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Review

Environmental Implications, Properties and Attributes of Crude Oil in the Oil-producing States of Nigeria

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Abstract

In Nigeria, oil exploitation occurs in the Niger Delta region which is one of the world's largest wetlands and includes by far the largest mangrove forest in Africa with a biological diversity of global significance. The study aimed in creating a synergy between the environment, farming system and crude oil sector with the need of government to implement feasible policies that will protect the health of all for a sustainable ecosystem. This review was achieved by using the online archives and personal interactions. The high demand for and use of petroleum and its derivatives worldwide has made petroleum hydrocarbon contamination a global problem with serious health and environmental consequences. One of the environmental challenges posed by oil pollution is the alteration in the physical and chemical nature of the soil which subsequently affects the growth of plants. Petroleum hydrocarbon contamination may affect plants by retarding seed germination and reducing height, stem girth, photosynthetic rate or resulting in complete mortality. In this review, relevance of crude oil in Nigeria and its environmental implication to the ecosystem was highlight.

Key words: Crude oil, Niger Delta, sustainable ecosystem, oil pollution, petroleum hydrocarbon contamination

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INTRODUCTION

The natural functioning of the environment provides both goods and services such as food and other products on which man depends upon for the continuity of life¹. The ecosystem stores large amount of carbon in both plants and soils and this regulates water flow and water quality and also assist in the stabilization of local climates². These services are not meant for financial value, but man nonetheless depends on them for survival¹.

Niger Delta environment is one of the world's largest wetlands and includes by far the largest mangrove forest in Africa³. It can be broken down into four ecological zones: coastal barrier islands, mangrove swamp forests, freshwater swamps and lowland rainforests⁴. In addition to support abundant flora and fauna, it contains arable terrain that can sustain a wide variety of crops, lumber or agricultural trees and more species of freshwater fish than any ecosystem in West Africa⁵.

This incredibly well-endowed ecosystem contains one of the highest concentrations of biodiversity on the planet¹. Its biological diversity is of global significance. The Niger Delta covers 20,000 km² within wetlands of 70,000 km² formed primarily by sediment deposition³. This floodplain is the home to 20 million people and 40 different ethnic groups and makes up 7.5% of Nigeria's total land mass⁶. It is the largest wetland and maintains the third-largest drainage basin in Africa⁶. Within this extremely valuable ecosystem, oil exploration and exploitation activities are widespread. The advent of oil as the world's leading fuel was partly due to its relative cleanliness but the enormous scale of the petroleum industry's operation has inevitably created a new set of difficult environmental problems as being experienced today in the Niger Delta region of Nigeria⁷⁻⁹. Among these environmental problems, crude oil pollution is becoming serious day by day. One of the biggest concerns associated with crude oil pollution in the environment is the risk to farmlands³ and fisheries and contamination of potable drinking water⁵, since most of the people's livelihood depends on farming, fishing and usage of water for their domestic purpose¹⁰.

Transportation of crude oil or its products from the point of production to that of processing has resulted in its spillage with adverse consequences. Oil blowouts have also occurred during extraction stage and when these happen, the oil empties itself either in the soil or water bodies while the volatile components escape to the atmosphere¹. When crude oil spills on land, it affects the soil in diverse ways. It is known that some crude oil components can directly affect soil organisms and other soil properties¹⁰.

Over the years, the utilization of crude oil and its refined products has been on the increase globally. As a result, concerted efforts are being made to understand its composition, structure and properties. This review attempted to bridge the dearth knowledge on the impact of the Nigeria crude oil production to the livelihood and environment as a whole, thereby elaborating on some of its components, the effects it has on the agricultural and health system of the country with a burgeoning population of about 170 million estimated to double by 2050. The objective of this review was to create a synergy between the environment, farming system and crude oil with the need of feasible policies implementation by government that will protect the health of all for a sustainable ecosystem.

