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RISK ASSESSMENT OF DRILLING MUD AND CUTTINGS FROM OHAJI WELLS X AND Y, NIGER DELTA

[1]Asano, N.O. and [2*]Aweto, K. E.

[1]Department of Geology, Delta State University of Science and Technology, Ozoro

[2]Department of Geology, Delta State University, Abraka

*Corresponding Author: keaweto@delsu.edu.ng

ABSTRACT

Drilling muds, commonly used in oil and gas industry in the Niger Delta often contain toxic heavy metals that poses significant environmental risks. They are capable of contaminating the soil and groundwater via leaching into soil and groundwater, especially in the Niger Delta where rainfall is high. This study seeks to appraise the risks connected with heavy metals in drilling mud and cuttings in onshore oil operations so as to ensure that disposed drilling mud do not pose danger to environment. The results obtained from this study show that mean concentration of Fe (2.99 – 494.36 mg/l), Cu (0.0 – 0.29 mg/l), Zn (0.03 – 3.17 mg/l), Pb (0.01 – 1.68 mg/l), Ni (0.0 – 1.82 mg/l), Cr (0.0 – 0.18 mg/l) and Mn (0.16 – 2.30 mg/l). Apart from concentration of iron that was high, all parameters were below the permissible limits. These heavy metals though present in small amounts may coalesce resulting to combined effects that may be detrimental to health and environment. The study validated that perceptivity of the ecological implication of heavy metals in spent drilling muds and cuttings is crucial for environmental sustainability

Key Words: drilling muds, cuttings, toxic, environmental risk, heavy metals

INTRODUCTION

Drilling operation is a process of boring a hole using a drill bit to create a well for oil and natural gas production. In the process of drilling, the drilling mud (water based mud – WBM or oil based mud – OBM) plays several roles that includes: cooling the drilling bit, control of formation pressure, prevention of well collapse, bearing and transporting of the rock cuttings up the hole being drilled. Drilling operations in the Niger Delta have created several environmental and health hazards. Studies by Iselema *et al.* (2012); Onwuka *et al.* (2018); Antia *et al*. (2023); Ndubuisi and Eguzor (2024) reported significant amount of contaminants in drilling mud. According to Bakke *et al*. (2013); Magalhaes *et al*. (2014); Orisakwe *et al*. (2021); Antia *et al*. (2022) WBM and OBM contain significant amount of heavy metals which are hazardous to the environment.

Drilling wastes accounts for the second largest volume of wastes produced by exploration and production sector (Ismail *et al*., 2017; Pereira *et al*., 2022). The drilling waste comprises mainly of leftover of drill mud, while the drilling cuttings consist of the broken rock cuttings from borehole and are returned to the surface with drilling fluid. Drilling mud contain small amount of heavy metals including the following: Hg, Pb, Fe, Cr, Cd, Ar etc. These metals in trace amounts are toxic and can constitute notable risks to groundwater quality and soils if not managed effectively (Antia *et al*., 2023). Other pollutants in drilling mud is caused by the biocides, materials from formation drilled, reservoir fluids (crude oil, brine), and various additives. Drill cuttings from WBM poses little threat particularly to the deep offshore environment, while those from OBM have caused high mortality of organisms. This is due to the presence of low quality base oils that may contain heavy metals (Iselema *et al*. 2012; Ismail *et al*., 2017). Hence the recent requirement of zero discharge for OBM. In Nigeria, there is need for a secondary treatment method and a responsible disposal method; disposal is dependent majorly according to the type of drilling fluid used in the initial operation. There are various kinds of disposal methods that can be used, which includes drill cuttings re-injection, onshore disposal and offshore disposal.

