Chapter

Environmental Evaluation and Biodegradability of Drilling Waste: A Case Study of Drill Cuttings from Ologbo Oilfield Wells at Edo State, Nigeria

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Abstract

Oil-laden drill cutting wastes have remained a serious environmental menace to well engineers and oil prospecting companies, due to unacceptability of oil-based muds to the environment as proscribed by the environmental guidelines. The problem of oil-containing drill cuttings can be better appreciated when viewed along the line that in Nigeria, about 3,900 billion barrel of drill cuttings are produced in a typical four thousand and fifty-four meter on shore drilling operation. Guidelines and standards of the regulatory authority in Nigeria, the Department of Petroleum Resources, forbid the discharge of drill cuttings into the environment without first ascertaining the nil or minimum impacts via carrying out Environmental Impact Assessment and Environment Evaluation Report studies. Biodegradation is the natural process whereby micro-organisms use up such substances as energy source, which are broken down into constituents such as fatty acids, carbon dioxide, and water. The biodegradation of oil pollutants is not a new concept; however, it is new as an increasingly effective and potentially inexpensive clean-up technology. Its potential contribution as countermeasure biotechnology for decontamination of oil-polluted ecosystems is enormous. Oil exploration industries should adopt biodegradation treatment procedures of their generated wastes before discharge into receiving environment.

Keywords: drill cuttings, biodegradation, guidelines, microorganisms, environment

1. Introduction

Drill cuttings are pieces of rocks that are generated when holes are drilled through the earth's crust to reach the oil and gas reservoir. Depending on the type of rock formation being drilled and the drilling rig being employed for the process, these small pieces of rocks can vary in size and texture, with particle size ranging from sand to gravel.

The environmental discharge of oil-laden drill cuttings have remained an unabated challenge to environmentalists and well engineers. This unabated challenge is majorly due to the presence of banned oil-based mud on the resultant drill cutting which cannot be discharged directly into the receiving environment without pre-treatment to meet the regulatory standards contained in the environmental guidelines for petroleum industries in Nigeria DPR [1] and other standards in the world.

Rotary drilling rigs are used throughout the world's oil regions, and its greatest advantage over other methods, such as the cable-tool drilling, is that the well bore is kept full of liquid (drill mud) during drilling. The composition of drill cuttings also includes a suspension of solids such as clays, barite, etc. in liquids (water or oil) with chemical additives to modify their properties [2]. According to DPR [1] and Odokuma and Ikpe [2], the chemical additives include bactericides, lubricants, thinner, dispersant and pH control additive.

According to Soegianto et al. [3], water-based muds are by far the most commonly used drill muds, both in onshore and offshore drilling operations. Water-based muds are widely used in shallow wells and often in shallower portions of deeper wells. Depending on the depth and diameter of the well, the use of water-based muds generate about 1400–2800 billion barrels (bbl) wastes, of that amount are drill cuttings [3]. Water-based muds are very economical and easy to dispose because of their biodegradability and low toxicity quality. Oil-based muds were developed and refined to overcome the limitation of water-based muds applications [3–5]. Oil-based muds have been observed to possess technological advantage in producing lower waste volume over water-based muds especially when drilling for oil and gas in adverse environmental situations such as including high temperature, hydratable shales, high angle and extended-reach well, high density mud and drill through to salt [3].

The problem of oil-containing drill cuttings can be better appreciated when viewed along the line that in Nigeria, about 3900 billion barrel (bbl) of drill cuttings amounting to 1482 million tones are produced in a typical 4054 m onshore drilling operation [6]. An average offshore well on the other hand generates approximately 1100 million tones of drill cuttings which, prior to being restricted by legislation, contained roughly 15% by weight of oil [6].

Generally, it is known that the accumulation of drill cuttings coated with drilling mud can have localised effects on the seabed and soil-dwelling microorganisms, due to its heavily laden suspended matter, oil and grease and heavy-metal concentration [5, 7–9]. According to [10] petroleum exploration in Nigeria began as far back as 1908, and in 1956, the first commercial oil discovery was made at Oloibiri in the onshore Niger Delta, and the production of the crude oil commenced in 1958. Seven years after, Chevron discovered the Okan field, the first commercial offshore field in 1963 [11]. Since that time, petroleum has played a progressively prominent role in the social and economic development of Nigeria. It is therefore not surprising that today, petroleum resources account for about 99% of the national economy.

