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Assessment of heavy metals concentration in mud cuttings of reserve pit 7 in Twiga 1 well pad South Lokichar Basin relative to acceptable levels in drinking water

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Abstract

Mud cuttings forms the largest volume of the waste generated during petroleum oil and gas drilling. Most often they are stored in reserve pits before final disposal which mostly is being spread in agricultural farms after incineration or being buried with shallow soil in reserve pits. Barite (Barium Sulphate) often added as a weighting agent to drilling muds to counteract pressure in the geological formations being drilled inhibiting well blow out contain elevated levels of heavy metals. These heavy metals contaminate the mud cuttings during the drilling process and if poorly managed these cuttings can leach out and contaminate underground water ecosystems. X-ray Florence machine was used to determine the heavy metals concentrations in the mud cuttings. The heavy metals concentration detected in the reserve pit was in the order of Iron> Calcium> potassium> lead> Manganese> Copper andd Nickel with their average values being 70.74ppm, 62.57ppm, 8.14ppm, 4.58ppm, 1.58ppm, 0.21ppm and 0.05ppm respectively. The results indicated that heavy metals such as Manganese (Mn), Iron (Fe), and Lead (Pb) concentration levels in the mud cuttings were all above World Health Organization (WHO), and United State Environmental Agency (USEPA), recommended levels for consumption water posing a potential danger to human and animal health in case of exposure.

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Introduction

Oil exploration activities results in generations of waste materials that are potential pollutants to water ecosystems (Namuyondo, 2014). The drilling stage of oil exploration leads to a lot of waste materials generation. According to (Mbithe, 2016) these waste materials entails the drilling fluids contaminated drill cuttings, that if poorly managed, may end up polluting the water bodies and other ecosystems. The aim of this study was to determine the concentration of heavy metals in the mud cuttings sampled from Twiga 1wellpad.The findings would help in guiding proper management of the cuttings averting possible pollution to the water ecosystems in the study area.

Mud cuttings forms the largest volume of the waste material generated from exploration drilling. According to Neff *et al.* (2000), mud cuttings comprise of minor rock debris formed when the drilling bit cuts into the rock and extends the hole. These small rock materials are generally uneven with flake structure and do vary in texture, size, and shape depending on the nature of the drill bit and the parent rock material (Balgobin, 2012).The formed cuttings are pumped out of the well by the drilling mud running inside the drill string down the drill pipe(Vaughan 2012). Devold (2013) explains that the drilling mud exists via the perforations in the drilling bit and suspends the mud cuttings and is carried to the surface through the annulus and eventually do sediment by gravity in the reserve pit. Mud cuttings account for the most significant percentage of the drilling waste materials, and therefore proper management strategies are very crucial for sustainable environmental management (Onwukwe & Nwakaudu, 2012). Mud cuttings gets contaminated by the drilling muds during exploration drillings. The structure of contemporary drilling mud can be quite multifaceted and can vary extensively, not only from one spatial area to another but also from one depth to another of a given well (Shadizadeh & Zoveidavian 2010). Mbithe (2016) observes that, there are three types of drilling muds the water-based, the oil based and the synthetic based fluids. Behnamanhar (2014) records that the water-based fluids can be prepared with saline or freshwater and are the ones used in most cases. They are a bit affordable and mostly used in upper sections of well drilling. In case of drilling of water sensitive formations, oil-based fluids form the best choice, also in cases of high temperatures or to prevent the bit corrosion (Katarina *et al.*, 2006).Synthetic-based fluids do not have polynuclear aromatic hydrocarbons, they are less toxic, decompose faster, and they bio accumulate less as compared to the oil-based muds(Neff *et al.,* 2000). The fluids performs various functions during the exploration activities, and key among them is transporting the mud cuttings away from the drill face, lubricating the drill bit and balancing the hydrostatic pressure (Gbedebo, 2010).