Muds and drill cuttings generated from drilling activities has led to massive pollution and degradation in the Niger Delta oil rich region: this includes contamination of water bodies, danger to aquatic life, destructions of flora, fauna and farmlands (Magalhaes *et al*., 2014). Cuttings are often more contaminated with heavy metals because the metals are naturally present in the formations drilled and can accumulate as drilling progresses with a greater potential for contamination. Siddque *et al*. (2017) reported that improper disposal of the spent drilling mud on the ground can lead to several negative effects on the environment. The aqueous fraction of the drilling mud can seep through the ground and ultimately polluting groundwater. This challenge has further been compounded because of the general high vulnerability of aquifers in the Niger Delta as reported by Aweto (2014), Ohwoghere-Asuma *et al*. (2018) and Aweto *et al*. (2023).

These environmental consequences resulting from disposal of spent drilling mud and cuttings has attracted proper investigation of heavy metal constituents of these waste and toxic nature. The findings of this study will guide treatment of toxic and hazardous spent drilling mud and cuttings, which can be safely disposed without negatively impacting on the environment.

MATERIALS AND METHODS

Location of Study Area

The study area (fig. 1) is Seplat Ohaji well X and well Y in the Niger Delta and located within latitudes 5º15'N, 5º30'N and longitudes 6º40'E, 6º55'E. The Cenozoic Niger Delta Basin is a strongly diachronous sequence subdivided into three lithostratigraphic units: Akata Formation, Agbada Formation and Benin Formation that represents a prograding depositional facies differentiated based on their sand – shale ratio.

The study area is underlain by the Benin Formation (Fig. 1) which is made up of mostly sand that display a range of textures; grain sizes varying from fine to coarse-grained, sub-angular to sub-rounded shapes, characterized by poor to well-sorted arrangement and predominantly sub-arkose to quartz arenites (Amajor 1991). Geochemical signature of sediments this formation indicates derivation from the granodiorites and geissic rocks of the Oban Massif (Nwajide, 2013). Granulometric and morphometric attributes of the Benin Formation are consistent with deposition in a transitional to fluvial environment (Ominigbo *et al*., 2019).