The geophysicists and geologists have shown that the Niger Delta basin has spectacularly maintained a thick sedimentary apron and salient petroleum geological feature. This feature is favourable for petroleum generation, expulsion and trapping from the onshore through the continental shelf and to the deepwater terrains [12, 13]. According to Ekweozor and Daukoru [13], among the sedimentary basins in Nigeria, aggressive exploration has been concentrated in the Niger Delta basins, which is to date the most prolific and economic sedimentary basin considering the extent of petroleum accumulations, exploration as well as the spatial distribution of the resources on the onshore, continental shelf through deepwater terrains.

Ologbo community is one of the oil-producing communities in Edo State. It shares part of its boundaries with the Koko community in the Delta state. Thus, the inhabitants are both the Edo- and Urhobo-speaking people living mutually alongside with other ethnic groups such as Igbos, Ijaws and Itsekiris. Currently, Ologbo community houses flow stations and oil and gas wells belonging to the Nigerian Petroleum Development Corporation and Pan Ocean Petroleum Corporation. The people of this area are predominantly farmers and traders. The major crops cultivated are yam, maize and cassava.

Several researches, which include Odokuma and Okpokwasili [12, 14, 15], have reported that increased exploration and production activities as well as improper waste disposal practices in the locations of boreholes had continued to encourage the widespread contamination of the receiving environments which include aquatic and terrestrial ecological systems. The Niger Delta region in Nigeria plays host to well over 85% of these exploration and production activities. Hence, the severity of this threat caused by drilling wastes by itself cries out for urgent adequate remedial actions. Disposal of waste is usually in temporary pits awaiting final disposal or is in permanent disposal pits. Whichever the case, many a times overflows are witnessed into the surrounding arable land. These overflows carry along the full compliments of the toxic components of chemicals (some of which are toxic to even microorganisms) and oil [16].

Several research works have been carried out on the degradation of different organic compounds including all those present in the drill cuttings [17–19].

The ability of *Staphylococcus* sp. isolated from the soil to utilise an oil base and its potential for application in bioremediation process involving oil-based drilling muds have been demonstrated by Nweke and Okpokwasili [21]. The role of composition in the degradability and toxicity of drilling muds was examined, and the oil-based muds were observed to be relatively toxic to the ecosystems [2, 8]. Research has shown that drilling muds and its additives can be biodegraded by microorganisms [22] and their toxic effects can be either acute or chronic [2, 16, 19]. The effect of drilling chemicals on nitrate utilisation and logarithmic rate of growth of *Nitrobacter* was investigated by Okpokwasili and Odokuma [16], and the results showed that drilling chemicals inhibit an aspect of nitrification in the biosphere, thereby negatively affecting soil and water fertility. The biodegradation, mobility and photo toxicity of fuel oil hydrocarbons contained in drill cuttings were investigated in an agricultural soil and were found to modify the soil fertility [20]. Studies have also shown that oil spill dispersants and drilling fluids affect the ability of marine bacteria to metabolise substrates in the environment [23]. They were also observed to enhance the growth rate of *Bacillus* species and decrease that of *Staphylococcus* species with increasing concentrations of oil spill dispersants [24].

Researches have abundantly shown that naturally occurring microbial degradation mechanisms in the environment result in the biodestruction of toxic substances such as hydrocarbons [25, 26]. Microbial degradation often represents the most desirable form of attenuation because of the irreversible nature of the reaction. In the majority of cases, microbial degradation is a detoxifying mechanism, which leads to complete mineralisation [26]. Evidence from different investigations had suggested that microbial degradation of oil and petroleum in the environment is affected by limiting amounts of essential nutrients especially nitrate and phosphate salts [4, 26]. The limiting factors include restricted substrate assimilation capacity of the microbial population, presence of toxic substrate, optimal temperature and pH of the medium. These conditions greatly affect the rate at which the microbes function.