Devold (2013) notes that drilling muds are composed of four components. These are the liquids which could be oil or water-based; the reactive solids which are the density and viscosity part of the system and they are often bentonite clays. The solids, which are inert in nature act as a weighting agent to sustain pressure in the well, and Barite (Barium Sulphte) which has elevated levels of heavy metals is the main agent used. Additives are used to control the physical, chemical and biological aspects of the drilling muds. They include the lime and caustic soda to control PH and other conditioning reagents that consist, starches, emulsifiers, lubricants, organic polymers, surfactants detergents lignite materials and salts (Mbithe, 2016). Many additives found in the drilling muds are toxic. Poor disposal of the drilling mud contaminated mud cuttings can lead to water pollution with heavy metals (Al-haleem Saeed *et al.,* 2013). This is evidenced by studies done globally that have shown poor reserve pit waste management contaminates underground water. In Mexico, the New Mexico Environmental Bureau, since its inauguration in the mid-1980s, has documented more than 6,700 cases reserve pits causing water and soil contamination in the state with 557 of those cases resulting into groundwater contamination (Anderson, 2003). This observation was also made by Balgobin (2012) who noted that heavy metals and hydrocarbons from poorly managed mud cuttings had contaminated both underground water and surface water in Niger Delta in Nigeria. The most frequently found selected heavy metals have customarily been Barium from Barite used as the density control material and Chromium from chrome-lignosulfonate deflocculates. According to Zoveidavianpoor *et al.,* (2012), Barite comprises of Barium Sulfate ($BaSO_4$), and it is generally crashed to tiny size symmetrical particles pre its use as a weighting agent in the fluid. Due to the contaminations in the Barites, other metals will also be generally present. Higher levels of Lead, Copper, Nickel and Zinc drill waste have been found relative to the commonly occurring metals. Barite has a high level of impurities,considered as the primary source of the mentioned heavy metals contamination in the drilling mud.

Another significant component of the heavy metal pollutants is the Chromium, which is a component of mud additives, principally Chrome-based deflocculates. The hexavalent form of Chromium used as a gel thinner, a stabiliser for high temperature, a biocide and a corrosion inhibitor is quite toxic (Mbithe, 2016). Lower concentrations of Arsenic, Cadmium, Mercury, Zinc have been detected in drilling muds (Rourke & Connolly, 2003). According to Conant & Fadem (2012) heavy metals do not stay confined within the waste material generated from the drilling activities but in most cases leach out into the underground water and the soil. The significant distress over their occurrence in an environment arises because they cannot be broken down to non–hazardous forms and so their pollution in any given biome remains a potential permanent threat (Adesodun, 2007). Bassey *et al.* (2013) indicated that the most hazardous heavy metals to both animals and humans health are Lead, Mercury, Cadmium, Arsenic, Copper, Zinc, and Chromium.The Government of Kenya has ventured into commercial oil exploration for the very first time in history, little research has been done on drill cuttings generation, their management and their potency in water and other ecosystems pollution in the oil fields. Lack of actual studies in Kenya comes amidst many documented negative effects caused by waste materials generated from oil exploration as observed by Plänitz & Kuzu (2015), Ajugwo (2013), Agwu *et al.* (2016) and Kadafa & Ayub (2012). Management of environment in the oil fields varies from one country to another depending on the surrounding ecosystems. Understanding specific concentration of heavy metals in mudcuttings from Twiga 1 wellpad in Lokichar basin in Kenya is critical for it will enhance their sustainable management.This information is not available due to the limited number of researches that have been done in the area before. The identified research gaps justifies the importance of this study

Materials and methods

The general objective of this study was to determine heavy metals concentration in the mud cuttings of Twiga 1 wellpad in Lokichar Basin,infer the potential negative effects they wound have if poorly managed to the underground water resources and subsequent implication this would have to the human health.

Study Area

The study was carried out in Southern part of Turkana County, South Lokichar Basin, oil Block 13T, Twiga 1 wellpad. Block 13T straddles in three sub-counties of Turkana County, i.e., Loima, Turkana Central and Turkana South (Tullow, 2017). The South Lokichar Basin is a Cenozoic sedimentary basin in Kenya. It is part of the East African Rift system. The basin is approximately 25km wide, 80km long and has a maximum depth of above 7km (Jarret, 2016). The main drainage in the study area is river Turkwel and underground water; inform of boreholes, and water pads constitute the largest source of water to the communities (Wendo, 2015).