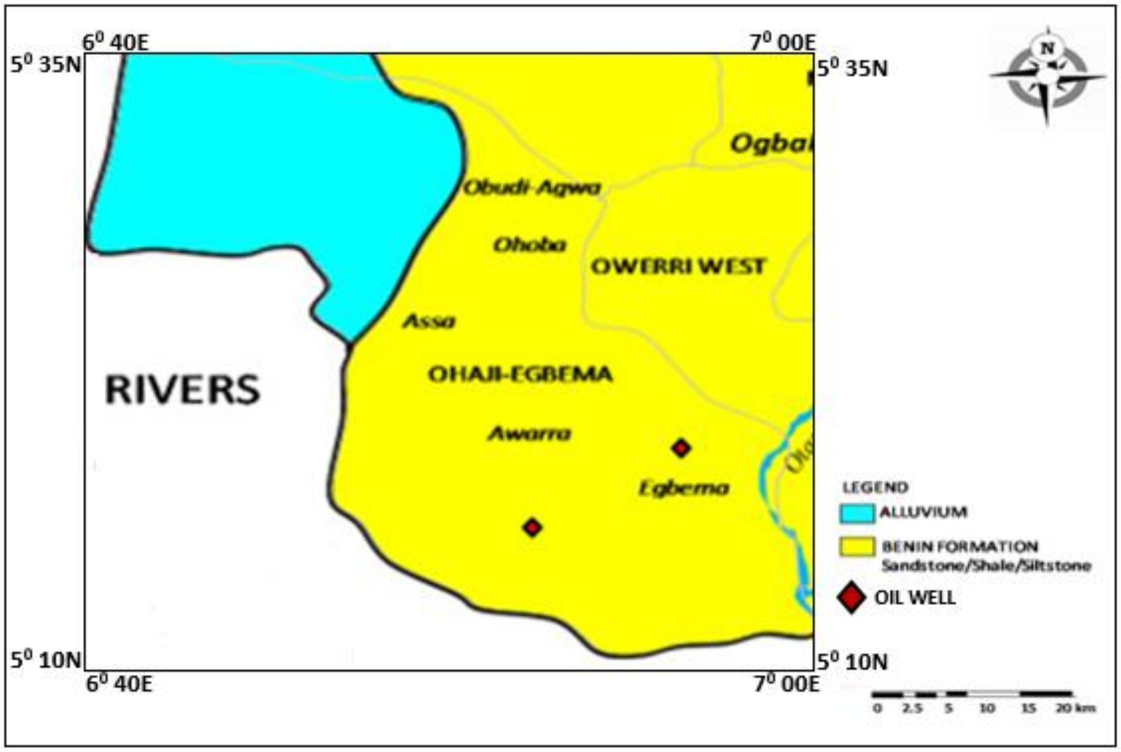

Fig 1: Map of study area showing sampling locations

Sample Collection and Analysis

Twelve (12) samples each of spent OBM, OBC, WBM and WBC from two (2) onshore oil wells were collected at 0 – 4121 feet, 4121 – 10171 and at greater than 10171 feet; making up a total of twelve (12) samples. One gram (1g) of Sodium bisulphate ($NaHSO_4$) was used for the preservation of drilling mud and cuttings samples. Heavy metal analysis involved digestion of 1 g of samples with a mixture of 25 ml of concentrated nitric acid and 10 ml of concentrated sulphuric acid (H_2SO_4) in a beaker. The mixture was carried out in a fume hood due to its health effects. The prepared solution was heated in order to dissolve all constituents; 50 ml of distilled water was slowly added to the mixture in a 100 ml volumetric flask. The prepared solution was then analyzed for the heavy metals of interest: iron (Fe) copper (Cu), zinc (Zn), lead (Pb), nickel (Ni) chromium (Cr) and manganese (Mn) using Atomic Absorption Spectrometer Schimadzu AA-6650 model at Getamme Laboratories Nigeria Limited, Port-Harcourt according to (APHA, 2005).

The Geo-accumulation Index (I_{geo})

The geo-accumulation index I_{geo} was presented by Muller (1969), it is a quantitative metric that show heavy metals enrichment in sediments in relation to background value. The I_{geo} is calculated using the equation:

$$I_{geo} = log_2 \frac{C_n}{1.5 \, X \, B_n} \quad \ldots\ldots\ldots (1)$$

Where c_n and B_n are the measured concentration of heavy metal and the ambient value of corresponding metal respectively and 1.5 is the ambient matrix correction due to the effects of lithology.

Typical background values as reported by Yan *et al.* (2020) will be used in this study.

The I_{geo} values are classified into seven (7) categories to indicate the level of pollution as follows:

$I_{geo} > 5$ (extremely polluted), $I_{geo} = 4 – 5$ (strongly to extremely polluted), $I_{geo} = 3 – 4$ (strongly polluted), $I_{geo} = 2 – 3$ (moderately polluted to strongly polluted), $I_{geo} = 1 – 2$ (moderately polluted), $I_{geo} = 0 – 1$ (unpolluted to moderately polluted) and $I_{geo} < 0$ (practically polluted).

RESULTS AND DISCUSSION

The results of heavy metal analysis in the drilling mud and cuttings collected from two onshore wells of at Ohaji X and Ohaji Y are given in Table 1.The present study indicates that the OBM, OBC, WBM and WBC contain heavy metals. Average Fe concentration in drill wastes samples vary from 2.99 – 208.66 mg/l, the highest value of 714.27 mg/l was measured from OBC at depths of 4121 – 10171 feet. All the values of Fe concentration exceeded the maximum contamination limits (MCL's) of 1.0 mg/l set by Department of Petroleum Resources (DPR) for all samples. Average concentration of Cu range from 0 – 0.29 mg/l; Cu concentration did not exceed the DPR threshold value of 1.5 mg/l except for WBC at depths greater than 10171 feet in well X. Average Zn concentration vary from 0.03 – 3.17 mg/l; these values were below the MCL's except at depths greater than 10171 feet for OBC, where values of 6.17 and 2.64 mg/l were recorded for wells X and Y. Average concentration of Pb which vary from 0.35 – 1.68 mg/l were below the DPR threshold value of 5 mg/l. The average value of Ni vary from 0 – 1.82 mg/l, a relatively high concentration of 2.55 mg/l was observed at depths of 0 – 4121 feet for OBC at well Y. Average Cr concentration vary from 0 – 0.64 g/l, these values were below the MCL's of 5 mg/l set by DPR. A natural component of drilling mud, bentonite contains Cr, however Cr concentration has not reach pollution level. Concentration of Mn averages from a minimum of 0.16 mg/l and a maximum of 2.30 mg/l; the result show contamination in about 40 % of the samples (mostly OBM and OBC) which is more than the DPR limits of 1.5 mg/l.

