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(Research Article)

Environmental and living organisms' disaster caused by discharge of drilling fluid waste

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Abstract

The oil and gas industry plays a vast and vital role in our society. Despite the numerous benefits of the production of crude oil, its activities pose a lot of dangers to the environment and living organisms because it generates a huge volume of solid and liquid wastes, thus, these wastes require treatment before disposal. The major drilling wastes are drilling muds, drilling cuttings, and obnoxious gas emissions. Parameters that should be considered during the disposal of decontaminated drilling muds and drill cuttings are heavy metals. These wastes are introduced into the environment through accidental spills as well as intentional discharge. The discharge into the environment has effects on humans, plants, birds, soil, and also aquatic life. Generally, oil based drilling fluid usage and disposal are not preferable. However, water based drilling fluid and synthetic based drilling fluid can be a technically and economically disposed because they are biodegradable. Generally, drilling waste disposal options are offshore disposal, onshore disposal and drill cuttings re-injection. Zero discharge can achieved by drill cuttings re-injection. However extensive study must be carried before drill cuttings can be re-inject to the formation. Disposal options must be evaluated based on economics, environment and operational aspects. This study aimed at evaluating the heavy metals present in the drilling fluid waste and drilling cuttings. The experiment was achieved with the aid of a Flame Atomic Absorption Spectrophotometer (FAAS). Upon the investigation, it was discovered that lead concentration in drilling cuttings was the highest with the concentration of 1,058.9 mg/l and drilling fluid was 190.3 mg/l whereas NUPRC limit is 5 mg/l; the total chromium concentration in drilling cuttings was 19.16 mg/l and drilling fluid was 8.38 mg/l whereas NUPRC limit is 8 mg/l; zinc was 58.10 mg/l in drilling cuttings while in drilling fluid it was 23.96 mg/l whereas NUPRC limit is 50 mg/l; silver concentration in drilling cuttings was 14.67 mg/l and drilling fluid 0.91 mg/l whereas NUPRC limit is 5 mg/l; Cadmium concentration in drilling cuttings was 2.17 mg/l and drilling fluid was 1.36 mg/l whereas NUPRC limit is 1 mg/l. In no doubt. The study has shown that disposal of this drilling fluid waste and drilling cutting directly into the environment without treatment will be detrimental to the living organisms and therefore should be discouraged.

Keywords: Cadmium, Emissions; Heavy Metal; Drilling Fluid Waste; Chronium

1. Introduction

Petroleum is one of the most vital natural resources worldwide and it is the largest highly traded primary commodity in the international market[1]; and has remained the main global source of energy for both industrial and domestic uses, since replacing coal early this century. However, the exploration and production of petroleum involve the generation of drilling waste which is a major source of pollution in oil-producing, which harms the environment. Until the 1980s, little or no attention was paid to the generation and disposal of cuttings and excess drilling fluids. According to[2], drilling fluid can be defined as all the compositions that are used to remove the cuttings from a borehole. There are four types of drilling fluid which are water-based drilling fluid (WBDF), synthetic-based drilling fluid (SBDF), oil-based drilling fluid