Research Design

This study adopted the exploratory mixed method research design. The study combined one-shot experimental research design and systematic review analysis .The design was adopted in this study since oil exploration is a new venture in Kenya and little research on how mud cuttings from the oil exploration activities could affect the ecosystems if poorly managed.

Exploratory one-shot experimental design was applied in analysis of mud cuttings waste materials sampled from Twiga 1 well pad while systematic review analysis got used in gathering secondary data on internationally acceptable levels of heavy metals concentration in drinking water.

Sampling and Data Analysis Technique

The mud cuttings were purposively sampled from Twiga 1 Well pad and analyzed to determine the concentration of heavy metals. Sampling was carried out in Twiga 1 because the site had been licensed by the Government environmental conservation lead agency to be a temporary storage site for the mud cuttings generated from all the Well pads being drilled within South Lokichar Basin. The study adopted a sampling procedure used on API Site 4 in Louisiana Gulf Coast (Deuel and Holliday, 1990) and Iranian Onshore site mud pits sampling (Taylor, 2014). The reserve pit had a rectangular shape whose dimensions are 16m length 9m width ×3m depth as shown in fig. 1. The sampling was done by subdividing the reserve pit into three layers; surface layer, middle layer, and bottom layer. The mud cuttings collection points were georeferenced and were dug through using a hatchet and the middle and the bottom layers samples scooped. Samples were `picked in all the layers diagonally at three uniformly spaced depths. Triplicate samples were selected from every point and then collective to form a single composite sample for that point. Fifteen samples were collected, five from each layer of the pit. The samples were well labeled and put in clean polythene bags and taken to the laboratory for analysis using the X-Ray Florescence machine. Systematic review was adopted in establishing the internationally acceptable heavy metals concentration in borehole drinking water by WHO and `USEPA and the findings were indicated in table 1. The mudcutting samples got analyzed by use of Picofox TXRF S2 spectrometer. The device works by generation of an X-Ray beam from the Molybdenum tube, which gets mirrored on a Ni/C-multilayer causing a monochromatic X-Ray beam. This ray passes the sample holder containing the sample at an angle of between (0.3 – 0.6°), producing total reflection of the ray beam. Samples were irradiated for 1000s using a 50kV and a current of 1000-μA. The distinctive radiation emitted by the sample is sensed by energy dispersive detector. The strength of the radiation is then measured by an amplifier attached to a multi-channel analyzer. The element concentration was then calculated by use of the equation below.

$$Cx = \frac{Nx / Sx \times Cis}{Nis / Sis}$$

Where,

C_x is the analyte concentration

C_{is} is the internal standard concentration

N_x is the analyte net intensity

N_{is} is the internal standard net intensity

S_x is the analyte relative sensitivity

S_{is} is the internal standard‘s relative sensitivity

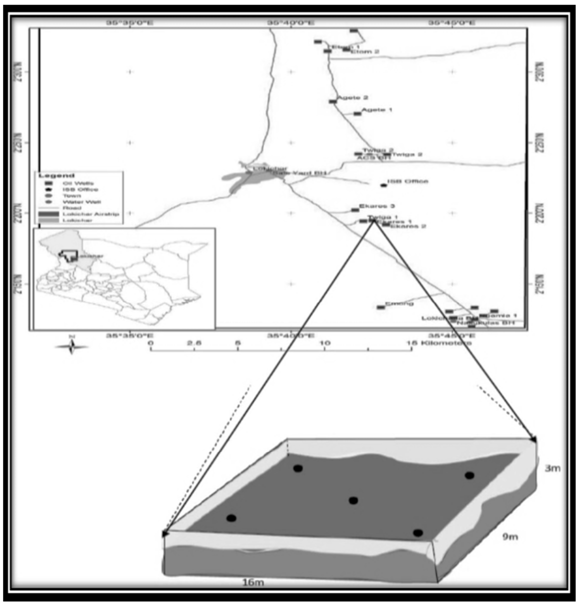

Fig. 1. Sampling design and location.

