

Environmental impacts of drilling mud and cutting wastes from the Igbokoda onshore oil wells, Southwestern Nigeria

A.M. Gbadebo, A.M. Taiwo and U. Eghele

*Dept. of Environmental Management and Toxicology, College of Environmental Resources Management
University of Agriculture, P.M.B 2240, Abeokuta, Nigeria
jumaid2000@yahoo.co.uk*

Abstract

The environmental impact of exploratory wastes (drilling muds & cuttings) generated during the drilling of Igbokoda X and Igbokoda Y onshore oil wells, was studied by analyzing its total hydrocarbon (TPH), aliphatic hydrocarbon (AH), polycyclic aromatic hydrocarbon (PAH) using gas chromatography-mass spectrophotometry (GC-MS) method and metal contents using atomic absorption spectrophotometry (AAS). The aim was to determine their toxicity and possible impacts on their immediate environments of disposal. These drilled wastes generated from the drilling of Igbokoda X and Igbokoda onshore wells indicated an exceedingly very high values of AH compared with the values of PAHs in both the oil based and water based muds and cuttings respectively. These values of aliphatic is generally >5000 mg/kg in all oil based sample types analyzed for the drilled muds and generally >4000 mg/kg in all the sample types analyzed for the drilled cuttings. However, these values of the AH varied according to sample types with the water based drilled mud collected at the depth of 4121-10171 feet having values of >6000 mg/kg while the value in the water based drilled cuttings is generally <5000 mg/kg. Both the oil based drilled mud and cuttings have higher values of PAHs at the drilled samples collected between 0-4121 feet than deeper depth and composite samples. Iron (Fe) has the highest concentration followed by calcium (Ca), magnesium (Mg) with varying level of toxic metals like lead (Pb), Nickel (Ni), Manganese (Mn) and Chromium (Cr) in both the oil and water based drilled mud and cuttings from Igbokoda X and Igbokoda Y wells. Most of the analyzed parameters (AH, PAHs, TPH) and metals like Pb, Mn, Cr, etc. generally have values higher than that of the United States Environmental Protection Agency, Federal Environmental Protection Agency and Directorate of Petroleum Resources Standards in some cases thereby implying possible negative impacts on the immediate environments.

Keywords: Total hydrocarbon; aliphatic hydrocarbon; polycyclic aromatic hydrocarbon; Igbokoda.

Introduction

Skeletal activity of onshore oil prospecting started in Nigeria in 1914 became halted and resumed again in 1937. After this period, it continued epileptically until 1958 when commercial quantity of oil was produced in Oloibiri area of Niger Delta. Since 1961, Nigerian oil sector has continued to witness increasing number of oil companies and also increased exploration activities and hydrocarbon production for decades, predominantly in the onshore area and recently extended to the offshore areas of Nigeria. It is evident that hydrocarbon exploration and production involve interplay of activities. These include location of the crude oil deposit through the help of geological mapping and seismic surveys, drilling of the oil wells and its development to production level (Levorsen, 1967). All the activities involved in the hydrocarbon exploration and production according to Odiere (1999) normally have one impact or the other on the environment. However, the greatest impact arises from the release of wastes into the environment in concentration that is not naturally found in such environment. The wastes generated during petroleum production can be broadly classified into liquid (i.e produced water & oil) and solid (i.e drilling muds & cuttings) (Ferrari *et al.*, 2000). Many of the additives used

as the drilling muds are believed to be toxic and should be regulated (Reis, 1988). Drill muds and cuttings may be oil-based or water-based in nature and are associated with varying concentrations of hydrocarbons and heavy metals. The oil based drilling muds (OBM) are largely associated with saturated and unsaturated hydrocarbons, which according to Darley (1988) could be as high as 60% and 45% respectively hence are more toxic than the water-based mud (WBM). Spent drilling fluids and cuttings account for about 2% of the total waste volume while other associated waste like produced formation water contribute over 90 % of the total waste volume (API, 1978). The drill cuttings waste aspect of oil production is generated in tens and thousands of tons during drilling exercise. Over 2.5 million tons of such drill cuttings stock piled in the Norwegian sector of North Seas drilling sites have been documented (Wills, 2000). Even after cleaning, the drill cuttings have been observed to contain a wide array of organic and inorganic traces especially when the oil based muds are used (Wills, 2000). One of the immediate physical environments that suffer the direct impact of drilling wastes disposal is the offshore and onshore. The onshore environment includes the swampy, freshwater and the dry land environments all of which have their peculiar features and ecological

characteristics. Although drilling muds (i.e WBM or OBM) used for drilling of onshore oil wells are primarily disposed off in reserve pits however, due to large quantity of the drill wastes, most of the muds and cuttings can get into the adjacent soil and water bodies during precipitation and run-off. Some drill wastes are even deposited directly on lands meant for farming (Thurber, 1992). Unlike in the dry land oil, waste pollution of the swampy areas and freshwater bodies by their nature are difficult to clean of contaminated oil (Imevbore, 1979). The heavy metal and hydrocarbon contents of the onshore drilling wastes are capable of polluting the environment with resultant effects on human health. However, this depends on the type, nature and concentrations of the heavy metals and hydrocarbons (Hastings *et al.*, 1984) and also the level of exposure (API, 1978). Since the disposal of drilling mud and cuttings has been observed to be of continuously growing concern especially to the researchers in the western world due to their numerous negative effects on the health, safety and environments (HSE) (Moseley, 1983), Nigeria cannot be an exception in this regard. The study therefore assessed the environmental impacts of drilling muds and cuttings generated from two onshore oil wells from Igbokoda field with respect to the toxicity of the constituent heavy metals and hydrocarbons, and suggest possible alternative ways of managing these wastes.

