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Mud rotary drilling in Southern Nigeria: Potential adverse effects of its by-products on the environment

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Boreholes are the major sources of potable water for households, communities, institutions and industries in Nigeria and the number of these boreholes continues to rise and does not show any sign of abatement. Among the current methods used for drilling boreholes, mud rotary drilling has been consistently chosen due to its low cost and efficient operation. However, no attempt has been made to assess the effects of the drilling process and the potential impact of its by-products on the environment. This work assesses the concentrations of heavy metal constituents of mud effluent collected from five well sites made of mud rotary drilling (Oraeri community in Anambra State, Yenegoa in Bayelsa State, Forcados Island in Delta State, Ohaji Egbema in Imo State, and Ndoni LGA in Rivers State) in Southern Nigeria and the impact of its by-products where they are indiscriminately disposed during and after drilling activities. The Mud effluent collected from all the sites were analyzed for metals (Manganese, copper, lead, nickel, zinc, chromium, arsenic, mercury, and iron) using atomic absorption spectrophotometery (AAS) method. The mud effluents from the wells in all the sites have concentrations in the range of Manganese (114 to 314 mg/kg), Copper (73 to 96 mg/kg), Lead (16 to 36 mg/kg), Nickel (36 to 70 mg/kg), Zinc (4 to 79.51 mg/kg), Chromium (320 to 423 mg/kg), Arsenic (2 to 3.2 mg/kg), Mercury (Trace to 2.93 mg/kg) and Iron (14 to 229.3 mg/kg) in that order. The study also highlights the possible methods of managing the drilling mud effluent and the best practices for disposing the waste materials.

Key words: Drilling process, drilling fluids, boreholes, drilling by-products, impact assessment.

INTRODUCTION

In recent times, water provision, both in quality and quantity, has been a major challenge globally. It is estimated that about 900 million people worldwide do not have access to potable water supply. Of these, 84% live in developing nations (WHO/UNICEF, 2010). Although the world as a whole is making progress towards achieving the Millennium Development Goal (MDG) target to “halve by 2015 the proportion of the population without sustainable access to safe drinking water”, the majority of countries lagging behind the MDG for drinking water are in sub-Saharan Africa (UNESCO, 2009). In addition, only 19 out of 50 countries in this region are on track to meet the target by 2015 (UNICEF/WHO, 2012). Adekile and Olabode (2008) have estimated that, to meet the year 2015 MDGs and national goals, 15,000 boreholes need to be drilled annually. In a paper titled “water is life”, Oloyede (2010) affirmed that the government needs to sink 77,500 boreholes in Nigeria to meet the domestic water demand. Fortunately for these assertions, it is good to know that groundwater is almost everywhere in nature and can be developed relatively cheaply and progressively to meet the demand (RWSN, 2010).

Currently, in the southern part of Nigeria, improved

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groundwater supplies provide a significant proportion of the population with access to safe water. The choice of drilling a productive borehole happens to be the most cost-effective and efficient method of providing potable water for households, communities, institutions and industries in the country. There is a range of borehole construction techniques available and the method used must take into consideration the available equipment, affordability, personnel skills, and geology. Among the four major methods employed in drilling boreholes, namely auger drilling, percussion or hammer drilling, mud rotary drilling and cable tool drilling (Stewart et al., 2010), mud rotary drilling has been chosen as the most consistent method because of its affordability. It is not the only way to sink a hole in the ground, but it is undoubtedly the most common, versatile and dependable method (Stewart et al., 2010).

For most of its operation, the water well drilling industry in Nigeria has embraced a drilling fluid of choice consisting of locally produced bentonite, and it is currently the largest consumer of this material in the country. The drilling fluid is a combination of several materials, which include bentonite, caustic soda, polyanionic cellulose and other additives used in achieving the desired workability. There is, however, no standard regulation guarding the quality of bentonite. Moreover, the effects of this process and the impact of its by-products on the environment have not been assessed. The development of boreholes is continuously on the rise and does not currently show any sign of abating. This poses a challenge to all in the industry. This challenge is not just to contractors to meet demands and to governments to supply funds, but also to environmental monitors. It is important that the activities of borehole drilling are not left unchecked and unregulated. A consistent failure to monitor the operators and their operations may, in time, lead to a massive environmental disaster which will be expensive to remediate. This work assesses the concentrations of heavy metal constituents of the drilling mud effluents and their possible impacts on the environments where they are indiscriminately disposed during and after drilling activities.

Mud rotary drilling technology

The mud rotary method of drilling is a process in which a hole is drilled into the ground by rotating a drill stem with a bit attached to its end. As the bit is rotated, it loosens and removes rock chips and cuttings. Simultaneously, a circulating fluid is forced down the inside of the drill pipe and forced out through ports in the bit. There the fluid picks up the cuttings and flushes them out of the hole through the space or annulus between the drill pipe and the hole wall (Papp, 2001; Sadiq et al., 2003; Khodja, 2008; Adewole et al., 2010). If water is used as the circulating fluid, it flows from the annulus to a settling pit, where the cuttings are removed from the fluid, and then to a storage pit where the fluid is picked up at the pump suction and re-circulated. A drill stem consists of a bit, drill collars, stabilizers, and a drill pipe. Bit selection depends on the anticipated formations to be encountered and on the high strata of hard clay identified in the geophysical survey. Figure 1 shows an example of the assemblage of the rotary drilling rig.