Results and discussion

The findings were shown in table 1 below. The results were presented as a mean positive or negative standard deviation of the triplicate analysis. From the data in table 1 below, the results indicated a substantial concentration of toxic metals such as (Lead (Pb), Manganese (Mn), Nickel (Ni), Iron (Fe) and Copper (Cu) and base metals such as Calcium (Ca) and Potassium (K), in the mud cuttings in the reserve pits.

These findings of heavy metals concentrations in the reserve pits were consistent with Mbithe (2016) and Balgobin (2012) observations who found high concentrations of Ca, K, Fe Mn and Pb in the mud cuttings analysis. The study noted that the concentrations of the selected heavy metals that were detected by the X-Ray Florence spectrometer in the reserve pit was in the order; Fe> Ca> K> Pb> Mn> Cu> Ni with their average values being 70.74ppm, 62.57ppm, 8.14ppm, 4.58ppm, 1.58ppm, 0.21ppm and 0.05ppm respectively. The concentration of Fe+ was way much higher compared to the rest of the metals as shown in fig. 3. The average concentration of the metals varied across the reserve pits depth. From top to the bottom of the pit the average concentrations of Fe, Ca, KA, Pb, Mn, Cu & Ni, were: Top (81.76±10.9, 64.24±5.27, 9.02±1.19, 3.03±1.26, 0.94±0.59, 0.21±0.03, and 0.03±0.02, Middle (60.85±10.9, 56.66±5.27, 6.78±1.19, 5.14±1.26, 1.43±0.59, 0.19±0.03 and 0.05±0.02), Bottom (66.80±5.27, 65.88±10.9, 8.62±1.19, 5.27±1.26, 2.12±0.59, 0.24±0.03, and 0.08±0.02 respectively. These findings of heavy metals concentrations in the reserve pits were consistent with Mbithe (2016) and Balgobin (2012) observations who found high concentrations of Ca, K, Fe Mn and Pb in the drill cuttings analysis. International bodies such as WHO and USEPA have set acceptable limits for heavy metals concetration in drinking water that will not cause any harm to human or animals upon consumption a shown in table 1.

Table 1. Findings presented as the mean ± standard deviation of triplicate analysis.

Sample collection point Coordinates	Sample No.	Parameters						
022406.6N, 0354256.2E		Cu	K	Ca	Fe	Mn	Ni	Pb
	1	0.17	5.91	60.00	33 .70	0.59	0.02	0.74
TOP	2	0. 1 7	12.18	35.50	69.15	1.12	0.02	4.30
	3	0.31	11.50	51.00	83.80	2 .93	0.01	2.00
	4	0.17	7.30	90.30	38.30	l.97	0.09	2. 1 7
	5	0.19	8.20	84.40	135.80	1.12	0.01	5.06
Top Average		0.21±0.03	9.02±1.19	64.24±5.27	81.76±10.9	0.94±0.59	0.03±0.02	3.03±1.26
	1	0.15	5.41	58.00	24 .70	0.39	0.01	3.4
	2	0.17	8.31	73.00	70. 15	2.91	0.01	3.34
MIDDLE	3	0.16	4.30	49.30	22.50	0.58	0.02	4.81
	4	0.26	12.8	74.00	99.20	2.72	0.19	4.9
	5	0.19	3.10	29.00	1 0.40	0.53	0.01	9.23
Middle Average		0.19±0.03	6.78±1.19	56.66±5.27	60.85±10.9	1.43±0.59	0.05±0.02	5.14±1.26
	1	0.22	9.21	80.00	100.00	1.60	0.04	0.94
BOTTOM	2	0.19	9.31	82.00	81.20	3.70	0.04	5.20
	3	0.21	5.30	53.4	26.80	0.64	0.06	5.60
	4	0.36	14.60	82	105.00	3.9	0.20	5.00
	5	0.24	4.70	36.6	16.40	0.78	0.04	9.60
Bottom Average		0.24±0.03	8.62±1.19	66.80±5.27	65.88±10.9	2.12±0.59	0.08±0.02	5.27±1.26
Mean STDV.S		0.03	1.19	5.27	10.9	0.59	0.02	1.26
Reserve pit average		0.21	8.14	62.57	70.74	1.58	0.05	4.58
WHO Recommended limits for drinking water		2.00	No limits	100	0.30	0.50	0.02	0.01
USEPA recommended limits for drinking water		1.20	No limits	<100	0.30	0.05	0.05	0.01