Materials and methods

Study area

Igbokoba onshore wells where this study is carried out are located in Ondo state, southwestern Nigeria. The wells lie between latitude $5^{\circ}50^1$ N and $5^{\circ}55^1$ N and longitude $5^{\circ}5^1$ E and $5^{\circ}10^1$ E. The Igbokoda wells X and Y are cited in the mangrove and fresh water forest respectively, which have been observed to be rich in both flora and fauna species (Imevbore, 1979).

Methodology

A total of twelve (12) oil based drilling wastes (i.e. cutting & mud) from two onshore oil wells were used for this study. Six samples (i.e. cuttings & mud) comprising of start samples (at 4121 feet); final/end samples (at 10171 feet) and composite samples (4121-10171 feet) collected from each well were analyzed for both the total petroleum hydrocarbon (TPH) and polycyclic aromatic hydrocarbons (PAHs). Also, a total of twenty-four (24) oil based and water-based exploration waste materials (i.e. cuttings & drill mud) generated at the above stated depths during the drilling process of Gbokoda X and Gbokoda Y onshore oil wells ready to be disposed into the environment were collected for the metal analysis.

A 10 g of drill mud (or cutting) was weighed into a solvent rinsed beaker. To this was added 50 ml of 50:50 mixtures of acetone and dichloromethane (DCM). The sample was spiked with 1 ml of a surrogate mix (ortho-terphenyl-OTP) and placed in a sonicator for about 15 min at about 20°C. 10 grams of anhydrous sodium sulphate was added to the sample and allowed to stand until a

clear extract developed and decanted. The solvent was concentrated, exchanged with HPLC grade hexane and reconcentrated to about 3 ml. The extracted samples was transferred into a Teflon lined screw-cap vial, labeled, corked and transferred to the GC-MS for the TPH analysis. Similarly, samples were extracted as done for TPH and to a 1 ml of the extracted samples was added 60 ml of hexane (HPLC grade) in order to first elute the aliphatic hydrocarbon, 75 ml of dichloromethane (DMC) was later added to elute the aromatics. The eluted samples were concentrated and the aromatic was exchanged with hexane before reconcentrating to about 3 ml. The sample was finally transferred into a Teflon lined screw-cap vial, labeled and transferred to the GC-MS for PAHs analysis. Metal Analysis involved digestion of 1 g of each sample type 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).

The results obtained were compared with DPR, (1991) and USEPA,(1990) standards for drilling waste disposal.

Results

Table 1 shows the concentration variations of the TPH while Table 2 shows concentrations of different metals obtained for both cuttings and the drilling muds in Gbokoda X and Gbokoda Y onshore oil wells. Here, the TPH contents of the composite cutting samples are higher than other sample types in both wells while the TPH of the end sampling point (10171 feet) drilling muds are higher than both the initial (4121 feet) and composite (4121-10171 feet) mud samples in both wells. This might be due to contact effects of both the drilling muds and cuttings with the hydrocarbon on the reservoir rocks drilling down the hole. The assay result of the analysis carried out on drilling mud and cuttings collected at different depths from the onshore oil wells are shown in Fig. 1-8. Total petroleum hydrocarbon analyzed in this study consists of aliphatic hydrocarbon (AH) and polycyclic aromatic hydrocarbons (PAHs). The values of the total petroleum obtained from the two wells ranged from 3737.90 to 4092.21 mg/kg for cuttings and 6, 449.54 to 7, 056.57 mg/kg for drilling mud. The aliphatic hydrocarbon content of the oil based and water based muds and cuttings are higher than that of PAHs in both wells. Further analysis revealed that OBM showed indication of relatively higher content of oil at almost all depths than WBM. The relatively higher aliphatic contents of WBM at depth (4121-10171 ft) may be as a result of natural mixing of oil with the drilling mud at greater depth from the oil well. In the case of drill cuttings, there is virtually no difference between the aliphatic contents of oil based cuttings (OBC) and water based cuttings (WBC) even at different depth. However, the values of TPH in the drilling mud and cuttings from both wells are quite low when compared with the FEPA (1991) while the values are quite higher than the permissible content of oil in discharged drill cuttings (GESAMP, 1993).