The 8½” Mill claw bit and the Gardner Denver 2500+ Deep Well Drilling Rig were employed for the projects that are the objects of this study. A total of four Johnson stainless steel screens, with a combined length of 40 ft, were welded to the top of the bottom bunk and introduced into the well. The screens employed in each project were ISO certified, with a loading capacity of 100 psi. Casing pipes of diameter $9^5/_8$” were used at the completion of each stage of the project. The casing pipes were ISO 9001 certified and passed all the necessary inspections. A total length of 642 ft of $9^5/_8$” diameter pipes were installed into the well. The pipes were screwed in order to maintain a truly vertical position for the pipes. The casing pipe was made to protrude about 2½ ft above ground level. This was done in order to provide enough room for fixtures (valves, flow meters, etc.) to be attached to the borehole. A concrete base of about 1 m^2 was placed around the well head to provide the necessary support/stabilization for the well assembly.

Components of drilling fluid

The drilling fluid is the most abundant waste material produced after the completion of any drilling exercise. Borehole stability remains the main problem during drilling and the selection of drilling fluid type and composition has being at the origin of successful drilling. Khodja et al. (2010b) have stated that a drilling fluid must generally comply with three important requirements: they must be easy to use, not too expensive, and environmentally friendly. The fluid of choice for most drilling operations is the drilling mud (Papp, 2001). This is preferred due to its viscous nature, versatility and ease of handling. Drilling fluids are used basically to provide hydrostatic pressure in order to prevent formation fluids from entering into the well bore, cooling and lubricating the drill bit and rods (Gonzalez et al., 2011). Their other functions include the extrusion of drill cuttings and the suspension of drill cuttings when there is a purse in drilling and when the drilling assembly is brought in or out of the hole in order to drop them in surface disposal areas (Khodja, 2008; Khodja et al., 2010a, b). The additional functions of the fluid include (i) improving sample recovery; (ii) controlling formation pressures; (iii) minimizing drilling fluid losses into the formation; (iv) protecting the soil strata of interest; (iv) facilitating the freedom of movement of the drill string and casing, and

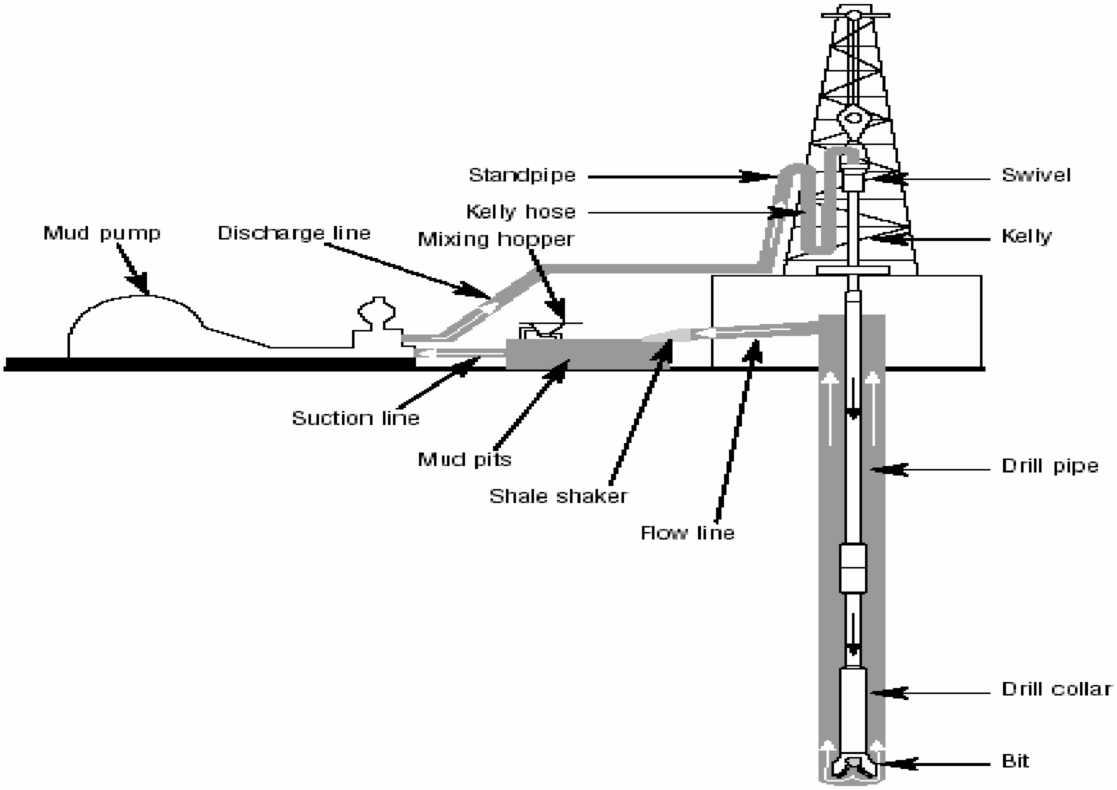

Figure 1. Diagram of a rotary drill rig (Source: Khodja et al., 2010.)

(vi) reducing wear and corrosion of the drilling equipment. Air and water generally satisfy the primary functions of a drilling fluid. However, additives must often be present in these fluids to overcome specific down-hole problems (Sadiq et al., 2003).

Drilling mud may consist of bentonite clay, with additives such as barium sulphate or hematite, partially hydrolyzed polyacrylamide (PHPA), drilling detergents and sodium carbonate (soda ash) (Papp, 2001). Various thickeners, such as guar gum, glycol, carboxymethylcellulose (CMC), polyanionic cellulose (PAC), starch and other additives, are included to obtain the optimum viscosity of the fluid. Reis (1996) stated that many of the components of additive in disposed drilling muds may be toxic to the environment. In a study of a cross-section of water well drillers in Nigeria, it was found that the basic composition of drilling fluid that they use most commonly consists of bentonite clay (gel) with additives such as calcium carbonate (chalk). The additives most readily available in the local market are CMC, PAC and starch. The most common mixing ratio is 100 bags of bentonite: 10 bags of PAC: 10 bags of CMC: 10 bags of caustic soda (10:1:1:1). Figure 2 presents the combining ratios of the mud components.