Poor management of contaminated mud cuttings can lead to leaching of heavy metals by surface runoff to the underground water aquifers. When human beings and animals gets exposed to elevated levels of heavy metals upon ingestion, adverse health consequences immerge. Reserve pits should be used for temporarly storage of mudcuttings and other sustainable techniques such as such as Thermal Desorption Unit (TDU) and Phytoremediation in the management of hazardous mud cuttings should be used. TDU is a technology used in recovering of oil-based drilling fluids from mud cuttings all over the world TDUs heat the mud cuttings that have been contaminated with the drilling fluids indirectly at 4000 degrees Celsius and recovers the drilling muds but it does not cause the destruction of the harmful chemicals such as heavy metal and therefore it needs to be complemented with phytoremediation technology. Phytoremediation is a technology that uses plants organism and related soil microbes to manage the high levels of heavy metals from the mud cuttings. It is economical, compelling, original, sustainable, and uses solar technology with good public acceptance. New effective metal hyperaccumulators are being discovered for applications in this new technology *Amaranthus sp.* have been found to hyperacumulate Nickel. *Agrostis tenuis* and *Festuca rubra* grass species have been found to phytostabilize copper, zinc, lead, and Zinc and lead respectively. Sunflower and spinach have been noted to phytoremediate lead from contaminated water and soil. Except for K, and Fe the concentration of the metals detected increased with increase in depth of the reserve pit 7. Mn, Cu and Ni were the least abundant metals as shown in fig. 2. Among the four most abundant metals it is only Ca that was within the international recommended standard limits by bodies such as WHO, and USEPA for heavy metals concentration in human consumption water as noted in table 1. The others that is Fe and Pb were above the recommended limits as shown in fig. 5 Among the least abundant metals, the concentration of Mn was higher than the recommended limits while Ni and Cu were within the limits as shown in fig. 4. Consistent with Balgobin (2012), (Anderson, 2003), (Al-haleem Saeed *et al.*, (2013) and Conant & Fadem (2012) poor disposal of the mudcuttings in Twiga 1 potends high risks of underground water contamination within Lokichar Basin. The study established that the mud cuttings were piled up on reserve Pit7 in Twiga 1 for an extended period of time as shown in fig. 6. There is a likelyhood of the surface runoff percolating heavy metals from the mudcuttings elevating the concetration levels of heavy metals in underground water aquifers. Exposure of human and animals to such contaminated water, according to Bassey *et al.* (2013), Mahurpawar (2015), Bakke *et al.*, (2013) Asche & Lead, (2013) causes harmful effect to the body's organ systems. Prolonged exposure to Mercury leads to fatigue, weakness, anorexia and gastrointestinal functions disturbances.

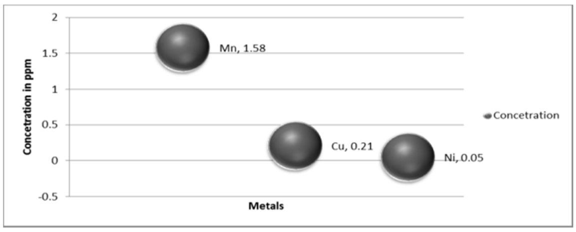

Fig. 2. The least abundant metals in the sampled mud cuttings from reserve pit 7 in Twiga 1 wellpad.

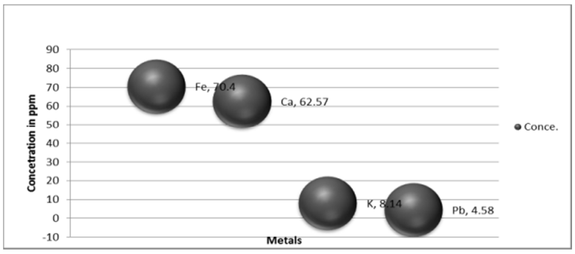

Fig. 3. Most abundant heavy metals concentration in the sampled mud cuttings from Reserve pit 7.