Table 1. Total petroleum hydrocarbon and PAHs concentrations of drilling muds and cuttings in Gbokoda X and Gbokoda Y onshore oil wells

Parameters (mg/kg)	Gbokoda X						Gbokoda Y					
	Oil-Based Mud			Oil-Based Cuttings			Water-Based Mud			Water-Based Cuttings		
	Depth (feet)			Depth (feet)			Depth (feet)			Depth (feet)		
	0-4121	4121-10171	Composite	0-4121	4121-10171	Composite	0 - 4121	4121-10171	Composite	0 - 4121	4121-10171	Composite
Aliphatics	5678.69	6435.82	5219.43	4430.72	4071.00	4854.18	3160.00	7132.97	4229.39	4504.65	3719.45	4877.90
PAHs	18.08	13.72	13.00	51.29	20.52	36.91	16.33	23.60	15.33	63.14	18.44	29.73
TPH	5696.39	6449.55	5232.76	4482.01	4092.21	4686.00	3175.95	7156.57	4244.74	4567.79	3737.90	4907.63
PAHs PROFILE												
Naphthalene	0.20	0.50	0.84	0.11	0.04	0.70	0.10	0.08	0.08	0.13	0.04	0.07
2-Methyl Naphthalene	0.57	0.56	0.34	0.91	0.42	0.35	0.60	0.66	0.42	0.89	0.25	0.52
Acenaphthalene	0.75	0.60	0.48	0.99	0.67	0.69	0.86	0.70	0.59	1.99	0.59	0.76
Florene	0.74	0.48	0.31	2.11	0.67	0.36	0.94	1.05	0.64	2.14	0.76	0.94
Phenathrene	0.51	0.76	0.80	1.21	0.84	0.85	0.42	0.58	0.31	1.39	0.43	0.46
Anthracene	0.74	0.63	0.41	2.61	0.51	0.64	0.81	1.06	0.57	2.22	0.80	0.93
Fluoranthrene	0.80	0.57	0.36	11.50	0.85	3.71	0.79	1.01	0.56	15.50	0.74	8.56
Pyrene	0.86	0.84	0.57	5.10	1.31	4.11	0.97	1.53	0.67	2.11	1.12	1.17
Benzo(a)anthracene	3.03	0.53	0.00	3.71	2.07	3.81	1.28	1.43	0.00	1.78	0.77	0.57
Crysene	0.55	0.61	0.58	3.31	1.21	5.32	0.63	0.00	0.30	8.13	0.51	2.69
Benzo(b)fluoranthene	3.03	0.53	0.00	5.71	2.07	3.81	2.66	0.57	2.42	4.39	2.00	1.72
Benzo(k)fluoranthrene	0.92	0.73	0.03	4.31	2.42	2.62	0.29	0.49	0.94	5.91	2.21	2.04
Benzo(a)pyrene	1.61	1.39	0.86	1.23	1.02	1.52	1.16	1.93	1.49	2.13	1.08	1.41
Benzo(a, h)pyrene	1.84	1.59	1.50	5.41	2.45	3.83	1.71	2.94	1.67	2.11	1.65	1.41
Dibenzo(a,h,i)pyrene	2.01	0.49	1.76	0.61	2.51	2.53	1.94	2.13	1.13	7.97	1.54	1.13
Indeno(1,2,3)perylene	1.84	1.48	1.50	2.00	0.99	1.63	0.48	5.77	3.62	0.00	3.35	3.72
Total PAHs	17.70	13.72	13.32	51.25	20.05	36.48	16.34	23.60	15.33	63.14	18.44	29.73

Table 2: Trace metal concentrations of drilling muds and cuttings in Gbokoda X and Gbokoda Y onshore oil wells

Parameters (mg/kg)		Oil-Based Mud			Oil-Based Cuttings			Water-Based Mud			Water-Based Cuttings			Standards	
		Depth (feet)			Depth (feet)			Depth (feet)			Depth (feet)			WHO (mg/l)	USEPA (mg/l)
		0 - 4121	4121 - 10171	Compo-site	0 - 4121	4121 - 10171	Compo-site	0 - 4121	4121 - 10171	Compo-site	0 - 4121	4121 - 10171	Compo-site		
Gbokoda-X	Fe	26.43	20.87	19.54	1.95	3.90	3.14	28.33	21.01	22.05	12.66	10.09	16.84		0.3
	Cu	0.00	0.00	0.00	0.06	0.06	0.32	0.32	0.28	0.26	0.12	0.13	0.16	2.0	1.3
	Zn	0.06	0.03	0.00	0.15	0.09	0.04	0.08	0.04	6.17	0.17	0.06	0.50	3.0	5.0
	Pb	0.00	2.64	0.71	0.71	1.68	0.71	1.20	0.69	0.97	0.00	0.04	0.00	0.01	0.0
	Ni	2.42	2.72	0.32	2.12	0.32	0.02	1.52	1.62	1.22	0.32	0.62	0.42		0.02
	Cr	0.01	0.01	0.00	0.02	0.08	0.06	0.02	0.21	0.01	0.65	0.63	0.63	0.05	0.1
	Mn	0.15	0.22	0.11	0.15	0.52	0.70	0.21	0.42	0.32	0.45	3.45	0.56	0.5	0.05
	Ca	5.17	7.03	6.06	5.70	1.42	0.89	6.76	6.64	4.64	6.24	5.06	6.78		
	Mg	0.19	2.88	0.99	1.51	3.07	3.86	4.62	4.37	4.28	4.73	9.24	5.52		
	K	0.15	1.76	0.02	0.30	5.76	4.56	1.47	1.95	2.03	1.58	1.73	1.06		
Gbokoda-Y	Fe	222.75	257.32	145.93	249.60	714.39	518.50	49.90	34.54	36.46	65.27	138.25	203.54	0.5	0.3
	Cu	0.35	0.14	0.12	0.02	0.16	0.24	0.08	0.00	0.00	0.00	0.03	0.00	2.0	1.3
	Zn	0.52	0.36	0.37	0.39	0.73	2.63	0.18	0.22	0.32	0.38	0.55	0.54	3.0	5.0
	Pb	0.00	0.65	0.40	0.20	2.19	0.14	1.81	0.91	0.91	0.78	0.97	0.33	0.01	0.0
	Ni	0.00	0.00	0.00	0.00	1.50	0.60	2.56	0.00	0.00	0.00	0.00	0.00		0.02
	Cr	0.06	0.32	0.08	0.25	0.09	0.20	0.00	0.00	0.00	0.01	0.06	0.03	0.05	0.1
	Mn	1.41	2.48	1.63	2.26	1.89	2.30	0.22	0.37	0.07	0.26	0.88	0.48	0.5	0.05
	Ca	126.56	112.01	178.86	22.87	0.59	22.50	45.16	30.30	60.02	37.73	37.70	30.30		
	Mg	18.00	12.83	7.83	14.33	52.50	22.50	8.75	1.75	13.13	4.42	9.58	8.00		
	K	9.84	7.17	7.17	11.78	3.21	2.20	4.65	0.00	0.19	0.04	1.77	0.04		