It had been observed that oil-based drill cuttings contain chromium (a pollutant heavy metal) at concentrations that could seriously threaten the life of edaphic systems, if it is continually injected into the ground without further remedial treatment measures [7]. The sorption of chromium by activated carbon from the flocculation effluent of liquid-phase oil-based drill cuttings (L-P-OBDC), which is heavily laden by oil/grease and suspended solids, had been investigated by Okparanma and Ayotamuno [9]. Toxicity and possible environmental impacts that may result from the indiscriminate disposal of drilling muds and cuttings derived from Ewan and Dibi offshore wells in the Niger Delta petroleum province of Nigeria had been studied by Adewole et al. [27]. Lethal and sublethal effects of the drilling-fluid XP-07 on the gill and liver morphology of *Tilapia guineensis* fry had been investigated in the laboratory using static bioassay for 96 h and 12 weeks exposure, respectively. At the end of 96 h, the gall and liver sections indicated minor lesions which were characterised by epithelial lifting and hyperplasia in gills, while irregularity in shape and size of the liver cell coupled with the presence of macrophages was observed in the liver [28].

2. Description of drill cuttings

Drill cuttings are the spoil which results from the exploration and production of well drilling activities and comprise small pieces of the strata through which the well is drilled. Together, they pass through the wellhead flow line into the primary shale shakers. The primary shale shakers are equipped with vibrating motor, and their vibrations make possible the filtration of drilling mud from drill cuttings through screen mesh on the shakers. The end-product of this filtration process is cutting with a much reduced drilling-fluid content. This system is placed downstream of the bell nipple, which is designed to minimise the contamination of cuttings due to mud, solids, caving and recirculated drill solids.

3. Types and compositions of drilling muds

The composition of drilling fluid depends upon the requirements of the particular drilling operation. The holes must be drilled through different types of formation requiring different types of drilling fluids. Economics, fluid contamination, available makeup water, pressure, temperature and many other factors are significant in the choice of drilling fluids [29]. A drilling fluid may be composed only of air. For example, one may decide to use air for drilling a hard rock of mountain size. Also water alone may be used to drill stable consolidated areas. However, in some areas, drilling can be started with water and the drilled solids incorporated into the water resulting in reasonably good mud. Generally, the functions to be performed require many properties, which cannot be obtained from ordinary liquid alone. Consequently, it may be necessary to add commercial clay to the water prior to drilling operations. Clay may also be added to oil to produce oil-based drilling mud. Both water and oil-based drilling muds are used in drilling oil wells.

Drilling muds are suspensions of solids (e.g. clay, barite, small cuttings) in liquid emulsions with chemical additives as required to modify their properties UKOOA [5]. Numerous chemical products are used daily in oilfield operations. The type and volume of chemicals vary depending on the type of production [6, 29]. Exploration and production operations generate chemicals such as crude oil, condensate, natural gas, hydrogen sulphide, carbon dioxide, heavy metals, brine salts and solid cuttings. These substances alongside with used muds and additives constitute what is called drilling wastes.

Drilling requires drilling mud to lubricate the drill bit, carry drill cuttings (rock chippings drilled from the reservoir formation) to the surface and control the downhole formation pressure of reservoir fluids. Water-based mud consists of natural clays and additives (organic or inorganic) to achieve proper density, viscosity and lubrication characteristic. Additives of particular concern from a pollution viewpoint are ferrochrome lignosulphonate (chromium pollution) and lead compounds (lead pollution). Oil-based muds contain oxidised asphalt, organic acid, alkali, stabilising agents and low toxic oil. Clay solids and weighing agents can also be added. Oil-emulsion muds are also used either as oil-in-water or water-in-oil varieties DPR [1]. Drilling muds contain heavy metals, either present in the mud for specific function (e.g. barium, chromium, zinc) or as impurities in natural mud additives (clay minerals and barite); such impurities include arsenic, copper, nickel and lead. Drilling mud also acquire heavy metal from the rock minerals in the drill cuttings and formation water [7]. These metals not only give rise to deterioration in environmental quality but also are potentially toxic to terrestrial plants [9]. The main sources of these elements are the two major solid components of drilling muds, which are barite and clays. Barium sulphate is the major constituent (80–90%) of barite, a weighting agent used to increase mud density. The amount of barite used depends on the drilling depth and the downhole condition and can be as high as 0.2 g barium per gramme of mud.

Several other potentially toxic metals such as cadmium and mercury are also present as impurities. Clay minerals like bentonite are added to water-based muds to enhance viscosity and suspension of properties. These clay minerals also act as fluid loss controllers. They constitute the second most abundant solid materials in water-based muds. Since clays are naturally occurring, their compositions largely depend on their geological source. Clay minerals also vary significantly in their potential for absorbing positively charged species DPR [1].