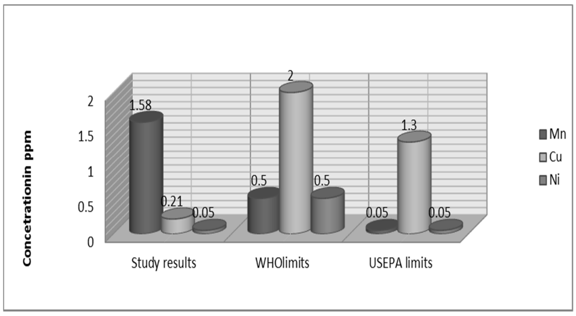

Fig. 4. Most abundant heavy metals concentration in the sampled mud cuttings from reserve pit 7 Twiga 1 wellpad relative to WHO and USEPA acceptable concetration levels in drinking water.

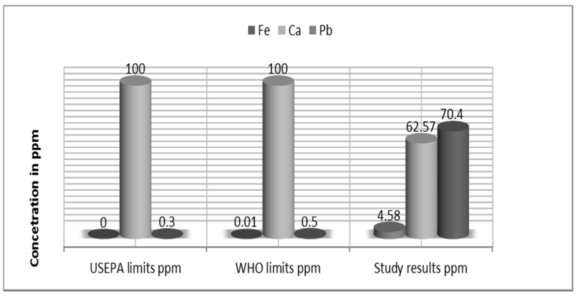

Fig. 5. Most abundant heavy metals concentration in the sampled mud cuttings from reserve pit 7 in Twiga 1 wellpad relation to acceptable concetration levels in drinking water.

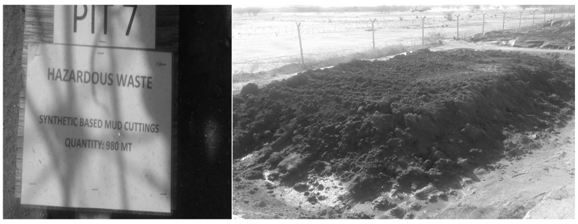

Fig. 6. Mudcuttings at reserve pit 7 Twiga 1 wellpad.

High exposures can cause spasm and tremors of the fingers, eyelids, lips and even the entire body which may culminate with hallucinations. Exposure to Mercury leads to the nervous system, kidney, and liver damage. Continued exposure to Lead according to the study causes toxic reactions in the neurological, haematological and renal systems, which results in brain damage, convulsions, and death. Lead solutions have been documented to be carcinogenic to animals. Exposure to nickel leads to respiratory tract infections and skin allergic reactions and prolonged exposure may lead to cancers cases and neurological breakdowns and eventually death. He further notes that too much exposure to Cadmium can result in, anaemia, renal failure, pulmonary emphysema, bone fractures, kidney stones, retarded growth, respiratory tract infections, cancer, joints and back pain. Prolonged exposure to Iron leads to cardiovascular diseases and respiratory tract infections. Exposure to hexavalent Chromium leads to severe irritation of the respiratory tract systems, kidney damage, asthma and some cancer cases.Other effects of chronic exposure at high levels include lung cancer and skin infections. Furthermore, the study reveals that prolonged exposure to Arsenic can cause gastrointestinal disturbances, bronchitis, peripheral neuropathy, weakness, skin disorder and damage to the kidney, the liver and the nerves. This calls for sustainable management of the mud cuttings in the oil fields.

Conclusion

Mud cuttings forms the largest volume of the waste generated from exploration drilling Drill cuttings forms the largest volume of the waste generated from exploration drilling. Drill cuttings gets contaminated majorly by the drilling muds during exploration drillings. drilling muds are composed of four components. These are the liquids which could be oil or water based; the reactive solids which are the density and viscosity part of the system and they are often bentonite clays. The solids which are inert in nature act as a weighting agent to sustain pressure in the well and Barite (Barium Sulphte) which has elevated levels of heavy metals impurities is the main agent used. The study established that the concetration of Mn, Pb, Fe were all obove the WHO, FEPA, USEPA recommended levels for heavy metals concetration in drinking water potending possible contamination of water ecosystems incase of poor management.This calls for sustainable management of the mudcutting.

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