Fig. 1. Concentration of aliphatic, PAHs and total hydrocarbon in oil-based mud and cuttings at Igbokoda X onshore oil well

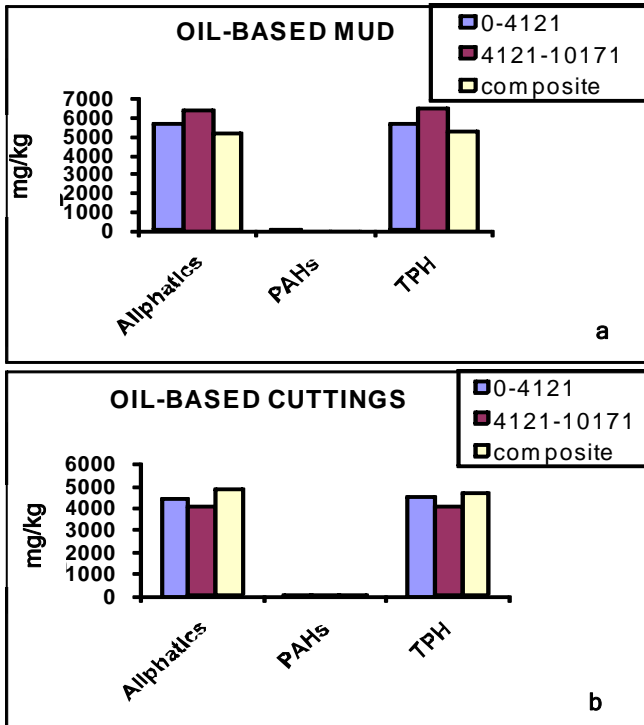


Fig. 2. Concentration of aliphatic, PAHs and total hydrocarbon in water-based mud and cuttings at Igbokoda Y onshore oil well

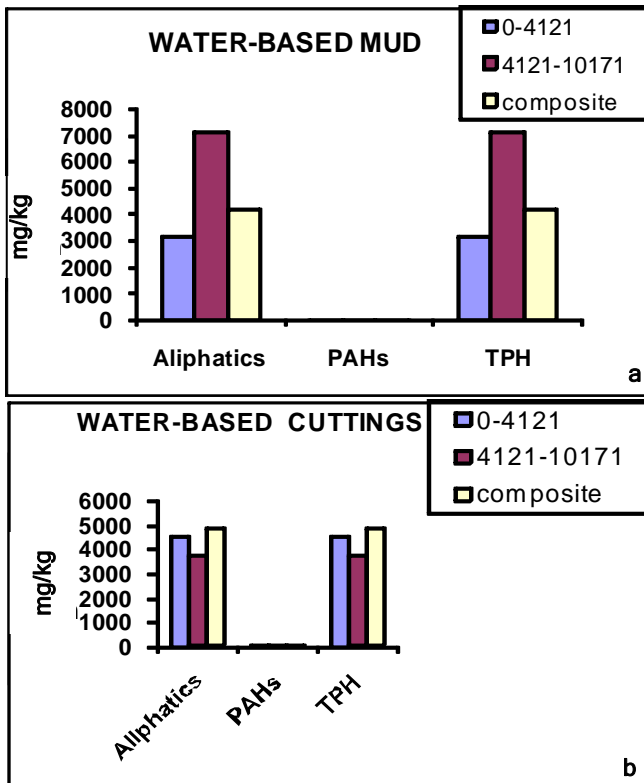


Fig. 3. PAHs concentrations in oil-based mud and cuttings at Igbokoda X onshore oil well