Drilling muds may also contain chromium in a variety of chemical forms. It is mostly complexed with lignosulphonate material as the hexavalent cation and accounts typically for 3–4% by weight of lignosulphonate complex. Lignosulphonates control viscosity in water-based muds by acting as thinning agents or deflocculants for clay particles. Calcium and iron compounds combine with chromium to form common ferrochrome lignosulphonates.

One of the major components of oil-based mud is the base oil. Mineral oil used in drilling muds is mixtures of alkanes, alkenes, cycloalkanes and aromatic hydrocarbons produced by petroleum refining DPR [1]. Diesel oil and lower toxicity base oil are produced initially from the kerosene and light gas oil fractions of crude oil. The aromatic content of diesel oil is usually in the range of 20–30%. Lower toxicity base oils are produced by further treatment by base stocks and are usually clear or slightly yellow with little odour. They normally consist of a narrow distillation cut of midrange aliphatic materials with an aromatic carbon content of 1–10%, although some are blended for certain application.

Diesel oil was used in the initial oil-based mud formulations, but they were found to be toxic on a wide range of microorganisms. Due to the higher concentration of the potentially toxic materials (2-, 3- and 4-ring aromatics) in diesel, a large number of highly refined mineral oils with a much smaller percentage of aromatic compounds than diesel subsequently became an alternative. This lower toxicity or alternative base oil is a mixture of alkane or cycloalkanes, and they are referred to as the synthetic-based muds.

Synthetic-based muds are classified according to molecular structure of the synthetic-based fluids which can be esters, ethers, etc. They have drilling and operational properties similar to oil-based muds but have the advantage of being more environmentally friendly. However, environmental monitoring of sites where cuttings from synthetic-based mud drilled well was discharged to the sea indicated that the majority of synthetic mud system fluids were in fact not as biodegradable in the marine environment as the laboratory tests had indicated UKOOA [5].

Regardless of the type of complexity of the drilling fluid or mud, nine basic functions stand out glaringly for consideration. These are to remove drilled cuttings from the hole; control subsurface pressure; cool and lubricate the bit and drilling stem; minimise washout and damage to well bore; suspend cuttings, weight materials and others solids when circulation is stopped; and help support the weight of drill stem and casing.

4. Guidelines and standards of the regulatory authority

Drilling wastes, as described in the guidelines and standards of the regulatory authority in Nigeria, the Department of Petroleum Resources, are forbidden pretreatment discharge into the environment without first ascertaining the nil or minimum impacts via carrying out the environmental impact assessment and environment evaluation report studies.

Even though the vast majority of exploration and production wastes and contaminated soil are not hazardous, the public and regulators alike have expressed concern regarding the environmental impact of exploration and production wastes on the environment DPR [1].

Specific chemicals considered hazardous to the environment and whose presence and level must be ascertained prior to disposal of drilling wastes include sulphur (iv) oxide, hydrogen tetraoxosulphate (vi) acid, hydrogen sulphide, ammonia, chloride, formaldehyde, hydrogen fluoride, crude oil (both on its own and as drill cuttings) natural gas, fuel oil, condensate, calcium hydroxide, hydrochloric acid, amines, propane, ethylene, glycol, methanol and heavy metals (zinc, chromium, cadmium, etc.). In addition to these possible hazardous drilling waste constituents, some whole field chemicals also contain hazardous constituents. These whole chemicals include oil-based mud additives, solvents, fuels, herbicides, biocides, emulsion breakers, corrosion inhibitors, deflocculants, defoamers, scale inhibitors, pH buffers, cement additives and weighting materials [29].

5. Modes of toxicity

As a consequence of the high demand for rapid, inexpensive and relatively simple screening tests for evaluating the acute toxicity of chemicals in the environment, the need for the knowledge of the mechanisms of toxicity received increasing attention. Chemical agents, toxic to microbial population, act by either inhibition or destruction of cellular components vital to cell functions.

Exposures of organisms to heavy metals result in the occurrence of a variety of abnormalities such as interference with cell wall synthesis, decreased enzyme activity and inactivation of DNA and RNA [30]. Other agents responsible for membrane disruption include quaternary ammonium compounds. These compounds also inhibit bacterial oxidase and dehydrogenase systems causing protein denaturation and enzyme suppression [31].