Brobst and Buszka (2007) investigated the effect of each of three different drilling fluids on ground water samples. Three monitoring wells were installed in borings that were constructed using water-based drilling fluids containing guar bean, guar bean with breakdown additive and bentonite. These fluids were selected to determine their effects on the chemistry of water samples subsequently collected from the wells. It was observed that the bentonite and guar drilling fluids temporarily caused deviations in the chemical oxygen demand (COD) of ground water samples collected from the monitoring wells. The elevated COD levels were attributed to the large concentrations of oxidizable carbon present in the guar bean drilling fluid and in the organic polymers present in the bentonite drilling fluid. It was stressed that future research should evaluate the physical and geochemical interactions of various drilling fluid compositions with a variety of geologic matrices and drilling, well development and well purging techniques. It was also observed by Hinwood et al. (1994) that the volume of cuttings emanating from a borehole depends on the type of drilling fluid used.

Drilling site construction

Mud pit and channel construction

In every water well construction process involving the mud drilling system, it is important and necessary to have

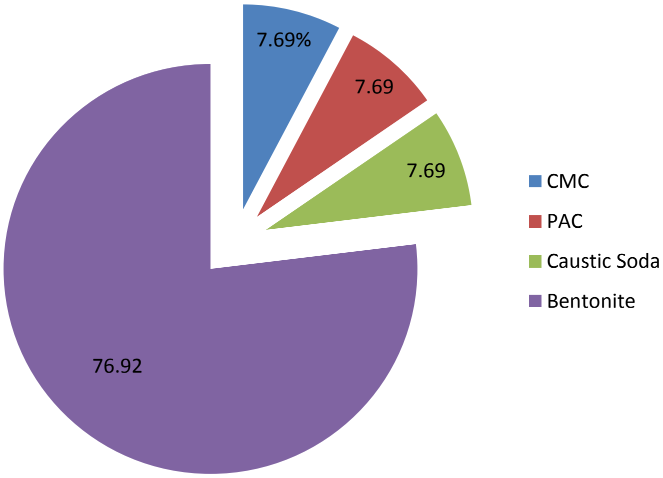

Figure 2. Mud component mixture ratios.

an appropriately sized mud pit. The mud pit serves as a reservoir for the drilling mud. The pit also serves as a point for mixing the drilling fluids to the right consistency and density. The mud channels serve as a pathway from the mouth of the well to the mud pit, where it is remixed and pumped back into the well. Four types of mud pit (shown in Figure 3) are currently being used in drilling wells in Southern Nigeria. They include (3a) unlined pits; (3b) lined pits; (3c) elevated pits and (3d) mud tanks.

Unlined pit

The unlined pit is dug into the earth when only a shallow well is required. It is suitable for a well in which the construction period is considered to be relatively short and the well does not require a lot of fluid. Unlined pits are also used in places where the soil is strong enough to support the hole and prevents its collapse. The advantage of this type of pit is that it is cheap to construct, easy to backfill and, in case of increased use, easy to expand. The disadvantage is that it is easy for the pit to collapse if it is not monitored. Furthermore, the seepage of fluids may increase and damage the surrounding soils.

Lined pit

A lined pit is a pit that is lined with mortar, concrete or blocks work, together with its floor, after construction. This type of pit is often used where the soil is considerably loose and may be a danger to the well. This type is also used when a huge volume of fluid is required for the well to be completed. In highly regulated areas it is used to prevent pollution. On the completion of the development of the well, the pit, including its block work, is buried. The advantage of this type is that the pit can be used for another purpose after the well has been constructed. In addition, seepage to the surrounding soils is extremely limited and, if it is properly built, pit collapse is extremely rare. It is also easy to backfill and cover after the construction of the pit. The disadvantage of this type is that the pit and channel construction time is relatively extended and the pit requires constant cleaning.

Elevated pits

These are structures built above ground to contain the mud flow and mud mixtures. The channel and the pit(s) are both built of sandcrete blocks and plastered internally (in some cases on both sides). This type of pit is used when the construction site is fully developed and excavation will be expensive and difficult. It is possible that the site already possesses a concrete base, or there are already existing underground infrastructures such as telephone lines, water and gas mains. The elevated pit is also useful when there are serious concerns for the environment. In this type of pit, proper sanitary conditions are easy to maintain and the occurrence of seepage in the soil is virtually negligible. The main disadvantage of this type is that the construction time is relatively long and there is a high risk of collapse if the walls are not properly built or a wall-equipment collision occurs. The cost of demolition and site cleanup is relatively expensive.

Mud tanks

These are steel tanks of any suitable shape with open tops. The tanks may be designed according to specific size requirements. The tank is placed above ground and filled with water before the additives are poured in. A

Figure 3. Types of mud pit used during the drilling process (a) unlined pit (b) lined pit (c) elevated Pits (d) mud tanks.

pump is connected to the well and draws the mud from the well into the tank. The mud pump is then connected to the tank and sends the mud to the drill stem. The driller or mud engineer can adjust the pumping rates or position in order to obtain a fine mud mix. This sort of tank is best suited for small sized wells. The advantage of this type of tank is that it is environmentally friendly and seepage is virtually nil. Moreover, the tank can be used repeatedly for several projects and the mixture ratio is easy to regulate. The disadvantage of this type of tank is that construction, transportation and handling costs may be relatively high. In addition, corrosion may affect the tanks, causing leakage that may lead to mud losses. Much larger wells under construction in environmentally regulated regions or zones may make use of a number of such tanks connected in series.