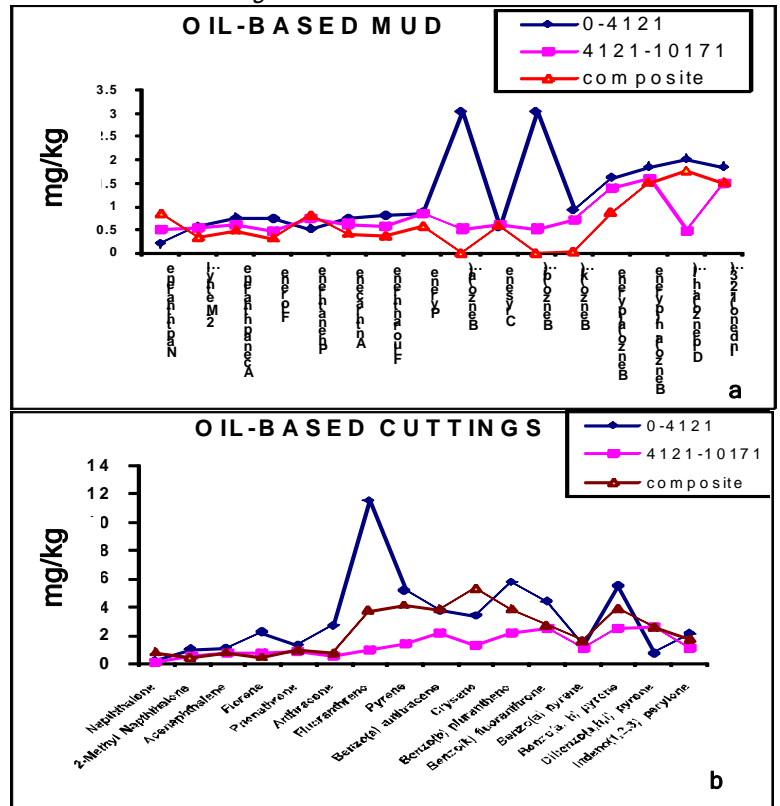


Fig. 4. PAHs concentrations in water-based mud & cuttings at Igbokoda Y onshore oil well

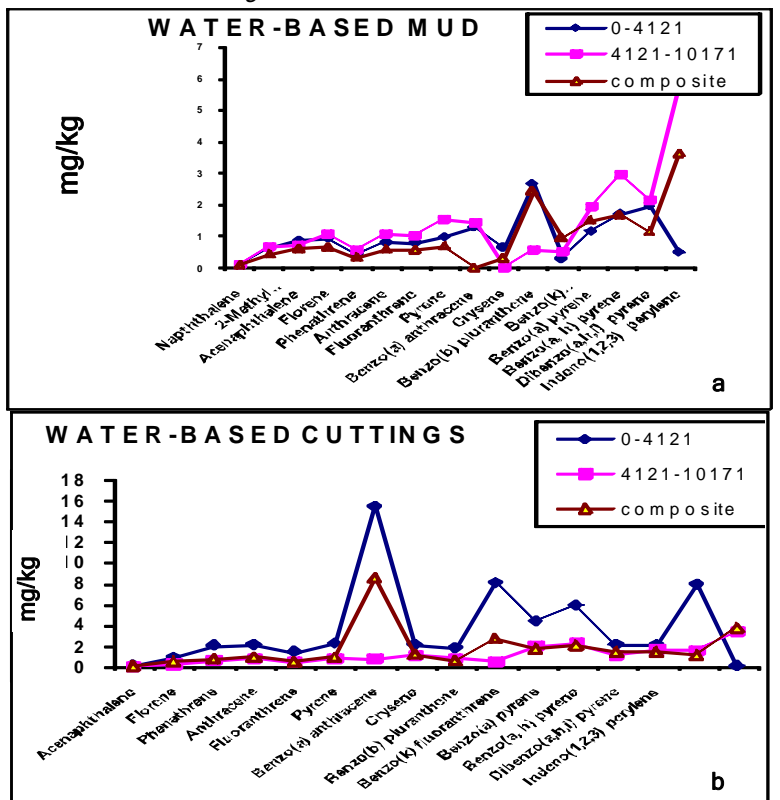


Fig. 5. Trace metals concentration in oil-based mud and cuttings at Igbokoda X onshore oil well

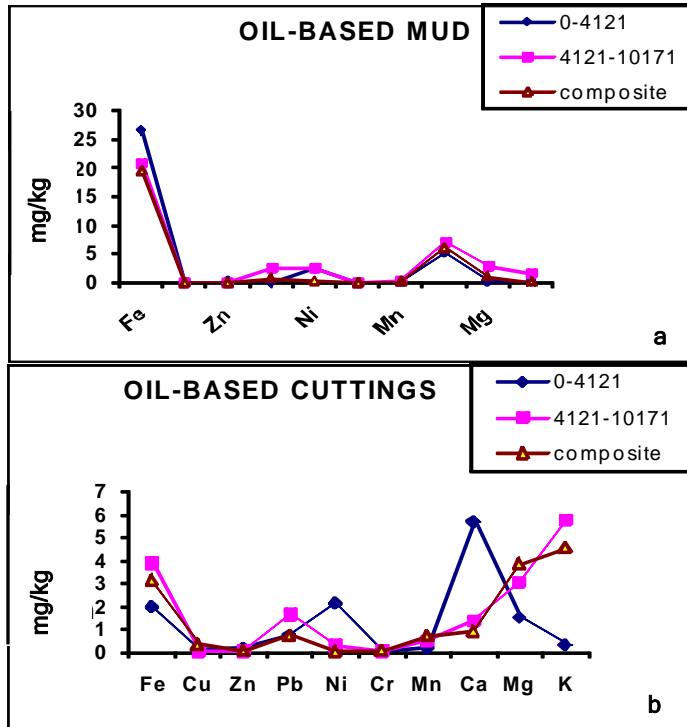


Fig. 6: Trace Metals concentration in oil-based mud and cuttings at Igbokoda X onshore oil well