6. Test organisms

The prime considerations in selecting test organisms for toxicity bioassay are their sensitivity to the factors under consideration; their geographical distribution, abundance and availability within a practical size range throughout the year; their recreational, economic and ecological importance; the availability of culture methods for rearing them in the laboratory and a knowledge of their requirements; and their general physical conditions and freedom from parasites and diseases APHA [32]. Macro-organisms like fish, rats, snails, crabs and prawns are used in toxicity test because of certain feature they possess. These include easy to rear, visible to sight, count, notice and detect, cheap to procure.

However, the advantages of bacteria over macro-organisms include the fact that bacteria take less time to grow, multiply into millions within a short period so that the process of getting bacteria for biomonitoring is simple, sensitive, rapid and inexpensive. The use of microorganisms in bioassays is based on cell lysis and the inhibition of physiological processes such as respiration [33].

7. Biodegradation

Biodegradation has been defined as the gradual breakdown of a compound to its constituents by microorganisms. In other words, it is the natural process whereby microorganisms use up such substances as energy source, which are broken down into other similar substances such as fatty acids, carbon dioxide and water, thereby multiplying in number in the process [34, 35]. The microbial utilisation of wastes is based primarily on the natural degradative capabilities of microorganisms. These capabilities are derived from the metabolic diversity of both bacteria and fungi, which evolved from their role in the biochemical cycling of organic and inorganic compounds in the environment. The presence of hydrocarbons in the environment selects hydrocarbon-utilising microorganisms within the total heterotrophic population [26, 36], irrespective of whether they are contaminated or not. Indeed, all available evidences suggest that hydrocarbon utilisation at contaminated sites proceeds naturally.

Biodegradation often represents the most desirable form of detoxification because of the irreversible nature of the reaction [15]. For the natural cleansing of hydrocarbon in the environment (soil/water), microorganisms are considered to play the major role. Oil-utilising microorganisms have been reported to include Gram-positive and Gram-negative organisms, and notable genera include *Pseudomonas*, *Alcaligenes*, *Rhodococcus*, *Acinetobacter*, *Arthrobacter* and *Corynebacterium* [35]. Odjadjare et al. [34] had earlier reported that for biodegradation process to be considered an acceptable remediation option, there must be evidence that the microorganisms were responsible for the degradation of organic contaminant. These evidences may include stepwise growth patterns of elevation, biomass concentration and metabolic changes over time.

Abiotic factors have been observed to influence both the weathering and degradation of petroleum spilled in the environment. Atlas [37] observed that after the removal of low-to-medium weight molecules by artificial weathering, weathered light oils were biodegraded by bacteria at a higher rate and to a greater extent than weathered heavy oils and fresh oils. Crude oils therefore contain some factors that are toxic to microorganisms. The complex high-molecular-weight compounds of heavy oils may also be resistant to degradation. Okpokwasili and Okorie [38] assessed the biodegradability of used and unused lubricating oil using mixed culture of bacteria isolated from used oil. Total viable counts and analysis by chromatography confirm that used oil has been modified in service and is more degradable than unused oil.

The susceptibility of petroleum hydrocarbons to utilisation is also determined by the structure, configuration and molecular weight of the hydrocarbon molecule [36, 37]. Despite the abundance of hydrocarbon-degrading microorganisms, the successful degradation of hydrocarbons requires optimization of environmental conditions (nutrients, temperature and pH). Suitable growth temperature and available supplies of fixed forms of nitrogen, phosphorus and molecular oxygen are required so that bioremediation occurs at the maximum rate and to the greatest possible extent. Atlas [37] reported that inoculation of polluted areas with oil-decomposing microorganisms was ineffective because of growth-limiting nitrogen and phosphorus concentrations in sea water.

There have been several reports showing that biodegradation of hydrocarbons that have low solubility or that may be absorbed by soil particles can be enhanced by the addition of biosurfactants [39]. Biosurfactants increase the availability of hydrocarbons by increasing hydrocarbon solubility and desorption. It also influences surface properties of degrading cells, resulting in enhanced hydrocarbon utilisation. Bioremediation has actually become an accepted technology for restoration of contaminated environments. However, successful applications have primarily involved degradable organics. Bioremediation is used infrequently with more recalcitrant pollutants, often because microorganisms indigenous to contaminated environments lack appropriate degradative capabilities [35]. In these cases, it may be possible to enhance bioremediation by adding microorganisms that have catabolic functions to degrade polluted site [40]. This process is referred to as bio-augmentation. Augmentation of the natural microbial population is by genetic engineering process and is an active area of research for recalcitrant contaminants and other commercial products.