MATERIALS AND METHODS

Description of the study area and site visits

Nigeria lies between latitudes 4° and 14° north and longitudes 3° and 14° east, covering an area of 923,768 km^2 (356,669 sq miles). In 2008, the estimated population of Nigeria was 151.5 million (UN, 2008), yielding an average density of 151 persons per sq km. Nigeria has 36 States plus the Federal Capital Territory (FCT)

Abuja. It is bordered by Chad and Niger Republics to the north, Cameroun to the east, the republics of Benin and Togo to the west and the Atlantic Ocean to the south. The focus of this research was on the southern part of the country with particular reference to five States: Anambra State, Bayelsa State, Delta State, Imo State and Rivers State. Site visitation was an integral aspect of this study. The study areas were visited to examine the impact of the drilling process on the environment: one drilling site each from the five States visited. The sites visited included Oraeri community in Anambra State, Yenegoa in Bayelsa State, Forcados Island in Delta State, Ohaji Egbema in Imo State, and Ndoni LGA in Rivers State. The proximity of the borehole drilling site to residential houses and commercial properties was noted.

Sample collection and analysis

Drilling mud effluent derived from the wells from the five sites was studied in order to evaluate their toxicity and possible environmental impacts that may result from their indiscriminate disposal. Prior to the collection of samples, the drilling mud components were examined and were certified to have been sourced locally. This was confirmed by inspecting the product packaging and by also questioning the drillers on site. The samples were collected during the actual drilling operation for purposes of analysis; the samples were collected as the mud flowed from the mouth of each well. One (1) litre sterilized plastic containers were used to collect the drilling mud samples from each of the sites investigated. The containers were sealed and made airtight to prevent the alteration of each sample. The water based drilling effluents collected from the sites were analyzed for metal concentrations in the drilling waste (that is, cuttings and muds). One (1) g of each of the sample type was digested using mixture of perchloric acid, nitric acid and sulphuric acid in the ratio 1:2:2. The prepared solution was analyzed for the metals of interest using atomic absorption spectrometer (AAS) method.

Mud effluent disposal methods

Drilling mud chemistry is quite complicated, and the consequence of discharging mud into the environment is still not completely understood, despite growing related research. Water well drilling activities produces wastes that need to be disposed of in a manner that is both economical and safe for the environment. Water-based mud (WBM) is disposed of when the drilling job is completed. Sometimes the physical and chemical properties of the mud employed have degraded somewhat, and the mud must be processed to rejuvenate the necessary properties if it is to be reused. In many cases the mud would have become so degraded that it cannot be reused economically, and it must be put to a different type of use or it may no longer be of any use. In the Nigerian context, the recycling of drilling fluid does not even come under consideration. This is due to several factors. First is the huge cost, which most water well drilling contractors or their clients cannot bear. Moreover, environmental issues are yet to be accorded any seriousness in Nigeria. A proper water based mud disposal technique that is both economical and practical is needed for the Nigerian water well drilling industry.

On-site burial

Burial is the placement of waste in man-made or natural excavations, such as pits or landfills. On-site burial is the most common disposal technique used for the disposal of drilling wastes (mud and cuttings). Generally, the mud is left in the pit to allow water and other fluids to evaporate; while the solids are buried in the same pit as was used for the drilling process. Pit burial is a low-cost and low-tech method that does not require wastes to be transported away from the well site. It is therefore very attractive to many operators. Burial may be the most misunderstood or misapplied disposal technique. Simply pushing the walls of the reserve pit over the drilled cuttings is generally not acceptable. The depth or placement of the burial cell is important. A moisture content limit should be established on the buried cuttings, and their chemical composition should be determined. On-site pit burial may not be a good choice for wastes that contain high concentrations of oil, salt, biologically available metals, industrial chemicals, and other materials with harmful components that could migrate from the pit and contaminate usable water resources through seepage (Morillon et al., 2002). It has been reported that heavy metals such as arsenic, cadmium, chromium, lead and mercury are diverse in their toxicities and impacts on the biota of the environment (Darley, 1988; Arscott, 1993; Adewole et al., 2010). Despite the ease of carrying out a proper on-site burial, many drillers and contractors still default on completing the burial process.

Disposal into flowing water bodies

This disposal method is commonly practised when wells are drilled in swampy, coastal or built up areas. This method is also common in Nigeria during the rainy season. In most cases the contractor handling the project does not have the time to allow the pit to dry up before commencing the burial. The constant rain or humidity will prevent the mud pit from drying up over a reasonable period. In this method of disposal, the pits content is stirred in order to form a fine colloidal mix. This mix is then pumped into a water body. The water body may be a public drainage system, a flowing stream, a canal, a river etc.

Other additives used as defoamers, descalers, thinners, viscosifiers, lubricants, stabilizers, surfactants and corrosion inhibitors all have reported effects on marine organisms, ranging from minor physiological changes to reduced fertility, lower feeding rates and higher mortality, depending on the concentrations. Although these elements are likely to be of nutritional importance to the aquatic animals, the associated metals will also constitute a problem to the aquatic lives even in very small concentration. Adewole et al. (2010) expressed that the presence of heavy metals in the aquatic ecosystem has far-reaching implications directly to the biota and indirectly on man.

Discharge into vegetation

This is a common practice that was witnessed during the site visits. It is more common in the rural areas. On completing a well, or during a fluid change in a well, many drillers pump the drill mud and cuttings into the surrounding vegetation, away from the site. This practice can be considered the most environmentally unfriendly. The mud is untreated and can cause serious damage to plant life around the site. Pollution is one of the most serious of all environmental problems and, at its worst, poses a major threat to the health and well-being of millions of people and the ecosystem.