PETROLEUM

Petroleum is defined as a substance generally liquid, occurring naturally in the earth and composed mainly of mixtures of chemical compounds of carbon and hydrogen with or without non-metallic elements such as sulphur, oxygen and nitrogen. The word petroleum comes from the Latin word, 'rock oil'¹¹. Petroleum according to World Resource Institute (WRI)¹² is referred to a mixture of naturally occurring hydrocarbons found beneath the earth's crust. This petroleum compounds occurs in various forms. They are called natural gas when occurring in the gaseous forms, crude oil when occurring in the liquid form and asphalt or tar associated with oil, sand and shale when occurring in the solid or semi-solid form Odu¹³. Petroleum products are made up of a number of complexities such as gaseous methane ranging from a molecular weight of 16-20,000 g mole⁻¹. According to Clark and Brown¹⁴, hydrocarbons are classified into three broad groups each with sub classes. They are:

- Aliphatic hydrocarbons
- Alicyclic hydrocarbons
- Aromatic hydrocarbons

Aliphatic hydrocarbons: They are also referred to as open chain compound and are categorized into two. If there is only a single bond between all adjacent carbon atoms, the molecules is said to be saturated. If the carbon atom has at least one double or triple bond, it is said to be unsaturated. Examples of saturated aliphatics are paraffins or alkenes and are chemically more stable than the unsaturated aliphatics. Naturally, the unsaturated aliphatics do not occur in crude oil but are produced during industrial photochemical refining or by processes after crude oil spill¹⁴.

Alicyclic hydrocarbons: These hydrocarbons are both saturated and unsaturated and have some or their entire carbon atom arranged in a ring structure¹⁴.

Aromatic hydrocarbons: These are hydrocarbon that contain at least six-carbon ring in their molecular structure. They have the following basic formula C_xH_x ring. Benzene is one of the many aromatic compounds present in petroleum and crude oil contributing to the octane rating of petrol. It is therefore; of economic importance to petrol-driven engines. Benzene is a clear, colorless and inflammable liquid¹.

CRUDE OIL

Crude oil is formed over millions of years deep under the ground from the remnants of forests and from a mixture of comparatively volatile liquid hydrocarbons (compounds composed mainly of hydrogen and carbon with some nitrogen, sulphur and oxygen) that occurs in the earth's crust¹¹. While it is a naturally occurring substance, it can be highly toxic and it burns fiercely¹⁵. Some of its products include: fuel oil, sludge and refined products such as petrol, diesel and kerosene¹.

Crude oil, described as the world's treasure¹⁵, is a vital resource which sustains and promotes economic growth of many nations, including Nigeria. Oil is used as fuel to run various types of engines of cars, planes, ships, tractors and trucks and is also used to generate a large portion of the world's electrical-power supply. It is customary used to identify two closely related compounds-natural gas (also known as methane) and oil. Both substances sometimes seep to the surface through cracks in the earth. Crude oil can be liquid or in form of asphalt, pitch, bitumen or tar⁸.

In Nigeria, oil has been reported by Adegeye *et al.*¹⁶ as the 'Life wire' of the Nigeria economy and is produced mainly in the Niger Delta region. Oil producing states in the region include: Awka-Ibom, Bayelsa, Delta, Edo, Imo, Ondo and Rivers States. The oil produced account for 90% of Nigeria's national income¹. Nigeria became an exporter of oil when production reached 6000 barrels per day¹⁷.

PHYSICAL PROPERTIES OF CRUDE OIL

Crude oil contains a wide range of hydrocarbon-based substances. Hydrocarbons are compounds composed of the elements; hydrogen and carbon. This included substances that are commonly thought of as oils, such as crude oil and refined petroleum products with each type of oil having a distinct

physical properties¹. These properties affected the way oil will spread and break down, the hazard it may pose to aquatic and human life and the likelihood that it will pose a threat to natural and man-made resources. The rate at which an oil spill spreads will determine its effect on the environment. Factors which affected the ability of an oil spill to spread include surface tension, specific gravity and viscosity¹⁸.

Surface tension: This is the measure of the attractive force between the surface molecules of a liquid. The force functions to keep the molecules or restrain them from escaping into the air. The higher the oil's surface tension, the more likely a spill will remain in place. If the surface tension of the oil is low, the oil will spread even without help from wind and water currents. Because increased temperatures can reduce a liquid's surface tension, oil is more likely to spread faster in warmer waters than in very cold waters.