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(OBDF), and pneumatic drilling fluid (air, gas, foam, mist). According to[3] OBDF and SBDF are non-aqueous drilling fluids (NADFs). SBDF is preferred due to its technical performance and small environmental effect[4]. The effect of drilling fluid disposal on offshore waste is primarily physical. According to[5] research has shown that the discharge of barite and bentonite prevents plant growth. The most common impact on health from drilling fluid waste to humans is skin irritation and contact dermatitis[6]. One of the most common environmental threats from drilling fluid waste is heavy metals, which may result in the bioaccumulation of aquatic organisms. Drilling mud consists of a big portion of oilfield chemicals consumed yearly. Typically, these materials were discharged overboard in offshore operations or buried during excavations on land[7]. Due to the increasing global environmental awareness in the late 1980s and early 1990s, the oil and gas industry and its regulators identified and recognized the potential environmental impact of drilling waste[8]. It is obvious that drilling oil and gas wells produce huge amounts of drill cuttings and used mud however, various technologies have been explored and publications are written to manage and reduce the environmental impact of drilling waste. Some drilling techniques that produce fewer waste include directional drilling, slim-hole drilling, coil-tubing drilling, and pneumatic drilling. Various drilling waste management plans and programs have also been designed by different companies and researchers[9]. Drilling waste management is a way by which drilling and associated wastes could be handled effectively to minimize their effect on the environment. Common wastes associated with drilling operations include drill cuttings, contaminated drilling fluids, and additives, gaseous contaminants from internal combustion engines, and produced water in addition to heavy metals. Drill cuttings are broken bits of solid material (crushed rocks) produced as the drill bits penetrate the earth. They range in different sizes, from clay-sized particles to coarse gravel having a configuration in angular form. The volume of the cuttings depends on the type of fluid used, the size of the borehole, and the depth of the well. Its composition depends on the type of rock, formulation of the drilling fluid, technology to separate and clean the cuttings, drilling regime, and other factors. Cuttings are sometimes contaminated with drilling muds from formation fluid and have harmful effects on the environment and their impact is determined by the nature and extent of their contamination with heavy metals and drilling muds. Another waste associated with drilling operations is heavy metals, they enter into drilling fluid either added as part of additives used to alter the fluid properties or naturally occurring in most formations and will be incorporated into the fluid during drilling. The ones that are naturally occurring include arsenic, barium, cadmium, chromium, lead, and mercury. The most commonly found are barium and chromium from the barite weighting agent and chromeligo sulfonate deflocculates. Effects of heavy metals include damage to the reproductive, liver, kidney, and nervous systems, or blood-forming. These effects may also include mutations[10]. The major objective of waste management is to prevent waste from polluting the environment at such a rate, form, or amount that overloads the natural process of assimilation. Eliminating or reducing waste generation is important in reducing environmental liability and operating costs[11]. The waste hierarchy is a common waste management technique that has been reported in some literature. It refers to the "3 Rs" of reduction, reuse, and recycling, which classify waste management strategies according to their desirability in terms of waste minimization[12]. However, this technique is not extensive enough. The volume of waste generated must be detected, classified, and estimated before the waste hierarchy can be effectively applied. An effective waste management modality must integrate these factors. The amount of drilling waste generated during well drilling is also an important and costly factor, especially if the waste is to be transported, treated, or disposed of offsite. The drilling fluid can potentially give adverse effects on the environment. The chemical and physical properties of drilling waste determine its environmental impact and hazardous characteristics potentially and the degree of the effect depends on the type, exposure, and dosage of the chemical[13].Exposure via drinking water or fish consumption would adversely affect populations, even with low pollution levels in the exposure medium[14]. Drilling waste could affect human health via several routes of exposure. While inhalation is an occupational concern for drilling workers, absorption of contaminated food or water remains the primary threat to the general population. This could happen through unintentional release; deliberate release, either allowed or not allowed, into the water body; or seepage from onshore storage areas into groundwater. The effects on human health include changes in the levels of certain blood enzymes, impact on children's neurobehavioral development, negative effects on the central nervous system, brain and eyes, and skin irritation. These include both non-carcinogenic and carcinogenic impacts based on exposure to a particular chemical and the full length and intensity of exposure[14]. Health experts have concluded that pollutants released by diesel engines adversely affect human health and contribute to acid rain, and ground-level ozone and lessened visibility. To handle exposure and risk to humans, below is the hierarchy of control that must be considered: 1. Elimination- Removal of hazardous and toxic materials in drilling fluid can reduce the risk to humans during the drilling operations. All operations should strive to minimize the number of chemicals being used to an absolute minimum; 2. Substitution- When low-toxicity drilling fluid or WBDF is used, it can reduce the carcinogenic hazard of exposure to drilling fluid; 3. Engineering controls- The design of the workplace should include this such as a ventilation system and enclosed drilling fluid circulation system, which minimizes exposure of hazardous substances to the workforce; 4. Administrative controls- Exposure and impacts to human health can be managed and assessed by monitoring the level of exposure by conducting skin monitoring and air monitoring. Managing the working hours through the use of the proper shift, maintaining health records and workplace health surveillance can also help to reduce the potential exposure to the workers and, Personal protective equipment- This is the final protection and most significant control. Examples are rubber gloves, rubber boots, masks, splash goggles, and coveralls. These equipment are important to act as the last barrier of protection to the workplace. Hydrocarbon concentrations of less than 1 mg/l in water have been shown to have a sublethal effect on some marine organisms. Other impacts of hydrocarbons include stunted plant growth if the hydrocarbon concentration is above about 1 % by weight. Lower concentrations however can increase plant growth. Marine animals that use hair or feathers for insulation can die of hypothermia if covered with oil. Coated animals can ingest deadly quantities of hydrocarbon during washing and grooming activities[15]. The study focuses on the experimental evaluation of the radioactive elements in the drilling fluid and drill cuttings in a filed in Niger Delta.