Heavy metals are known to have several adverse effects on man and animals. They include lead, zinc, copper, cadmium, chromium, nickel, manganese and iron. The downward movement of these metals as a result of leaching over a prolonged period may result in the contamination of ground water. Some of these trace metals may prevent or inhibit the uptake of useful soil minerals by plants such as potassium, phosphorus, nitrogen, among others (Atuanya et al., 1999). The accumulation of heavy metals as well as metals predominantly toxic to plants in the soil can be a consequence of

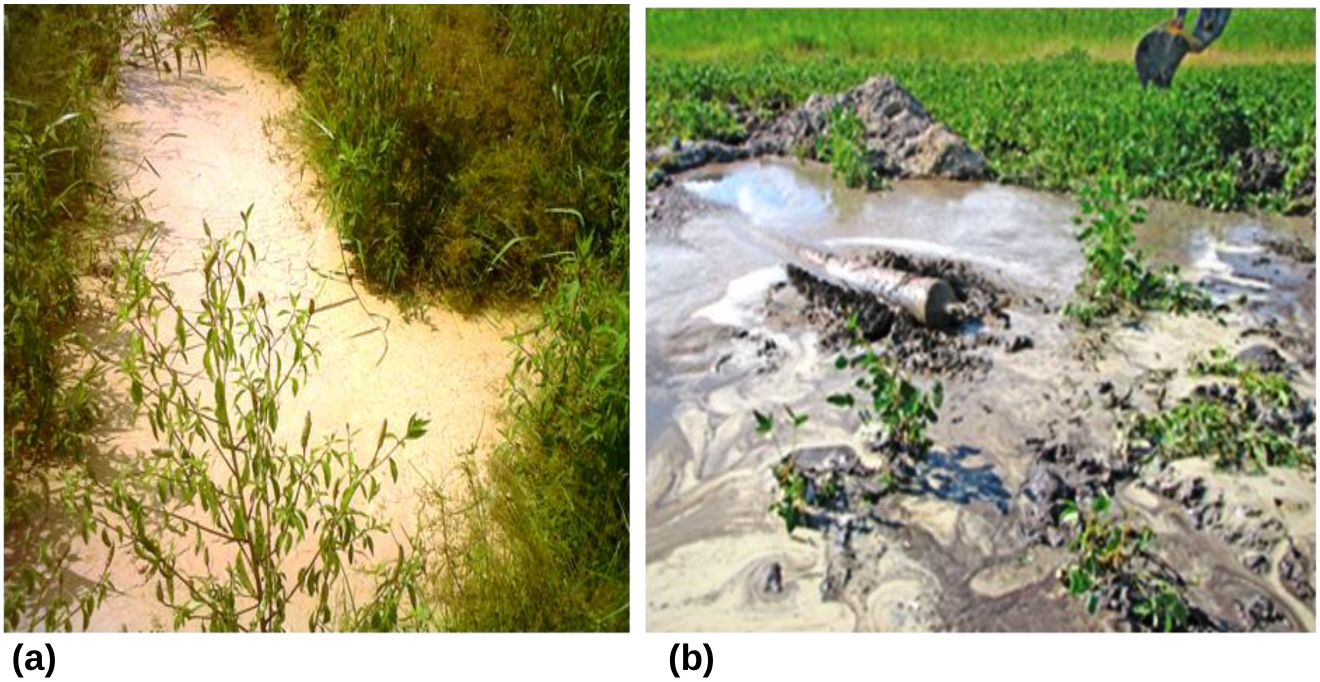

Figure 4. Discharge of mud effluent into the vegetation in Nonwa and Bayelsa in Bayelsa State.

the natural lithogenic and pedogenic processes as well as anthropogenic factors which result in environmental pollution (Woolhouse, 1983).

Anthropogenic inputs are associated with industrialization and other activities, such as atmospheric deposition, waste disposal, waste incineration, urban effluent, fertilizer application and long term application of sewage sludge in agricultural land. The accumulation of heavy metals in agricultural soils is of great concern to the public as well as to governmental agencies due to food safety issues and potential health risks and its detrimental effects on the soil ecosystems (McLaughlin et al., 1999; Yanez et al., 2002). Food chain contamination is one of the important pathways for the entry of these toxic pollutants into the human body (Ferner, 2001; Ma et al., 2006). Figure 4 describes the discharge of mud effluent into the vegetation in Nonwa and Bayelsa in Bayelsa State. In its ground-water monitoring technical enforcement guidance document, The United States Environmental Protection Agency (US EPA) states that the mud rotary drilling process has the ability to pollute existing underground aquifers if the drilling fluid contains harmful additives (EPA, 1986b). An assessment of the environmental risk due to soil pollution is of particular importance for agricultural and non-agricultural areas, because heavy metals which are potentially harmful to human health persist in soils for a very long time. According to soil parameters, they may enter the food chain in significantly elevated amounts (Grzebisz et al., 2001).

Waste products from mud rotary drilling

Smoke/fumes

Most drilling rigs, mud pumps and other accessory equipment used on the drill site run on either petrol or diesel. These hydrocarbons are burnt off by the engines and they, in turn, release fumes into the atmosphere. The fumes released into the atmosphere may contain harmful gases. These gases pose a threat to the environments even though they might be in relatively small quantities.

Diesel, petrol, grease and other petroleum products

Drilling rig engines run on several fuel types (basically hydrocarbons). Aside from running the engines, they also serve as lubricants for moving parts in the equipment. On every site there is a tendency for spillage and the drill site is no exception. The lubricants and fuel will, in one way or the other, come into contact with the ground or soil beneath their points of application. Leaking or damaged engine parts may also serve as sources for expelling these liquids. These losses may be considered minute or negligible; but at sites where protracted, the effects could be much more pronounced, especially if the equipment being used are extremely weathered or the workers are indifferent to or ignorant of environmental issues.

Concrete and block work

At the end of the project, the concrete and blocks used on the site during the construction of the mud pit, as well as the materials used to construct the rig base are regarded as waste materials. In most cases, these materials must be removed from the site especially in the case of elevated pits where they cannot be buried. The blocks may serve as a base material for other projects or may be buried on site. In sensitive areas, it may be necessary to excavate these materials.

