecular weight PAH, that was detected in water samples collected from Ogale community during a cross-sectional pilot study in the region of Ogoniland [9], can adversely affect the hematopoietic system, damaging and killing red blood cells, causing symptoms such as shortness of breath and fatigue [97, 98]. Alkylated PAHs comprise the majority of PAHs detected in petroleum products and are particularly persistent in the environment. Although the health effects of alkylated PAHs have not been well investigated, limited evidence suggests that they may be more toxic and carcinogenic than their parent PAH compounds [109]. The results obtained in a cross-sectional study revealed that blood samples of oil spill workers revealed alterations consistent with impairment of the hepatic and hematopoietic systems [20]. Research on the Prestige oil spill has provided preliminary evidence of exposure-dependent DNA damage in clean-up volunteers [21]. The ongoing NIEHS Gulf Long Term Follow Up (GuLF) Study on Deepwater Horizon spill workers appears to be the first investigation on long-term physical health effects using a prospective cohort design [22,23].

In the Nigeria's Niger Delta region, it has been reported in few studies that petroleum hydrocarbons associated with artisanal refining have had negative impacts on groundwater quality in the polluted areas since 2002 [10,89]. The crude oil spills contaminate the surface water, ground water, ambient air, and crops with hydrocarbons, including known carcinogens such as polycyclic aromatic hydrocarbon and benzo (a) pyrene, naturally occurring radioactive materials, and trace metals that may have been further bioaccumulated in some food crops [23]. According to Ordinioha and Brisibe [23], petroleum hydrocarbon spills could lead to a 60 % reduction in household food security, 36 % reduction in the ascorbic acid content of vegetables and 40 % reduction in the crude protein content of cassava. Consequently, various adverse effects associated with petroleum hydrocarbons contamination of arable land in the Niger Delta may contribute to a 24 % increase in the prevalence of childhood malnutrition in the region [23]. Over the past fifty–five years, high levels of

disease symptoms and environmental distress (worry, annoyance and intolerance) associated with petroleum hydrocarbons pollution in the Niger Delta region have been documented [5,22,23]. Apart from inorganic contaminants, some of the organic contaminants in contaminated food and controlled water sources are associated with adverse human health risks, environmental degradation and socioeconomic impacts. Although only a small portion of the total controlled water sources in some heavily impacted sites or hot spots in the Niger Delta region is thought to be contaminated with petroleum hydrocarbons, the potential effects associated with such contamination are significant and warrant national as well as international attention. In a study, Clinton et al. [110] evaluated total petroleum hydrocarbon concentrations in some aquatic media in a petroleum hydrocarbons polluted mangrove wetland in the Niger Delta. The results obtained in this study indicated that the environment has been polluted and the total petroleum hydrocarbon concentrations in water sample at the wellhead stations were above 10 mg l^{-1} which is the maximum permissible limit recommended by the Federal Ministry of Environment in Nigeria [110]. In a related study, Obida et al. [42] used spatio-temporal analysis techniques to identify petroleum hydrocarbon pollution hotspots along the pipeline network, and to quantify the exposure of residents and the environment to petroleum hydrocarbons pollution in the Niger Delta region. The results obtained in this study demonstrate the high levels of environmental and human exposure to petroleum hydrocarbon pollutants in the Niger Delta [42]. Petroleum hydrocarbons may have contaminated about 66 km^2 of water bodies from 2007 to 2015 and subsequently, about 29 % of the population living within a spill impact radius might have faced either acute (short term) or chronic (long term) health consequences [42].

The level of petroleum hydrocarbons contamination of some controlled water sources and arable land in the Niger Delta region suggests that no meaningful activities such as farming and fishing can be undertaken safely in the affected areas [70]. The unsustainable development, utilization of petroleum hydrocarbon resources, and improper disposal of petroleum hydrocarbon–derived chemical wastes may pose negative impact on, not only air, water and land, but increasingly on the entire ecosystem and human health [1,5,7,111]. Over the years, it has been recognized that the sustainable management of natural resources requires a synergy between ecological and human/social systems as the two sub-systems interact [17]. In view of the negative impact of petroleum hydrocarbons contamination of controlled water sources in the Niger Delta, we recommend water quality monitoring and suggest the possibility of development of a strategy and/or approach for determining the age of a particular pollutant.

5. Conclusions

Petroleum hydrocarbons contamination in the Niger delta region of Nigeria have had acute and long-term adverse effects on human health and the ecosystem over the past fifty–five years. Apart from petroleum hydrocarbons contaminants found in surface water and groundwater, petroleum hydrocarbons pollution has negatively impacted the total environment as well as socio–economic factors. Although only a small portion of controlled water resources in the Niger Delta region is thought to be contaminated, the potential effects of long term exposure to petroleum hydrocarbons contamination are significant and warrant urgent national attention. In the Niger Delta region, activities associated with petroleum exploration and production and subsequent discharges of hydrocarbon–derived chemical wastes have led to contamination of soils, pollution of controlled water sources and ecosystem degradation. This paper suggests that relevant academics (experts) and government agencies should monitor the activities of stakeholders involved in the exploration, exploitation and production of petroleum resources in the Niger Delta region of Nigeria so that adoption of emerging technologies/optimization of bioremediation strategies for petroleum hydrocarbon contamination could be developed. In conclusion, the paper suggests that the Nigerian government and multinational oil companies (MOCs) must ensure that genuine efforts are made towards addressing the costs of resource extraction in the oil–rich but ecologically fragile Niger Delta region [21]. The issue of environmental sustainability cannot be overemphasized in the Niger Delta region and the development of the area especially the well-being of future generations should not be ignored. Although environmental contamination associated with petroleum exploration and production in the Nigeria's Niger Delta region has not yet been addressed properly, effective management of petroleum hydrocarbons contaminated controlled water resources, land and the marine environment is essential for risks mitigation.

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