It had been observed that pure cultures of individual species have only limited substrate range and are of little help in consuming the complex hydrocarbon mixtures found in crude oil [41]. Most effort in oil spill clean-up by microbial seeding has been directed towards the use of mixed culture, such that the individual species of the consortium would have the ability to consume either aliphatic, aromatic or polynuclear aromatic hydrocarbons [42, 43]. During the growth of mixed culture, interactions such as the production by one strain of organisms, toxic compounds that are inhibitory to others and the differences in growth rates among species can limit the number of surviving organisms. An ideal solution for rapid microbial consumption of crude oil for the rapid removal of oil slick will be to construct novel strains, which would have the genetic potentialities to degrade simultaneously, a variety of oil components.

Recombinant DNA technology, however, permits the incorporation of the diverse types of genetic information extracted from several organisms into a single organism [37]. Through genetic engineering a “super bug” has been created that is capable of degrading many different hydrocarbons structures and that is potentially useful in oil pollution abatement programme [37].

The biodegradation of oil pollutants is not a new concept. It has, however, taken a new significance as an increasingly effective and potentially inexpensive clean-up technology. Its potential contribution as countermeasure biotechnology for decontamination of oil-polluted ecosystems is enormous. The successful treatment of spilled oil requires both a proven microbial population and well-engineered support systems that optimise the microbes’ inherent favourable characteristics while providing needed protection against the catalysts.

8. Drill cutting management

The exploration and production industries continue to be faced with the challenges associated with discovering and economically recovering new oil and gas reserves. Explorations of new fields, as well as the exploitation of existing fields, require well drilling operations, along with the continuous task of reducing drilling programme cost intelligent and environmentally prudent disposal solutions for the associated drilling fluids and cuttings. Drilling waste management is, therefore, the planning and implementation of a cautious waste collection, treatment and disposal plan. Within the planning, detailed analysis of the treatment and disposal options are performed.

The disposal options listed below are typically used:

Injection: In the injection process, the cuttings are converted into slurry, which is then pumped into a receiving formation at pressures exceeding the fracture gradient.

Offshore discharge: Depending on local regulations, cuttings with low environmental risk can be disposed into the sea. However, most local regulations require relative levels pretreatment of waste to reduce the concentration of oil-on-cuttings to <6.9% on a wet weight basis.

Solidification: This is considered as a nontreatment option. The waste is mixed with a material (activated lime, kiln dust, fly ash, cement, etc.) to form a solid product that immobilised potential contaminants.

Waste-soil mixtures: Waste-soil mixtures are considered a nontreatment option. It consists of mixing the waste with soil or subsoil to decrease the concentration of the potential contaminants. The chemical proportion of the waste is adjusted to meet regulatory standards.

Thermal desorption: This process is a separation and recovery process that is achieve by the application of heat which results in three streams of water, oil and solids. The vapours are cooled and separated into water and oil phases. The recirculating processes usually include a water phase which is used to cool and return moisture to the solid stream, the oil phase is recovered and used as a drilling-fluid system or fuel source, and the solids could be disposed of or reused.

Bioreactor: This process involves the application of indigenous topsoil bacteria and fungi with the ability to utilise the base oil as a primary source of carbon. The rate of biodegradation of the cuttings will be faster if properly mixed with water, oxygen and appropriate nutrients. In a bioreactor system, factors that should be properly monitored are aeration, mixing, nutrients and bacterial colony strength.

Land farming: In this technique, the cuttings are applied to a soil surface and ploughed to ensure adequate mixing and aeration. The rate of degradation is controlled by using the correct levels of nutrients, soil moisture and air.

9. Physicochemical qualities of drill cuttings collected from Ologbo oilfield wells

The physicochemical characteristics of drill cuttings collected from Ologbo oilfield wells are shown in **Table 1**. The pH ranges from 5.2 to 5.9, the electrical conductivity ranges from 220.0 to 309.0 μS, the oil and grease range from 38.0 to 309.0 mg/kg, and the total hydrocarbon content was 33.5–79.1 mg/kg. The variations in the parameter values obtained in this study clearly attest to the different characteristics of the drill cutting profiles from oil and gas wells. This evaluation had further buttressed the fact that drill cuttings are usually laden with high concentrations of oil and grease, especially when oil-based or synthetic-based muds are used in the drilling process. At these high concentrations, discharge of drill cuttings into the environment without pretreatment can have adverse effects on the edaphic systems and on groundwater if it permeates through the aquifer and also as runoff into water bodies [2].