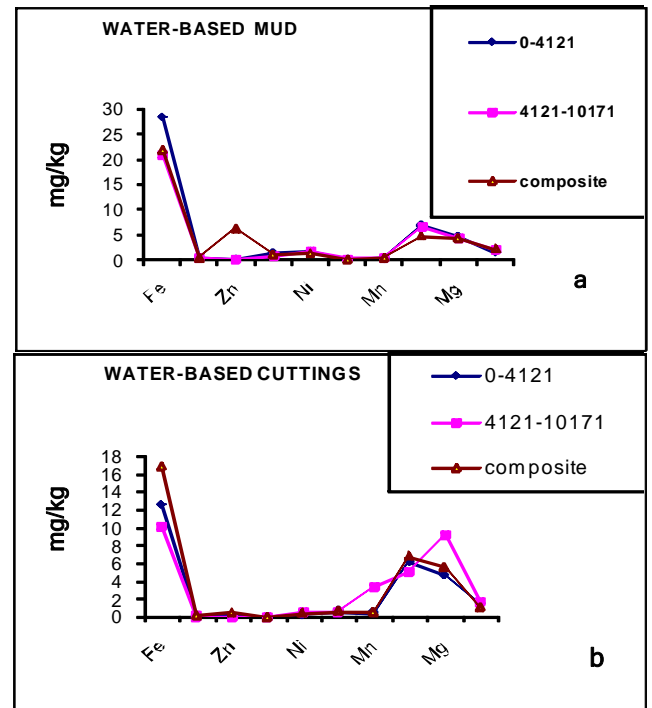


Fig. 7. Metals composition of oil-based mud & cuttings at Igbokoda Y onshore well

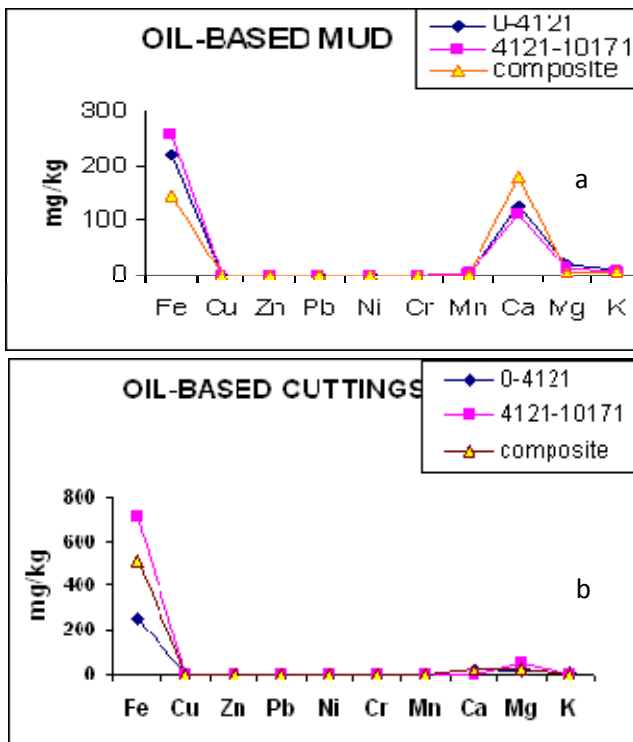
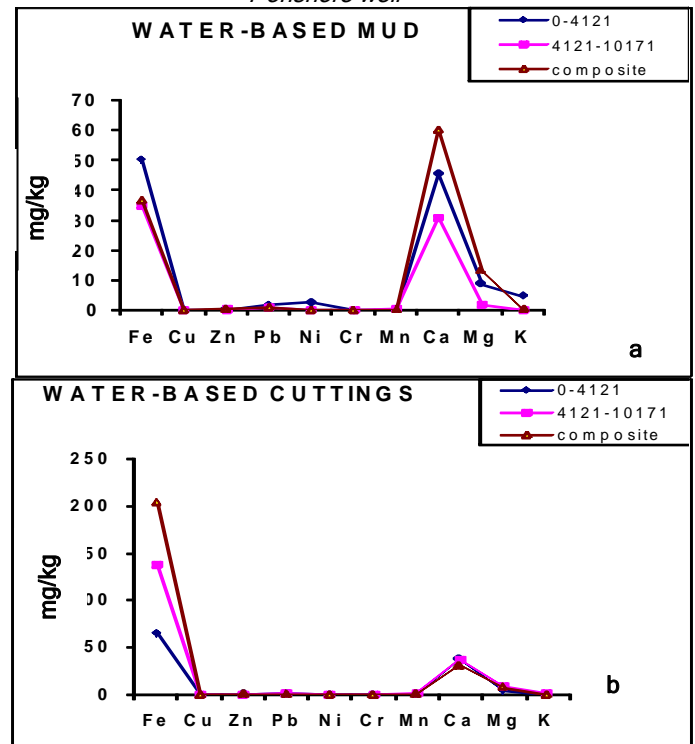


Fig. 8. Trace metals concentration of water-based mud and cuttings at Igbokoda Y onshore well