2. Methods

The methodology was based on the listed objectives of this work and was obtained from a spectroscopic analysis technique known as atomic absorption spectroscopy (AAS) that determines the concentration of a particular element in a sample.

The work involves different stages ranging from the collection of samples to the evaluation of heavy metals in the samples.

Drilling mud and cutting samples from an off-shore field in Niger Delta were analyzed to identify the concentration of heavy metals. The samples were dried, digested, and spectrophotometrically analyzed for eight heavy metals (Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Silver, and Zinc).

The materials and equipment used are shown in Table 1 and Table 2 while the GBC 908PBMT Model Flame Atomic Absorption Spectrophotometer is shown in Figure 2.

Table 1 List of materials used

S/N	Material
1	Oil-based drilling mud
2	Drilling cuttings
3	Concentrated nitric acid (HNO_3)
4	Concentrated hydrochloric acid (HCl)
5	Distilled water

Table 2 List of equipment

S/n	Material	function	Model
1	Mesh sieve	To sieve the dry sample	Ofite
2	Glass beaker	To hold the sample	Ofite
3	Hot plate	To heat sample	Corning PC-351
4	Standard volumetric flask	To measure volumes of prepared solution	Ofite
5	Flame Atomic Absorption Spectrophotometer (FAAS)	To analyze the sample	GBC 908PBMT

After the sample collection, the samples were air dried at room temperature, then homogenized by grinding and sieving through a 2 mm mesh sieve. Exactly 5 g of sample is transferred into a 100 ml glass beaker, while a mixture of 2 ml of concentrated nitric oxide, 10 ml of concentrated hydrochloric acid, and about 20 ml of distilled water is added. Samples were digested on a corning PC-351 model hot plate at medium to low heat until about 5 ml concentrated extract was left (or with sample concentrate tending towards near-dryness). Afterward, the content of the beaker was left to cool for about thirty minutes. The sample solution was filtered and quantitatively transferred into a 50ml standard volumetric flask.

Figure 1 GBC 908PBMT Model Flame Atomic Absorption Spectrophotometer.

Finally, filtered solutions were marked up to a 50ml graduation line using distilled water. Test metals were determined using the GBC 908PBMT Model Flame Atomic Absorption Spectrophotometer (FAAS). Each sample was individually aspirated. The total metal concentrations were reported in units of ppm (mg/l).

Calculation of metal concentration:

Total metal concentration = (D x R x V) / W

Where:

D = Serial dilution
R = Concentration reading (ppm or mg/l)
V = Final volume of acid digest (ml)
W = Dry weight of the sample (g)

3. Results and discussion

The data obtained from the metal analysis of drill cuttings and mud are shown below. Table 3 shows the result of the concentration of different heavy metals in the drilling cuttings and drilling mud samples from an offshore field in the Niger Delta. Figure 2 has graph of heavy metal distribution in drill cuttings; Figure. 3 shows heavy metal distribution in drilling mud and Figure 4showns Comparison of drilling cuttings and drilling mud to NUPRC limits respectively.

Table 3 Result for Heavy Metal Analysis of Drill Cuttings and Drilling Fluid Waste

S/N	Heavy metals	Drill Cuttings (mg/l)	Drilling Fluid Waste (mg/l)	NUPRC Limit (mg/l)
1	Arsenic	1.33	0.70	5
2	Barium	5.21	0.13	100
3	Cadmium	2.17	1.36	1
4	Total Chromium	13.16	8.38	5
5	Lead	1,058.9	190.3	5
6	Mercury	1.77	1.38	0.2
7	Silver	14.67	0.91	5
8	Zinc	58.10	23.96	50