Packaging materials

Most consumables used to work at a site are manufactured goods, which come pre-packaged. Some of these include bentonite sacks, CMC sacks, plastic wrappings, electrode packets, etc. At the completion of the project, many contractors leave all these materials at the site. These could easily be properly taken care of on-site through proper housekeeping practices.

RESULTS AND DISCUSSION

Physical properties

Prior to the laboratory testing, the fluid samples collected from the well sites had a light brown colour of varying degrees. The colour was due to the high proportions of bentonite present in the mixture. The fluids had a gel-like feeling and gritty to the touch. Figure 5 shows the graphical representation of the concentrations of the heavy metals and other characteristics of the mud samples from the five (5) sites visited.

Chemical properties

The pH value/rating of the entire drilling fluid waste collected from all sites fell within the 8.0 to 8.5 range. This pH values (8.0 to 8.5) are alkaline in nature and are not considered harmful to the environment. The analysis shows that manganese occurs in distinct quantities when compared to other constituents of the drilling fluid. The concentration of manganese in the waste fluid from the five sites ranged from 114 to 314 mg/kg. Manganese is present in greater quantities than other trace elements, with the exception of chromium, which is highest in all the sites. In contact with man, manganese is relatively harmless: the body absorbs it and excretes the excess (Habeck, 1992). For copper, it has been reported that copper causes gastrointestinal irritation in man (WHO, 1993). The analysis carried out on the waste drill fluid from the sites visited showed that the concentrations of copper in the waste drill fluid ranged from 76 to 96 mg/kg.

Uncontaminated soil contains lead concentrations less than 50 mg/kg but soil lead levels in many urban areas exceed 200 mg/kg (AAP, 1993). The United States Environmental protection Agency's standard for lead in bare soil in recreational and work areas is 400 mg/kg by weight and 1200 mg/kg for non-useable land areas. The lead content in the waste drilling fluids investigated from the five sites showed an average lead content of 16 mg/kg with a maximum value of 36 mg/kg at the Ohaji site in Imo state. A Pb concentration in soil up to 792 mg/kg does not cause an excessive intake of Pb by humans as evaluated by a direct soil ingestion exposure model (Dukha and Miller, 1999). These levels of lead recorded pose no serious threat to the soil, vegetation and human around the site. Nickel occurs naturally in soils as a result of the weathering of the parent rock (McGrath, 1995). The range of the variation of the nickel content of the surface levels of various soils is 4-50 mg/kg. The mean Ni concentration of light sandy soil is 15 mg/kg. The highest concentrations are found in basic igneous rocks; much lower levels are found in sedimentary rocks like shale, clays, limestone, and sandstones (McGrath, 1995). The Ni content of the drilling fluids investigated fell within the range 36 to 70 mg/kg.

The zinc content was highest at Forcados, with a value of 79.51 mg/kg. This is followed by Ndoni and Yenegoa, each with a concentration of 65 mg/kg. Hess and Schmid (2002) have stated that though Zn has been found to be of low toxicity to man, the prolonged consumption of large doses can result in certain health complications, such as fatigue and dizziness. When soils in farmlands are polluted with zinc, animals absorb concentrations that are damaging to their health. This is not a threat to cattle, but also to plant species. Plants often have a zinc uptake that their system cannot handle due to the accumulation of zinc in soils. Due to its effects on plants, zinc is a serious threat to production in farmlands.

The chromium content in the mud effluent ranged from 320 to 423 mg/kg making it the most prominent element present in all the sites. Chromium is present in freshly mined bentonite. The chromium content in the waste fluid depends on its content at the bentonite mining site. Although most of the chromium in water binds to dirt and other materials and settles to the bottom, a small amount may dissolve in the water. A very small amount of the chromium in soil, however, will dissolve in water and can move deeper in the soil to underground water. The most toxic drilling muds are those that contain high concentrations of hexavalent chromium (10,000 mg/kg), diesel fuel or surfactant (Neff, 1987). Arsenic is widely distributed in nature and is classified as a metalloid. It can exist both in solid and liquid states. The permissible limit of arsenic in agricultural soils is 20 mg/kg of soil; but 5 mg/kg arsenic in soil is toxic to sensitive crops (Hassan, 2002). A conservative risk analysis shows that As concentrations in soil can reach 40 mg/kg without being hazardous to exposed organisms (Dukha and Miller, 1999). The arsenic levels in the drilling fluid ranged from 2 to 3.2 mg/kg. This result shows that even at the end of the drilling process the soil will still be safe for both plants and organisms in the drilled area.

The mercury content of the drilling fluid obtained from the sites investigated ranged from trace quantities to a maximum of 2.93 mg/kg. The maximum permissible level of mercury in the soil is 6.44 mg/kg (Wang et al., 1982). The quantity of mercury found in the drilling fluid was far below the standard. While the iron content of the fluid varied sharply in several sites, the iron content was not due to the components of the constituents of the drilling mud, but due to the high iron content of the underground water aquifer(s) passed on the way to the maximum drilling depth. The high iron content in some wells can be said to be due to the iron content in the water and the surrounding soils around the aquifer. The readings of the iron content in the waste drilling fluid ranged from 14 mg/