Specific gravity: This is the density of a substance compared to the density of water. Since most oils are lighter than water, they float on top of it. However, the specific gravity of an oil spill can increase if the lighter substances within the oil evaporate. Heavier oils, vegetable oils and animal fats may sink and form tar balls or may interact with rocks or sediments on the bottom of the water body.

Viscosity: This is the measure of a liquid's resistance to flow. The higher the viscosity of the oil, the greater the tendency for the oil to stay in one place¹⁸.

CHEMICAL COMPOSITION OF CRUDE OIL

Crude oils vary widely in chemical composition depending on their sources. Crude oil from the same source may show variation in chemical composition as extraction progresses¹. Hydrocarbon is one of the major components of crude oil constituting mainly of hydrogen and carbons in various molecular arrangements. These include straight chain, branched and cyclic alkanes, aromatics and traces of alkanes. Other organic and inorganic component of crude oil includes sulphur, nitrogen and oxygen. Sulphur containing compounds including naphthenic acids, carboxylic acids, ketones, esters, xylols¹⁹ and phenols while nitrogen containing compounds including cycloalkyl thiols, alkyl thiols and sulphur-aromatics are all present. Crude oil also contains heavy metals such as iron, nickel, cobalt, copper, vanadium and nickel¹. They are collectively called heteroatoms. Udo and Fayemi¹⁹ reported that hydrocarbons have more carbon than nitrogen,

increasing the C:N ratio and noted that extractable phosphorus decreases with hydrocarbon addition. Micronutrients like magnesium and calcium increase with hydrocarbon addition²⁰.

Crude oils contain lighter fractions similar to gasoline, heavier tar or wax constituents and vary in constituents from a light volatile fluid to a semisolid. Odebunmi *et al.*²¹, however noted that, heavier crude oil produces higher fractions of kerosene, gas oil and other higher-boiling fractions. The Nigeria light crude oil contains higher percentage of naphthenic hydrocarbon and the Nigeria medium crude has a higher specific gravity and more of the boiling point residue¹³ with above 370°C.

USES OF CRUDE OIL

Life without petroleum and its products would have been difficult now that the world is yet to discover an alternative fuel lubricant. Lubricating oil lessens frictions, thus slowing the breakdown of machine components. Oil is used as fuel for planes, automobiles and heating systems. A lot of cosmetics, paints, inks, drugs, fertilizers and plastics as well as myriad of other items contain petroleum products.

POLLUTION

FEPA²² defined pollution as man-made or man-aided alteration of chemical, physical or biological quality of the environment to the extent of been detrimental to that environment or beyond acceptable limits. Pepper *et al.*²³, defined it as the addition of persistent toxic compounds, chemicals, salts, radioactive materials or disease causing agents which have adverse effects on plant growth and animal health. Similarly, it won't be out of place to define pollution generally as the change in the physical, chemical or biological characteristics of the air, land and water that can harmfully affect human life and desired plant species, industrial processes, living conditions and cultural assets.

Agbogidi²⁴ in a study observed that crude oil pollution is an inevitable consequence of oil exploration and exploitation activities both in oil producing and consuming areas due mainly to accidental discharge, human error, sabotage, transportation, natural causes, etc. Thus, it creates a negative effect on vegetation, both directly and indirectly. Nwilo²⁵ presented data to show that 50% of oil spills in Niger Delta is due to pipeline corrosion, 28% sabotage, 22% to oil production operations and engineering drills.

Oil pollution in the Niger Delta has been a major source of concern to the people living in the crude oil-rich-areas²⁶. Oil

spills adversely affect the nutrient level and fertility status of the soils, thereby affecting the growth of agricultural crops². In Nigeria, a substantial amount of crude oil is spilled annually. For example, Nwankwo²⁷ reported 2,000 oil spillages in Nigeria between 1976 and 1988. During this period about 2×10^6 barrels of crude oil were spilled into the environment. Al-Qahtani²⁸ stated that the crude oil contains a number of organic compounds removed as solid wastes from the oil refinery which can cause significant environmental instabilities.