		Cutting depth (m)			Acceptable limits
		0–305	610–915	Composite	DPR
Location 1	pH	5.2	5.2	5.2	6.5–9.0
	Electrical conductivity (μS/cm)	231.0	309.0	274.0	8 mm hos/cm
	Oil and grease (mg/kg)	38.0	125.0	175.5	100 mg/kg
	Total hydrocarbon content (mg/kg)	37.6	57.1	59.0	10 mg/kg
Location 2	pH	5.8	5.3	5.3	6.5–9.0
	Electrical conductivity (μS/cm)	220.0	278.0	253.0	8 mm hos/cm
	Oil and grease (mg/kg)	40.0	252.0	258.0	100 mg/kg
	Total hydrocarbon content (mg/kg)	33.5	43.4	47.2	10 mg/kg
Location 3	pH	5.3	5.9	5.8	6.5–9.0
	Electrical conductivity (μS/cm)	222.0	262.0	279.0	8 mm hos/cm
	Oil and grease (mg/kg)	48.0	289.1	309.0	100 mg/kg
	Total hydrocarbon content (mg/kg)	52.5	78.0	79.1	10 mg/kg

Over all mean value source: DPR [1], Imarhiagbe [44].

Table 1.
Some physicochemical parameters of drill cuttings from Ologbo oilfield wells.

10. Heavy-metal qualities of drill cuttings collected from Ologbo oilfield wells

Several studies have shown that waste drill cuttings harbour levels of heavy metals (Veritas (2000), [6, 45]). Study by Imarhiagbe [44] revealed that drill cutting

		Cutting depth (m)			Standards
		0–305	610–915	Composite	DPR
Location 1	Pb	2.6	1.2	1.5	0.0
	Fe	4.4	2.7	2.2	0.3
	Zn	0.8	2.0	1.5	5.0
	Ni	1.9	1.5	1.7	0.0
	Cu	0.0	0.0	0.0	1.3
	Cr	0.0	0.0	0.0	0.1
Location 2	Pb	0.8	0.9	0.7	0.0
	Fe	2.4	2.0	2.0	0.3
	Zn	2.1	1.7	2.0	5.0
	Ni	1.2	1.0	1.2	0.0
	Cu	0.0	0.0	0.0	1.3
	Cr	0.0	0.0	0.0	0.1

		Cutting depth (m)			Standards
		0–305	**610–915**	**Composite**	**DPR**
Location 3	Pb	0.5	0.5	0.5	0.0
	Fe	3.8	3.3	2.9	0.3
	Zn	0.0	0.2	0.0	5.0
	Ni	0.8	1.2	1.2	0.0
	Cu	0.0	0.0	0.0	1.3
	Cr	0.0	0.0	0.0	0.1

Over all mean value source: DPR [1], Imarhiagbe, [44].

Table 2.
Levels of heavy metals of drill cuttings from Ologbo oilfield wells.

samples from Ologbo oilfield wells contained high concentrations of iron compared to other heavy metals such as lead, zinc, nickel, copper and chromium (**Table 2**). However, the levels of heavy metals were less than the permissible limits as set by the Department of Petroleum Resources, which is the Nigeria government regulator of the oil and gas sector [1]. The presence of these toxic heavy metals may play an inhibitory role in the pollutant's biodegradation through the interaction with microbial enzymes [46]. Therefore, preventing heavy-metal pollution is very critical, considering the difficulty and cost of cleaning contaminated environment [47].