Shown in Fig. 3 and 4 respectively are the results of PAHs analysis of the collected cuttings and mud samples. The results highlighted the distribution of different components of the PAHs and their concentration profile in both the drilling muds and cuttings. The different types of PAHs analyzed in this study have been considered as priority pollutants (EPA, 2003). The values of the PAH in both wells ranged from 18.44-20.52 mg/kg for cuttings and from 13.72-23.60 mg/kg for drilling muds. The results indicated relative abundance of the various components of the PAHs in both oil based and water based cuttings than muds. This may be due to the fact that the drill cuttings are originally derived from the reservoir rocks that pay host to the hydrocarbon. The results of metal analysis in the drilling muds and cuttings collected from two onshore wells of Igbokoda are shown graphically in fig. 5-8. From the distribution profiles of the metal contents of the drilling muds and cuttings, it can be observed that both the muds and cuttings contain an appreciable contents of Fe, base metals (Ca, Mg, K & Na), and toxic elements (Mn, Pb, Ni & Cr). Although, FEPA (1991) guidelines for the disposal of petroleum exploration wastes (i.e muds & cuttings) into Nigerian environment has no limit for PAHs, however the PAHs values obtained in this study are far higher than the Canadian interim standards on PAHs in soils and water (Wilson & Jones, 1992).

Discussion

Since hydrocarbons are among the most persistent organic chemicals in the environment, the long-term effect of the TPH found on the disposed drilling mud and cuttings (in this study) by most of the oil companies on the terrestrial ecosystem may be far serious and long lasting than the obvious short-term effects (Imevbore, 1979). This TPH content of the drilling mud and cuttings generated by the oil companies becomes a thing of great concern when one considered its environmental pathway. According to national research council, NRC (1985) hydrocarbons are transferred from prey to predator and can be retained in organisms for a very long period or entire lifetime. PAHs are of particular interest due to their established mutagenic and carcinogenic activities (IPCS, 1998). The threshold limit value of each constituent of PAHs in both the land and marine environments has been given as 0.1 mg/kg in soil and 0.2 µg/l in water in order to be able to assess the degree of release of PAH in the environment (Wilson & Jones, 1992). Most values of PAHs obtained in this study are higher than this limit both in water-based and oil-based mud and cuttings (Figs. 3 & 4). From the mean values for the PAHs in oil-based and water-based mud and cuttings at the two sites, pyrene, benzo(b)fluoranthrene, benzo(a) pyrene exhibit remarkable but varying peaks of concentration. Both the TPH and PAHs values suggest that the oil wastes generated from the studied wells are probably not properly treated before disposal.

In all the wells sampled, the occurrences of the following metals are recorded viz: iron, copper, chromium and magnesium etc. The results showed higher metal contents in the drill cuttings than drilling muds, a trend that conforms to the findings of Veritas (2000), who also observed high concentration of chromium, lead, copper, zinc and barium in the analyzed drill cuttings. The results also generally indicated that iron is relatively higher in concentration than all metals. The value ranged from 1.95-714.39 mg/kg for oil based cuttings; 20.87-257.32 mg/kg for oil based mud while it ranged from 10.09-2003.54 mg/kg for water based cutting; 21.01-36.46 mg/kg for water based mud. These values were generally higher when compared with the established standard (0.1 mg/l) for iron in inland fresh surface water (FEPA, 1991). This then explains why there may be corrosion in the drilling equipments and oil water waste storage facility and even abundant of iron in the soils of the study area. Manganese metal was found relatively abundant in Igbokoda well Y than Igbokoda X. The maximum value of 2.48 mg/kg obtained for Mn in this study is still within the acceptable limit. This metal was found in abundance in the drilling wastes from Igbokoda X wells and almost totally absent in Igbokoda Y well (Table 2). The highest value of 2.72 mg/kg recorded for nickel metal was in Igbokoda X oil based mud. This metal ranks fourth in concentration in the two onshore wells in Igbokoda. In the onshore drill wastes, the value of lead ranged from 0.00-2.64 mg/kg for oil based samples and 0.0-1.81 mg/kg for water based samples. The concentration of lead in the disposed drill cuttings and muds (both oil & water based) are far higher than the recommended 0.005 mg/l by FEPA (1991) and the threshold level of 0.05 mg/l. There is possibility of increased lead concentration in the surrounding environment of the drilling operation resulting from continuous discharge of lead containing drill wastes (i.e muds & cuttings). The values of copper, zinc and chromium all appear to be relative low in both oil based and water based drill wastes however the concentrations are still considered very high when compared with the FEPA standards and established threshold levels. The continuous entry of these metals into the surrounding environment can result in serious contamination. Alloway (1968) inferred that chromium has a high potential of accumulating in the soil. Where they are less mobile and less absorbed by plant the adverse effect is the high level of accumulation and contamination in soil. It has also been observed that both the oil-based and water-based drill wastes are relatively rich in calcium, magnesium and potassium which are differently required by different categories of plants and animals in the environment. The environmental impacts of drilling muds and cuttings aspect of oil production activities can be extensive and biologically significant. WBMs produce short term minor impacts on the sea birds and other aquatic animals while the OBMs are capable of producing long-term and more severe impacts (Veil *et al.*, 1999). The drill cuttings may

be contaminated with the hydrocarbon contents of WBMs or OBMs. The drill cuttings chips are capable of escaping into the aquatic environments directly or indirectly thereby causing serious possible ecotoxicological disturbance. Similarly, the drill cutting piles are capable of smothering seabird and the cuttings remain toxic for many years due to its hydrocarbon content. Besides, Patin (1999) inferred that drill cuttings discharges from oil activities can cause effects that are more hazardous due to contamination by oil and toxic components of drilling muds.