On January 21, 2010, about 1,245 barrels of crude oil was spilled in Edo state following malfunctioning of the Nigerian National Petroleum Company equipment¹⁸. The spill allegedly destroyed about 169,231 farmlands. Spillage of crude oil on soil makes it unsatisfactory for plant growth as a result of insufficient aeration of the soil as air is displaced from the spaces between the soil particles by crude oil⁵. This affects the soil and its productivity in terms of the growth of crops. One of the environmental challenges posed by oil pollution is the alteration of the physical and chemical nature of the soils which subsequently affects the growth of plants²⁹. This alteration is achieved by many means including the reduction of the pH content of the soil. This affects the soil and its productivity in terms of the growth of plants.

Consequences of oil pollution: Due to the ineffectiveness of purification systems, wastewaters may become seriously dangerous; leading to the accumulation of toxic products in the receiving water bodies with potentially serious consequences on the ecosystem¹⁷. The environmental consequences of crude oil pollution on the inhabitants of Ologbo in Edo state are enormous. Crude oil pollution has degraded most agricultural lands in the area and has turned hitherto productive areas into wastelands. The increased soil infertility due to the destruction of soil micro-organisms and dwindling agricultural productivity, farmers have been forced to abandon their land to seek alternative means of livelihood which may be non-existent³⁰.

Soil acidity or alkalinity otherwise known as soil pH is a most crucial factor in determining the performance of soils with respect to plant growth¹. Besides controlling the degree of nutrient availability to plants, it also controls microbial environment necessary for optimum crop growth³¹. Considering this large quantity of crude oil going into the environment, especially farmlands and the fact that the inhabitants of these areas are subsistence farmers, there is an urgent need for the various agencies connected with oil production in Nigeria to pay more attention to the problem of oil spillage.

Sources of oil pollution: The known sources of environmental pollution from petroleum industrial operations worldwide include the following: transportation of petroleum products, operational discharge, oil well blow-outs, leakage of oil storage tanks and pipelines, refinery effluents discharged into the environment, natural oil seeps, industrial municipal wastes, urban and rural run off, biosynthesis, atmospheric fall out, dry docking, terminal loading and other accidental discharge of waste oil^{1,25-28}.

ENVIRONMENTAL IMPLICATION

Oil pollution on most agricultural lands have turned hitherto productive areas into wastelands with the alteration of physicochemical properties of the soil and dwindling agricultural productivity has led to redundancy in farming and fishing activities resulting in urban and rural migration, in oil producing area due to the attendant economic downturn^{30,31}.

Developing countries are faced with critical environmental problems arising from poor to non-existent environmental management plan. Some of these problems are caused by:

- Improper disposal of household refuse
- Open-air disposal of sewage waste forming sewage lagoon
- Flooding brought about by poorly designed drainage
- Desertification occasioned by massive deforestation leading to the destruction of water catchments areas and hence less rainfall
- Oil spillage in petroleum producing communities: This produces a twin problem of polluting the land, rivers and creeks, thus exterminating a considerable percentage of the aquatic faunal population
- Discharge of untreated industrial effluent including gases

Effect of oil pollution on soil: Environmental degradation of the oil-rich Niger Delta region has been wanton and continuous with dire health, social and economic consequences for the people^{1,25}. The emergence of oil as the world's leading fuel was partly due to its relative cleanliness but the enormous scale of the petroleum industry's operation has inevitably created a new set of difficult environmental problems as being experienced today in the Niger Delta region of Nigeria⁷⁻⁹. When crude oil spills on soil, its condition could become unsatisfactory for plant growth because of insufficient aeration as the air-filled pore space are reduced due to the hydrophobic layer of such soils⁹ and increased

demand for oxygen as a result of oil decomposing organisms^{8,31}. Crude oil pollution leads to the unavailability of mineral nutrients in soils and have been reported to cause such harmful effects as leaf chlorosis, necrosis, growth stunting in shoots and roots thereby leading to a reduction in biomass accumulation^{32,33}.