NUPRC- Nigerian Upstream Petroleum Regulatory Commission

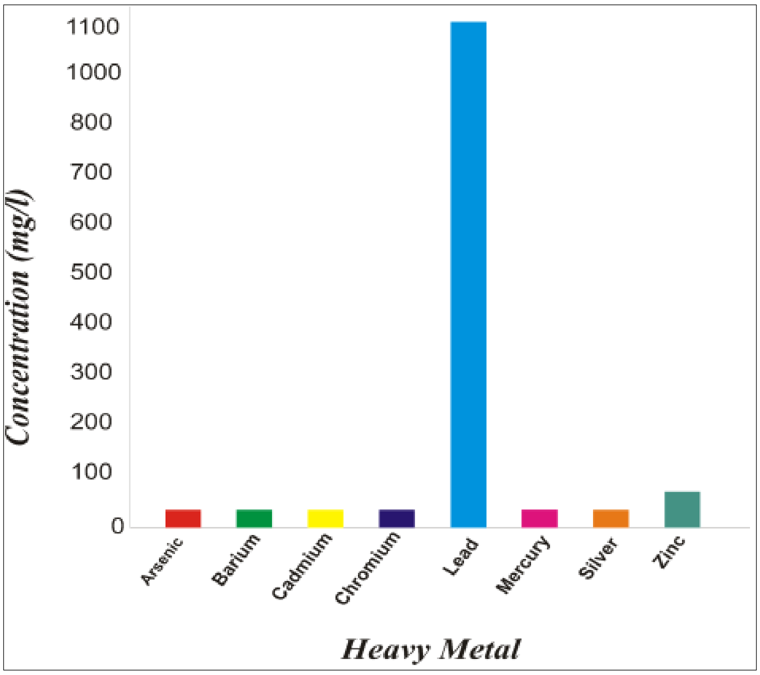

Figure 2 Heavy metal distribution in drilling cuttings.

From the result of the heavy metal analysis for the drilling cuttings, it was observed that the drilling cuttings recorded the highest concentrations of heavy metals; Lead (1058.9 mg/l), Zinc (58.10 mg/l), Silver (14.67 mg/l), Chromium (13.16 mg/l), Cadmium (2.17 mg/l) and Mercury (1.77 mg/l) in that order which exceeded the regulatory limit by NUPRC. The drilling cuttings recorded an appreciable concentration of heavy metals in Barium (5.21mg/l) and Arsenic (1.33 mg/l) which is less than the NUPRC limit.

The drilling mud recorded the highest concentration of heavy metals; Lead (190.3 mg/l), Chromium (8.38 mg/l), Mercury (1.38 mg/l), and Cadmium (1.36 mg/l) in that order which exceeded the regulatory limit by NUPRC. The drilling mud recorded an appreciable concentration of heavy metal in Zinc (23.96 mg/l), Silver (0.9 1mg/l), Arsenic (0.7 0mg/l), and Barium (0.13 mg/l) which is less than the limit by NUPRC. Therefore, the spent mud and cuttings will lead to the increase of some of these heavy metals in the environment and so disposal into the environment to reduce contaminants to an acceptable degree should be highly discouraged.

The maximum value of 1058.9 mg/l in the drilling cuttings and 190.3 mg/l in the drilling mud for lead in this study exceeds the NUPRC acceptable limit of 5 mg/l. This metal ranks first in the drilling cuttings and drilling muds analyzed and has the potential of producing long-term, severe environmental impacts on flora and fauna according to Veil et al, (1999), so if this metal is disposed into the environment there will be a possibility of increased lead concentration and this can cause brain damage and fetal malformation.

The concentration of Zinc in the drilling cuttings was 58.10mg/l which is more than the NUPRC limit of 50mg/l and this can cause nausea, vomiting, and diarrhea to living organisms, while its concentration in the drilling mud was 23.96 mg/l which less than NUPRC limit. However even though Zinc is present in humans in little concentrations, its prolonged presence in the human body in large concentrations could lead to dizziness, fatigue, etc according to Gbadebo et al (2010).

Arsenic and Barium concentrations in the drilling mud were 0.70mg/l and 0.13mg/l respectively, while that of the drilling cuttings were 1.33mg/l and 5.21mg/l respectively, which showed concentrations less than the allowable limits of 5mg/l and 100mg/l respectively by NUPRC.