Table 1: Heavy metal concentrations in drilling muds and cuttings in Ohaji X and Ohaji Y

PARAMETER (mg/l)		OIL BASED MUD			OIL BASED CUTTING			WATER BASED MUD			WATER BASED CUTTING			STANDARD
		Depth (feet)			Depth (feet)			Depth (feet)			Depth (feet)			DPR (mg/l)
		0-4121	4121-10171	>10171	0-4121	4121-10171	>10171	0-4121	4121-10171	>10171	0-4112	4112-10171	>10171	
OHAJI X	Fe	26.42	20.86	19.55	28.32	21.03	22.05	1.94	3.90	3..15	12.66	10.08	16.85	1.00
	Cu	0	0	0	0.07	0.06	0.68	0.33	0.27	0.26	0.12	0.13	0.16	1.50
	Zn	0.15	0.09	0.04	0.08	0.04	6.17	0.06	0.03	0	0.17	0.06	0.05	1.00
	Pb	0	1.64	0.71	0.71	1.68	2.64	0	0.04	0	1.21	0.69	0.98	0.01

	Ni	2.11	0.32	0.02	2.42	2.72	0.32	0.32	0.62	0.42	1.51	1.63	1.22	-
	Cr	0.01	0.01	0	0.65	0.63	0.63	0.02	0.21	0.01	0.02	0.08	0.06	5.00
	Mn	0.15	0.22	0.11	0.45	3.45	0.56	0.21	0.42	0.32	0.15	0.52	0.7	1.50
OHAJI Y	Fe	222.75	257.32	145.92	249.6	714.27	519.2	49.97	34.55	34.47	65.23	138.15	203.55	1.00
	Cu	0.02	0.14	0.12	0.02	0.17	0.35	0.08	0	0	0	0.03	0	1.50
	Zn	0.52	0.36	0.37	0.39	0.73	2.64	0.18	0.23	0.32	0.38	0.55	0.54	1.00
	Pb	0	0.65	0.4	0.2	2.19	0.15	0.73	0.97	0.33	1.81	0.91	0.10	0.01
	Ni	0	0	0	2.55	0.62	0	0	1.49	0	0	0	0.03	-
	Cr	0	0	0	0.25	0.09	0.2	0.01	0.06	0.03	0.06	0.32	0.08	5.00
	Mn	1.14	2.48	1.63	2.72	1.88	2.3	0.23	0.37	0.07	0.26	0.88	0.48	1.50

Table 2: Geo-accumulation Index (I_{geo}) of Drill cuttings

Location	Fe	Cu	Zn	Pb	Ni	Cr	Mn
Well X	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Well Y	3.4	< 1	< 1	< 1	< 1	< 1	< 1

The presence of heavy metals in drilling cuttings do not show a particular pattern with depth. This is adduced to the characteristics of the geologic formation being drilled; heavy minerals are inherent to minerals present in the various formations. Heavy minerals were significantly higher probably in lithologies that were mostly black shales rich in organic matter while clastic rocks like sandstones showed lower or no heavy metal content. The results (Fig. 2) also highlighted higher heavy metal contents in the drill cuttings than drilling mud; this trend was also observed by Iselema *et al*. (2012); Siddique *et al*. (2017). Ayotanmuno *et al*. (2012) attributed this to the fact that the cuttings incorporate heavy metals from the minerals in the rocks and formation water.