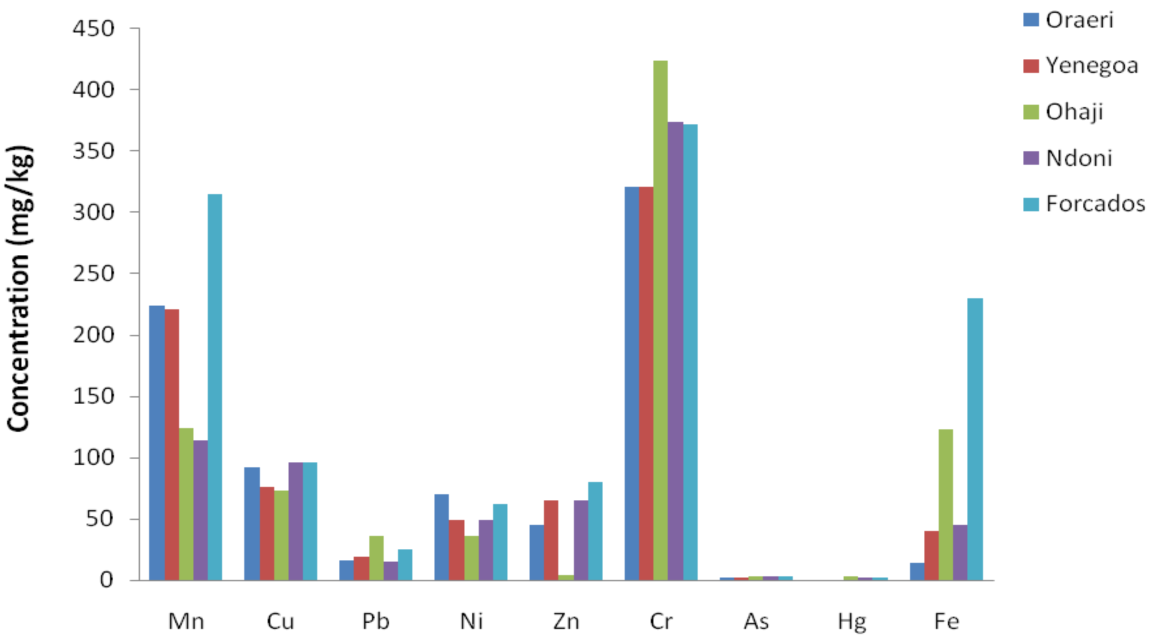

Figure 5. Graphical representation of the concentrations of the effluent constituents.

kg to 229.3 mg/kg.

CONCLUSION AND RECOMMENDATIONS

An assessment of the mud rotary drilling process and the possible impact of its by-products on the immediate environment have been carried out. Investigations reveal that the drilling fluids composed entirely of locally sourced materials. It was observed on site visits that very few drillers or drilling contractors possessed any knowledge of the constituents of the by-products of the drilling process or of the potential risk they pose to the immediate environment. At all the sites visited in the course of this study, the waste fluids were deposited in the vegetation surrounding the site. Some drillers had plans to abandon the mud pits and the construction channel at the end of the drilling process.

The tests carried out showed that, except for copper and nickel compounds, most of the parameters tested for fell within the concentration limits allowed in soils. The concentrations of Cu and Ni were, however, not so high as to cause harm to the plant life and human population around the site. Nevertheless, a consistent discharge of these elements will build up and at some point, reach unbearable levels. One can conclude that mud rotary drilling using materials locally sourced in Nigeria is a safe drilling process and the waste effluents and cuttings have little or no adverse impact on the immediate environment surrounding the drill site. It was also observed that the drilling fluid had no effect on the quality of the ground water sourced from the boreholes. Such groundwater contained very few of the impurities found in the waste drilling fluids.

It is recommended that drillers and drilling contractors carry out regular tests on their drill fluids when working in environmentally sensitive areas such as swamps and residential areas in order not to damage already fragile ecologies. Other recommendations could be seen in the following path:

1. “Site cleanup and restoration” clauses should be added and insisted on by clients when preparing and signing contracts. This would provide the drillers with a sense of minimizing waste generation and develop cleanup strategies which would limit the effect of the construction on the environment.
2. During borehole construction activities, it would be recommended that secondary mud pits be constructed alongside the functional mud pit(s) used in the drilling process. The secondary pit would have to be lined with cement or block work to prevent seepage into the environment. This secondary mud pit would be used as a reservoir for spent drill fluid during the process which would equally allow the drilling fluid to evaporate naturally.
3. The sludge left at the end of the drilling process should be backfilled with the excavated material on site and permanently buried. The drawback to this process would be the poor performance of the process during rainy season as evaporation would be extremely limited and there would be a possibility for flooding to occur in the pits. This might be considered an extreme measure in remediation but should be considered necessary.

Further research is recommended on this study. The sample test and analysis should show a comparison between the initial concentrations of the heavy metals of the drilling fluid and the final concentration of the effluent. This test would enable the effect of the soil formation on the fluid quality to be monitored properly.

REFERENCES

Adewole GM, Adewale TM, Ufuoma E (2010). Environmental aspect of oil and Water-based drilling muds and cuttings from Dibi and Ewan off-shore wells in the Niger Delta, Nigeria. Afr. J. Environ. Sci. Tech. 4(5):284-292.

Adekile D, Olabode O (2008). Study of Public and Private Borehole Drilling in Nigeria. Consultancy. Report for UNICEF Nigeria Wash Section. Available from: http://www.rwsn.ch/documentation/skatdocumentation. Accessed 21st May, 2011.

American Academy of Pediatrics (AAP) (1993). Lead poisoning: from screening to primary prevention. Pediatrics. 92(1):176-183.

Arscott RW (1993). New directions in environmental protection in oil and gas operations. Petroleum Technology, Texas. pp. 193

Atuanya EI, Obuekwe CO, Ehigie SO (1999). Microbial studies and lead tolerance levels of microbes in lead accumulator dumps. J. Environ. Sci. Health 2(1):8-13.

Brobst RB, Buska PM (2007). The Effect of Three Drilling Fluids on Ground Water Sample Chemistry. Ground Water Monit. Remed. 6(1):62-70.

Darley HC (1988). Composition and properties of drilling and completion fluids. Gulf publishing company, Houston, Texas, p. 665.

Dukha S, Miller WP (1999). Permissible Concentrations of Arsenic and Lead in Soils Based on Risk Assessment. http://www.springerlink.com/content/ Accessed 18th May, 2011.