Abii and Nwosu² reported a significant decrease in the Ca, K, P, as well as a significant increase in the sand fraction and content of oil spill affected soils. Similar studies carried out by Khomehchiyan *et al.*³⁴ using sandy loam soil polluted with crude oil also confirmed pronounced changes on the physicochemical and the microstructure of the oil contaminated soil. Oil contamination of soil also limits normal diffusion processes thereby reducing the availability of nutrients in the soil to the plants³⁵. Russel³⁶ reported that soil saturated with natural gas could cause severe physical and chemical changes. These changes could result in the unavailability of nutrients to plants cultivated in soils polluted with crude oil causing many harmful effects.

Effect of oil pollution on plants: Many authors have demonstrated the phytotoxic effects of crude oil on crop, plants and tree species^{24,37-41}. These effects have been observed to occur due to interference with plants' uptake of nutrients and the unfavorable soil conditions created due to crude oil pollution. Chindah and Braide⁴² in a study on the effect of oil spill on crop production in the Niger Delta reported that oil spill on crops caused great damage to the plant community due to high retention time of oil occasioned by limited flow. The oil hampered proper soil aeration as oil film on the soil surface acts as a physical barrier between air and the soil. Thus, it affects the physicochemical properties of the soil such as temperature, soil structure, nutrient status and pH.

Gaseous pollutants such as sulphur dioxide and nitrous oxides enter the plant leaves through the stomata and affect the palisade and mesophyll cells causing leaf collapse, damage to the plastids and hence irreversible loss of photosynthetic capacity⁴³. It has been reported in this review that crude oil could penetrate into plants by moving within the intracellular spaces and possibly in the vascular system. Plants and soil microbes compete for the little nutrient available in soils polluted with crude oil thereby suppressing the growth of plants in such soils. Omosun *et al.*⁴⁴ reported that plants are highly susceptible to oil exposure and this may kill them within a few weeks to several months. According to Amakir and Onofegera⁴⁵, the effect of crude oil pollution depends on the type and amount of oil involved, soil type,

time of the year, the species and age of plants concerned. Odu¹³ reported that pollution effect on plants system are a function of exposure time of the pollutant, the manner of disposal and the innate genetic response of the plant system as modified by environmental influences. Plants grown in oil polluted environment are generally retarded with chlorosis of leaves coupled with dehydration of the plant⁴⁶.

Effects of crude oil on crop plants: Ebenezer *et al.*⁴⁷ showed the negative impact of oil spill on agricultural production. Some of these negative impacts include reduction in crop yield, pollution of rivers for fishing, land productivity and reduced farm income and standard of living of the people. Many researchers have studied the effects of crude oil on seed germination of crop plants^{23,45,46}. Achuba⁴⁸ studied the effect of crude oil contaminated soil at various sub lethal concentrations on the growth and metabolism of cowpea (*Vigna unguiculata*) seedlings showing that crude oil induced environmental stress in the seedlings, thereby hindering the productivity of the plant. Similar effect was also observed in soil contaminated with Bonny light whole crude or its fractions on the germination of beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.)⁴⁹. They reported that, dose dependent reduction in the number of bean or maize seeds that germinated in the contaminated soils compared with the control.

Ekpo and Nwankpa⁵⁰ contributed that, while soil polluted with 1% crude oil enhanced the sprouting of ginger (*Zingiber officinale*), 15% crude oil pollution completely suppressed the sprouting of ginger. Ekpo and Ebeagwu³³ also reported the increasing concern regarding guard against crude oil pollution of arable agricultural land in order to maintain the quest for sustainable agricultural productivity. In polluted soil, Asoque *et al.*⁵¹ reported that okra (*Abelmoschus esculentus*) and fluted pumpkin (*Telfairia occidentalis*) seeds showed a delayed germination in the 2 and 4% crude oil treated soils and a total inhibition of germination in the 8% crude oil treated soils. Lack of seed germination in crude oil has been severally associated with oil induced loss of vitality or with unfavorable soil condition⁴⁶.