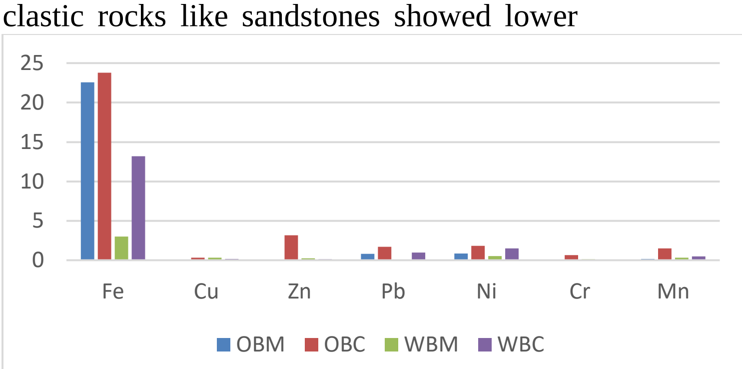

Fig. 2: Average composition of heavy metals in drilling fluid and cuttings from Ohaji well X

Results of geo-accumulation (Igeo) show that Igeo ranged between the values of < 0 in 92 % indicating that the drilling wastes were practically unpolluted with most heavy metals except for Fe in well Y where Igeo was > 3 indicative of srongly polluted. This is due the high concentration of Fe (138.15 – 714.27 mg/l).

The results show that most of the heavy metals in spent drilling mud and cuttings were significantly lower than the recommended standard by DPR and may likely have little or no effect on the environment**.** This was supported by Onwukwe and Nwakauda (2012) who also reported relatively low concentration of heavy metals in spent drilling muds and cuttings in the Niger Delta. However studies by Iselema *et al*. (2012); Onwuka *et al*. (2018); Obinduka *et al*. (2018); Antia *et al*. (2023); Ndubuisi and Eguzoro (2024) reported presence of heavy metals far above DPR permissible limits; with deleterious environmental effects if the drilling waste is dispose into the environment without treatment. The result also generally showed that concentration of iron were notably higher than other metals (Fig. 2). Among the heavy metals analyzed Fe showed the highest concentration of 713.27 mg/l for OBC at Ohaji well Y. This explains why severe corrosion of drilling equipment's and oil water waste storage facility was observed in the study area.

Exposure to spent drilling mud and cuttings to the environment can cause serious harm; even when concentrations of pollutants in spent drilling mud and cuttings is low. Onwukwe and Nwakauda (2012) reported the likelihood of impacts of spent drilling mud after chronic exposure. Pra *et al*. (2012); Okoro *et al*. (2020) has established high carcinogenic and mutagenic risk attributed to heavy metals and radionuclides exposures. The presence of most heavy metals in spent drilling mud and cuttings in this study was quite low (less than the MCL'S set by DPR). This was supported by results of geo-accumulation of heavy metals in drill cuttings (table 2) which show that the drilling mud were practically unpolluted except for Fe pollution of drilling cuttings from Ohaji well Y. However, it is important to note that if these metals are continually released into the environment can result in serious contamination. Anyagwu *et al.* (2018) reported that these metals can increase or decrease each other's toxicity. It is very pertinent to consider that these heavy metals may coalesce resulting to synergistic impacts that may be detrimental to human health and environment. Such discharge into the environment could lead to bioaccumulation in aquatic organisms causing serious environmental and health hazards. It is therefore recommended that drilling waste should be properly treated before disposal.

CONCLUSION

This study assessed the risk associated with heavy metals in drilling mud and cuttings from oil operations, highlighting potential environmental and health risks. The findings indicate significant low levels of heavy metals in drilling mud and cuttings which may likely have effect or non on the environment**.** The heavy metals have the ability to coalesce resulting to synergistic impacts that can increase each other's toxicity; an effect that may be detrimental to human health and environment. Other factors such as bioaccumulation and environmental factors like pH, temperature is capable of making drilling mud and cuttings with low heavy metals content below permissible limits pose contamination risk. This study confirms that improper disposal of drilling mud containing heavy metals poses significant environmental risk.

It is therefore recommended the implementation of stringent disposal guidelines and regular monitoring will help to minimize environmental contamination and protect public health.

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