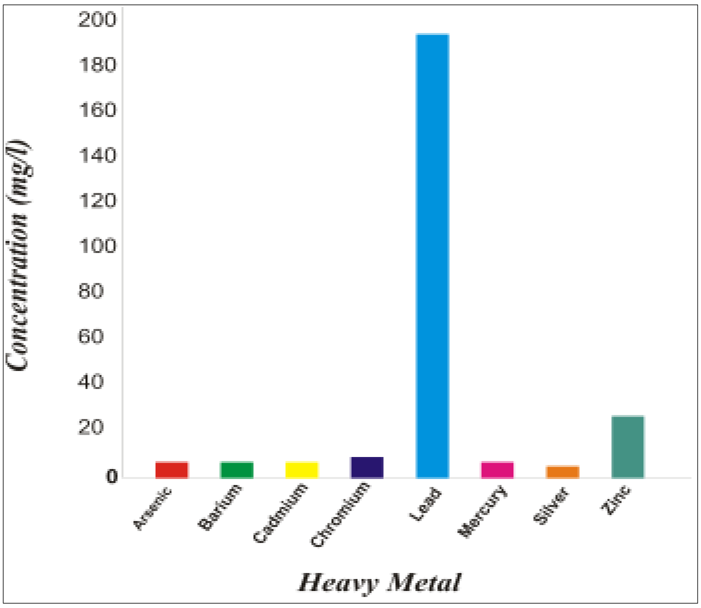

Figure 3 Heavy metal distribution in drilling mud

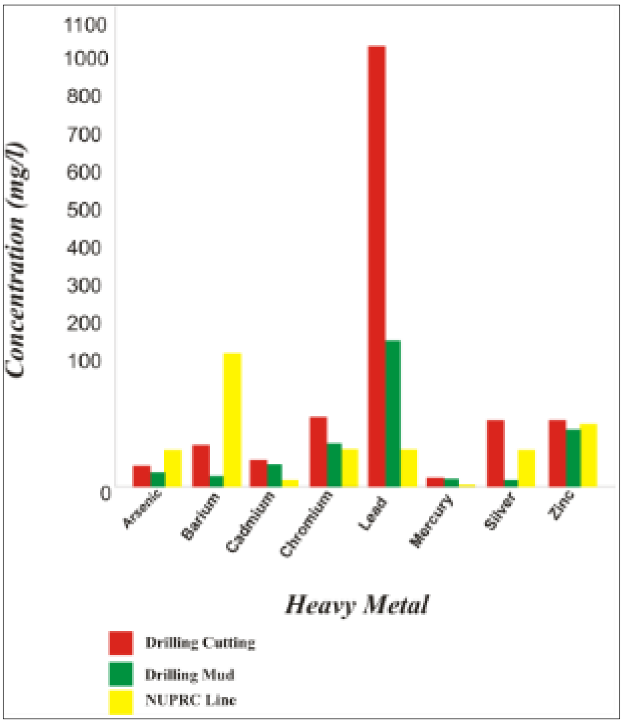

Figure 4 Comparison of drilling cuttings and drilling mud to NUPRC limits

The total Chromium in the drilling cuttings and drilling mud were 13.16mg/l and 8.38mg/l respectively which is above the NUPRC limit and can cause lung cancer, gastric damage, kidney and liver disease if it is disposed to the environment.

Cadmium in the drilling cuttings and drilling mud showed a concentration of 2.17mg/l and 1.36mg/l which is higher than the NUPRC limit of 1mg/l and can cause lung disease, carcinogenic effects, fever, muscle pain to living organisms if it gets into the environment. It is toxic to aquatic organisms according to Woodworth and Poscoe, 1982.

The value of Mercury in drilling cuttings and drilling mud was 1.77mg/l and 1.38mg/l which is higher than the NUPRC limits of 0.2mg/ and the disposal of these metals could cause kidney damage to living organisms.

Silver showed a low concentration of 0.9mg/l in the drilling mud and a high concentration of 14.67mg/l in the drilling cuttings that is above NUPRC limits of 5mg/l, and disposal of soluble Silver into the environment may cause liver and kidney damage, irritation of the eye, skin, respiratory and intestinal tracts and changes in blood cells.

The overall summary of the concentration of heavy metals in drilling cuttings and drilling mud with the NUPRC limits is shown in Figure 4.

List of Abbreviations

- NUPRC – Nigerian Upstream Petroleum Regulation Council
- FAAS - Flame Atomic Absorption Spectrophotometer
- AAS - Atomic Absorption Spectroscopy
- WBDF – Water Based Drilling Fluid
- SBDF - Synthetic-Based Drilling Fluid
- OBDFs – Oil- Based Drilling Fluids
- NADFs – Non-Aqueous Drilling Fluids.

4. Conclusions

The study shows that high concentrations of some heavy metals were present in the drilling cuttings and oil-based mud samples in a Niger Delta oil field. The heavy metal analysis conducted showed a high concentration of Cadmium, Chromium, Lead and Mercury in the drilling mud samples and a high concentration of Cadmium, Chromium, Lead, Mercury, Silver, and Zinc in the drilling cutting sampled above regulatory limits and this could result in accumulation in aquatic and land organisms in the event of a spill. However extensive study must be carried before drill cuttings can be re-inject to the formation. Disposal options must be evaluated based on economics, environment and operational aspects.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Declarations

We hereby declare that this work is our original work and has not published on any Journal before now.

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