11. Microbiological qualities of drill cuttings collected from Ologbo oilfield wells

The order of microbial population density of composite cutting samples from oilfield wells ranges from 10 to 10^5 cfu/g for total heterotrophic bacterial counts,

			Cutting depth (m)		
			0–305	**610–915**	**Composite**
Location 1	Total heterotrophic bacterial counts		7.2×10^3	1.1×10	7.23×10^5
	Total heterotrophic fungal counts		3.0×10^3	0.0	3.3×10^3
	Total heterotrophic anaerobic bacterial counts		1.7×10^2	5.3×10^3	5.7×10^3
	Total mud utilizing Bacterial count	WBM	5.0×10	2.5×10	7.7×10
		NABM	2.0×10	0.0	3.2×10
	Total mud utilizing fungal count	WBM	2.8×10	1.0×10	0.0
		NABM	1.3×10	0.0	0.0
Location 2	Total heterotrophic bacterial counts		5.4×10^3	0.0	5.4×10^5
	Total heterotrophic fungal counts		2.7×10^3	0.0	3.7×10^5
	Total heterotrophic anaerobic bacterial counts		1.5×10^2	2.7×10^3	4.4×10^3
	Total mud utilizing bacterial count	WBM	4.2×10	2.0×10	6.5×10
		NABM	1.8×10	1.0×10	4.0×10
	Total mud utilizing fungal count	WBM	2.3×10	1.1×10	0.0
		NABM	1.1×10	0.0	0.0

			Cutting depth (m)		
			0–305	**610–915**	**Composite**
Location 3	Total heterotrophic bacterial counts		2.8×10^3	0.0	4.0×10^5
	Total heterotrophic fungal counts		2.1×10^3	0.0	2.5×10^5
	Total heterotrophic anaerobic bacterial counts		1.5×10^2	4.1×10^3	3.8×10^3
	Total mud utilizing bacterial count	WBM	4.5×10	0.0	6.0×10
		NABM	2.2×10	0.0	2.5×10
	Total mud utilizing fungal count	WBM	1.3×10	0.0	0.0
		NABM	1.0×10	0.0	0.0

Over all mean values; WBM, water-based mud; NABM, nonaqueous-based mud. Source: [44].

Table 3.
Mean total heterotrophic microorganism counts (cfu/g) of drill cuttings from Ologbo oilfield wells.

Bacterial isolates	**Fungal isolates**
Enterobacter spp.	*Aspergillus niger*
Micrococcus spp.	*Aspergillus clavatus*
Bacillus spp.	*Rhizopus nigricans*
Staphylococcus spp.	*Penicillium expansum*
Clostridium spp.	*Penicillium glaucus*
Mycobacterium spp.	*Cladosporium* spp.
Desulfotomaculum spp.	
Nocardia spp.	
Citrobacter freundii	

Source: [44].

Table 4.
Microorganisms isolated from drill cuttings collected from Ologbo oilfield wells.

total heterotrophic fungal counts, total heterotrophic anaerobic bacterial counts and total utilising bacterial counts, respectively (**Table 3**).

Microorganisms associated with drill cuttings from Ologbo oilfield wells are stated in **Table 4**. Gram-positive bacteria such as *Clostridium* spp., *Mycobacterium* spp., *Bacillus* spp., *Staphylococcus* spp., *Nocardia* spp. and *Micrococcus* spp. were the predominant bacterial isolates. The Gram-negative bacterial isolates were *Desulfotomaculum* spp., *Citrobacter freundii* and *Enterobacter* spp. The predominant fungal isolates were *Cladosporium* spp., *Penicillium glaucus*, *Penicillium expansum*, *Rhizopus nigricans*, *Aspergillus clavatus* and *Aspergillus niger*.

12. Conclusion

In conclusion, it was quite clear that drill cuttings emanating from these oilfield locations were unsafe for disposal, and the regulating agency in Nigeria needs to enforce treatment prior to disposal; otherwise appropriate sanctions should be applied.

Recommendations from the study of drill cuttings from Ologbo oilfield wells:

I. It is therefore recommended that oil exploration industries should adhere strictly to the procedures and instructions described for waste management in oil drilling exploration and procedure waste management in Nigeria.

II. The ban on the use of toxic oil-based mud by oil exploration companies in Nigeria and globally should be properly monitored and enforced by appropriate regulatory agencies.

III. It is therefore recommended that wastes resulting from oil activities should be properly treated before it is disposed into the receiving environment.

IV. The new trend is that waste materials from the oil industries should be seen as raw materials for reuse. If solid wastes are properly treated, it can serve as raw materials for cement-producing plants, bricks and expanded clay-producing plants and can also be used in land restoration projects. Appropriate application of these technologies can help in the creation of jobs for the teeming youths where these projects are sited.

V. In furtherance to enforcement, disposal of cuttings and drilling wastes into the onshore environment should be totally discouraged and litigated. This act had observed to have significant adverse effect on the aquatic ecosystem.

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