However, the study of the accessions of *Glycine max* and *Lycopersicon esculentum* for germination, survival and growth by Njoku *et al.*⁵², also revealed that the different accessions of these crops have different levels of tolerance to crude oil polluted soil. Merckl *et al.*⁵³ reported the death of *C. mucunoides*, *C. brasilianum* and *S. capitata* six weeks after germination in the crude oil contaminated soil. According to Merckl *et al.*⁵³, the reason for the death of the plants after germination could be as a result of continual

exposure of the crops to crude oil in the soil. Also, Merckl *et al.*⁵³ reported that oil prevents perforation of water into the soil leading to limited moistening effect in the root area. This could also lead to death of the crops after germination as the germinated seedlings could have died as a result of the uptake of phytotoxic compounds present in the crude oil⁵⁴.

Effect of crude oil on photosynthesis: Photosynthesis in plants can also be affected directly through the alteration of cell membrane as a result of constant uptake of heavy metals into their system¹. The crude oil in soil creates an unsatisfactory condition for plant metabolism due to insufficient aeration brought about by an increase in oxygen demand by oil decomposing micro-organisms⁴⁶. Smit *et al.*³⁸ also reported stomata closure and decrease in leaf, stem and root dry weight in poorly aerated soils. This can be attributed to the decrease in plant dry weight and plant fresh weight as the crude oil concentrations increased. The yield of a crop is a complex trait affected by genetically controlled physiological components⁵⁵. Crude oil contamination of soil has been reported to cause reduction in the germination, growth performance and even yield of plants^{46,56,57,39}.

Studies have showed that oiled shoots of crops like pepper and tomatoes may wilt and die off due to blockage of stomata thereby inhibiting photosynthesis, transpiration and respiration⁴⁶. In fact, the germination, growth performance and yield of these crops were stifled by oil spillage³⁷. Dung *et al.*⁵⁸ explored the spatial variability effects of gas flaring on the growth and development of cassava, water leaf and pepper, which are crops commonly cultivated in the Niger Delta. Results showed retardation in crop development manifested in decreased dimensions of leaf lengths and width of cassava and pepper crops closer to the gas flare point.

Effects of heavy metals on plants: Madejon *et al.*⁵⁹ defined heavy metals as a member of a loosely defined subset of elements with densities of 5.0 g m⁻³ or greater. Some heavy metals are essential as micronutrients for plant growth and development. For instance, copper plays an important role in several plant metabolic processes. It activates enzymes by incorporating it into metalloenzymes of the electron transport system and is involved in protein synthesis, carbohydrate, nucleic acid and lipid metabolism¹. It forms complexes with DNA and RNA and affects the stability of these components. Vanadium was also found to stimulate growth in Lettuce and Asparagus at unusually high concentration of 27 ppm in Kuwait crude oil⁶⁰.

However, at excess amount, heavy metals have a pronounced effect on plants growth⁴⁶. Heavy metal accumulation in plants may lead to poor growth resulting in yield reduction. Lead and cadmium have been reported by Epstein⁶¹ to prevent mineral uptake by either synergistic or antagonistic reactions. Khan and Frankland⁶² studied the effect of cadmium and lead on the growth of radish, which resulted in the death of the plant within 3 weeks of contact when contaminated with 1000 μ Cd g⁻¹.

CONCLUSION

This review concluded that crude oil is a major source of energy that drives industrialization in the world especially Nigeria. However once spilled in the environment, it forms a hydrophobic layer which adversely affects soil properties by limiting availability of water and nutrients for crop productivity.

SIGNIFICANCE STATEMENT

This study discovered the environmental consequences of crude oil pollution to the Nigeria economy as the spill tend to degrade agricultural farming systems, microbial population and general health of the populace. The various component derived from the crude oil can be used in diversification by implementing policies that will be beneficial for the sustainable development, farming and adequate monitoring of crude oil drilling, processing and transportation in the Niger Delta region. This study will help the researchers, policy makers and farmers in bridging the antagonistic relations created by lack of communication and uncover the critical areas of interest for a sustainable economy for all. Thus a new theory on the evaluation of environmental impact assessment with experts, government agency, farmers and regions affected can be arrived.

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