EPA (1986b). Determination of reportable quantities for hazardous substances. U.S. Environmental Protection Agency. Code of Federal Regulations. 40 CFR 117.

Ferner DJ (2001). Toxicity of heavy metals. eMed. J. 2(5):1.

Gonzalez JM, Quintero F, Arellano JE, Marquez RL, Sanchez C, Pernia D (2011). Effects of interactions between solids and surfactants on the tribological properties of water-based drilling fluids. Colloids and Surfaces A: Physicochem. Engr. Aspects 391(1):216-223

Grzebisz W, Ciesla L, Diatta JB (2001). Spatial distribution of copper in arable soils and in non-consumable crops cultivated near a copper smelter. Pol. J. Environ. Stud. 10(4):269.

Habeck M (1992). Toxicological Profile for Manganese Agency for Toxic Substances and Disease Registry, United States Public Health Service. http://www.ecousa.net/toxics/chemicals/disclaimer.shtml. Accessed 20th May, 2011.

Hassan A (2002). Contamination of soil due to irrigation with arsenic laden water and its impact on phosphorus leading to crop production in Bangladesh. http://www.eng-consult.com/arsenic/article/DU-ACIAR_Project.html. Accessed April 1, 2012.

Hess R, Schmid B (2002). Zinc supplement overdose can have toxic effects. J. Paediatr. Haematol. Oncol. 24:582-584.

Hinwood JB, Potts AE, Dennis LR, Carey JM, Houridis H, Bell RJ, Thomson JR, Boudreau P, Ayling AM (1994). Environmental Implications of Offshore Oil and Gas Development in Australia-Drilling Activities in Environmental Implications of Offshore Oil and Gas Development in Australia - The Findings of an Independent Scientific Review, Swan JM, Neff JM, Young PC. Eds, Australian Petroleum Exploration Association, pp. 124-207.

Khodja M (2008). Drilling Fluid: Performance Study and Environmental Consideration, Thesis, National Polytechnic Institute, Toulouse, France.

Khodja M, Canselier JP, Bergaya F, Fourar K, Khodja-Saber M, Cohaut N, Benmounah A (2010a). Shale problems and water-based drilling fluid optimization in Hassi Messaoud Algerian oil field. Appl. Clay Sci. 49:383-393.

Khodja M, Khodja-Saber M, Canselier JP, Cohaut N, Bergaya F (2010b). Drilling Fluid Technology: Performances and Environmental Considerations. Products and Services; from R&D to Final Solutions. Intech Open Access Publishers, pp. 228-256.

Ma HW, Hung ML, Chen PC (2006). A systemic health risk assessment for the chromium cycle in Taiwan. Environment International. http://dx.doi.org/10.1016/j.envint. Accessed 25th January, 2012.

McGrath SP (1995). Nickel in Heavy Metals in Soils (2nd edn.) (Ed. B.J. Alloway). London: Blackie Academic & Professional.

Morillon A, Vidalie JF, Hamzah US, Suripno S, Hadinoto EK (2002). Drilling and Waste Management," SPE 73931, presented at the SPE International Conference on Health, Safety, and the Environment in Oil and Gas Exploration and Production.

Neff JM (1987). Biological Effects of Drilling Fluids, Drill Cuttings and Produced Water. Off-shoreenvironment.com. http://www.offshore-environment.com/envimpact. Accessed 20th March, 2011

Oloyede IO (2010). Water Has No Enemy. Unilorin Bulletin Monday August 2, 2010, 4(29).

Papp J (2001). Water-based Drilling Fluids. http://www.intechopen.com/source/pdfs/12330/InTech Drilling fluid technology performances and environmental considerations.pdf. Accessed 12th February, 2012.

Reis JC (1996). Environmental control in Petroleum Engineering, Gulf Publishing Company, Houston, Texas, p. 560.

RWSN (2010). Code of Practice for Cost-Effective Boreholes, Rural Water Supply Network. http://www.rwsn.ch/documentation/skatdocumentation. Accessed 26th April, 2011

Sadiq R, Husain T, Veitch B, Bose N (2003). Evaluation of generic types of drilling fluid using a risk-based analytic hierarchy process. Institute for Research in Construction, National Research Council, Ottawa, Ontario, Canada.

Stewart Brothers & Co., (2010). The Benefits of Mud Rotary Drilling. http://www.stewartbrothters.com Accessed 5th November, 2010.

UN (2008). “We the people” : The role of the United Nations in the 21st century. Secretary-General of the United Nations. Department of Public Information, New York.

UNESCO (2009). EFA Global Monitoring Report: Overcoming Inequality-Why Governance Matters. Paris.

UNICEF (2008). Water, Sanitation and Hygiene Annual Report. http://www.unicef.org/wash/files/Accessed 12th April, 2012

UNICEF and World Health Organization (2012). Progress on Drinking Water and Sanitation. Joint Monitoring Programme for Water Supply and Sanitation. ISBN: 978-92-806-4632-0.

Wang HK, Liv BY, Feng GZ, Wang QM (1982). A Study of the permissible level of mercury due to the utilisation of sludge on land. Environ. Manage. 32(6):778-787.

WHO/UNICEF (2010). Joint monitoring report: Progress on Sanitation and Drinking Water http://www.who.int/water_sanitation_health/monitoring/fast_facts/en/index.html.Accessed 13th April, 2012.

Woolhouse HW (1983). Toxicity and tolerance in the response of plants to metals. In: Encyclopedia of Plant Phisiology, New Series, Springer-Verlag, New York, Heidelberg, Berlin, 12(C):246-289.

World Health Organization (1993). Guidelines for drinking water quality-recommendations. 2nd Ed.Geneva WHO.

Yanez L, Ortiz D, Calderon J, Batres L, Carrizales L, Mejia J (2002). Overview of human health and chemical mixtures: Problems facing developing countries. Environmental Health Perspectives. 110:901-910.