Conclusion and recommendations

This study has revealed the high concentrations of various aliphatic, polycyclic aromatic hydrocarbons and total petroleum hydrocarbon, which are released into the environment during oil-exploitation and processing. These discharges have potential environmental implications. Heavy metals analyses done on the muds and cuttings from different onshore oil wells were high in concentrations and this could lead to bioaccumulation in aquatic organisms. It is therefore recommended that wastes resulting from oil activities (cuttings & muds) should be properly treated before it is disposed into the environment by oil exploration companies. Wastes from drillings and cuttings should be disposed of in secured landfills. The new trend is that waste materials from the oil industries should be seen as raw materials for re-use. The solid wastes (drilling muds & cuttings) if properly treated can serve as raw materials for cement producing plants, bricks and expanded clay producing plants and can also be used in land restoration projects. Disposal of cuttings and drilling wastes into the onshore environment should be totally discouraged and litigated.

References

1. Alloway WH (1968) Agronomic controls over the environmental cycling of trace elements. *Adv. Agronomy*. 20, 235-274.
2. API (American petroleum institute) (1978) API recommended practice. Standard procedure for testing drilling mud, API, Washington D.C, pp:35.
3. Darley HCH (1988) Composition and properties of drilling and completion fluids. Gulf publishing company, Houston, Texas. pp: 665.
4. DPR (Department of Petroleum Resources) (1991) Environmental guidelines and standard for the petroleum industry in Nigeria.
5. EPA(2003) Drinking water infrastructural needs survey. www.eoa.gov/safewater/needssurvey/pdf2003. Factsheet 816F05014.
6. FEPA (Federal Environmental Protection Agency) (1991) National interim guidelines and standards for environmental pollution in Nigeria. Federal environmental protection agency. pp: 54-58.
7. Ferrari G, Ceccini F and Xiao L (2000) Drilling wastes treatment and management practices for reducing impact on HSE: ENI/AGIP experiences, Paper SPE 64635 presented at the SPE int. oil and gas conf. and exhibition in China, Beijing. pp: 1-11.
8. GESAMP (1993) *Impact of oil and related chemicals and wastes on the marine environment*. GESAMP reports & studies No. 50. International maritime organization, London.
9. Hastings L, Cooper GP and Burg W (1984) Human sensory response to selected petroleum hydrocarbons. In: *Advances in modern environmental toxicology*. MacFarland HN, Holdsworth CE, MacGregor JA *et al.* (eds.), Vol. VI: Applied toxicology of petroleum hydrocarbons. Princeton, NJ: Princeton Sci. Publ. Inc., pp: 255-270.
10. Imevbore AMA (1979) Impact of oil production on 5 biota of the Niger Delta, lecture series 10. University of Ife Press, Nigeria.
11. IPCS (1998) *Methyl tertiary-butyl ether*. Geneva, WHO, Int. Prog. Chemical Safety (Environmental health criteria 206).
12. Levorsen AF (1967) *Geology of petroleum*. Freeman & Co. London (2nd Ed.). pp: 724.
13. Moseley HR (1983) Summary of API onshore drilling and produced water environmental studies. SPE.11398 presented at IADC/SPE drilling conf. New Orleans.
14. NRC (National Research Council) (1985) *Oil in the sea: inputs, fates, and effects*. National academy of sciences press, Washington, DC. www.nap.edu/books/0309084385/html.
15. Odiete WO (1999) *Environmental physiology of animals and pollution*. Diversified resources Ltd. Lagos, Nigeria. pp: 261.
16. Patin S (1999) *Environmental impact of the offshore oil & gas industry*, (Elena Cascio, trans.). pp: 3-77.
17. Reis JC (1988) *Environmental control in petroleum engineering*, Gulf publishing company, Houston, Texas. pp: 560.
18. Thurber NE (1992). Waste minimization for land-based drilling operations. *J. Petroleum Technol.* 44 (5), 542-547.
19. USEPA (United States Environmental Protection Agency) (1990) National primary and secondary drinking water regulations; Synthetic organic chemicals and inorganic chemicals. Federal register. 55(143), 30370.
20. Veil JA, Daly JM and Johnson N (1999) EPA Speeds Regs for offshore synthetic-based mud. *Oil Gas J.* 97(37), 78-85.
21. Veritas DN (2000) Technical report - Drill cuttings joint industry project. Phase I summary report. Revision 2: 20th Jan 2000. DNV doc. order No. 29003500. Oslo.
22. Wills MAJ (2000) Muddied waters: A survey of offshore oilfield drilling wastes and disposal techniques to reduce the ecological impact of sea dumping. *Ekologicheskaya Vahkta Sakhalina* (Sakhalin Environment Watch). pp: 32-36.
23. Wilson SC and Jones KC (1992) Bioremediation of soil contaminant with polycyclic aromatic hydrocarbon (PAH): a review, *Environ. Poll.* 31, 229-249.