

COMPOSITIONAL STUDY OF OIL AND GAS DRILLING WASTES IN AN ONSHORE NIGER DELTA FIELD, NIGERIA

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Received November 21, 2018; Accepted January 11, 2019

Abstract

Hostilities often arise between oil companies and host communities in the Niger Delta region of Nigeria due to environmental challenges instigated by drilling activities, especially the poor handling of drilling wastes. The bulk of the wastes, dominated by waste drilling fluids and lithological cuttings are those generated in the course of drilling oil and gas wells. In their raw state, the waste materials constitute a considerable hazard to the environment as the concentration of the physico-chemical properties grossly violate the acceptable regulatory standard. With improved local awareness, modern technology, and efficient regulatory monitoring, oil field waste disposal and management practices have improved over the years. However, gaps in the waste management chain often lead to spillages and improper disposal which compromises environmental quality and safety. As a result, the corporate integrity of oil companies suffers greatly with the implication of costly litigations and violent reactions from the host communities and other stakeholders. This case study examines the constituents of spent materials at a typical drilling site in an onshore oilfield located in the Niger Delta. The results show that many of the constituent physico-chemical parameters are significantly above the recommended limits. As such, the materials pose significant environmental hazards and therefore need to be safely handled and properly treated before disposal into the natural environment.

Keywords: drilling wastes; Niger Delta; environmental pollution; physico-chemical properties.

1. Introduction

Drilling activities have been established in the Niger Delta region since 1951 when the first generation of exploration wells was spudded in Owerri area, in the northern fringes of the region. Subsequent commercial discoveries created a thriving national economy that is almost entirely dependent on petroleum resources. The phenomenal rise in exploration and production activities generates various types of wastes at each stage of the operation, and these have different physico-chemical compositions. Thus, the presence of vast loads of solid and fluidized wastes has given rise to environmental pressures especially in the onshore areas where most of the infrastructure are sited close to human settlements, farmlands and communal water sources (e.g., ponds, creeks, streams, and rivers). As a result of this, the human population that is dependent on the natural environment for sustenance is exposed to significant health and socioeconomic risks [1].

The major sources of oil field waste materials are drilling wastewater, rock cuttings, muds, and well treatment discharges. Drilling operations make use of drilling fluids (mixtures of various liquids and weighting agents, like barite) to wet and soften the geological formations, circulate and cool the drilling bit, stabilise the wellbore by controlling formation pressures and flush out drilled rock cuttings to the surface. Hence, spent drilling fluids may contain oil, gas, heavy metals and other toxic additives of the original mud mix as well as the geochemical members of the penetrated rock sequences. In many instances, produced water is channelled

into water bodies with little or no treatment. Another contributor to environmental stress is the enormous quantities of solid matter in the form of mud and rock cuttings produced during drilling. Often, these are dumped in open land spaces and mud pits, reworked into cheap local construction and fill materials, or disposed into flood channels, natural water systems, and river banks. With the introduction of these sediments into the environment, toxic leachates from sediment particles can considerably compromise the environment. Although the Department of Petroleum Resources (DPR) is empowered by law to regulate and monitor compliance with environmental standards in the Nigerian oil and gas industry, unfortunately, lack of reliable data makes it difficult to assess the extent of risks posed to the ecosystem of the operational areas by drilling industry effluents. Therefore, there is a need for field-based monitoring and laboratory analysis to assess the composition and potential environmental effects of drilling wastes in order to devise an efficient management strategy.

2. Study area

This case study was conducted in the Greater Ughelli Depobelt (Figure 1) in the northwestern margin of the Niger Delta sedimentary basin where a well was drilled for hydrocarbon exploration.

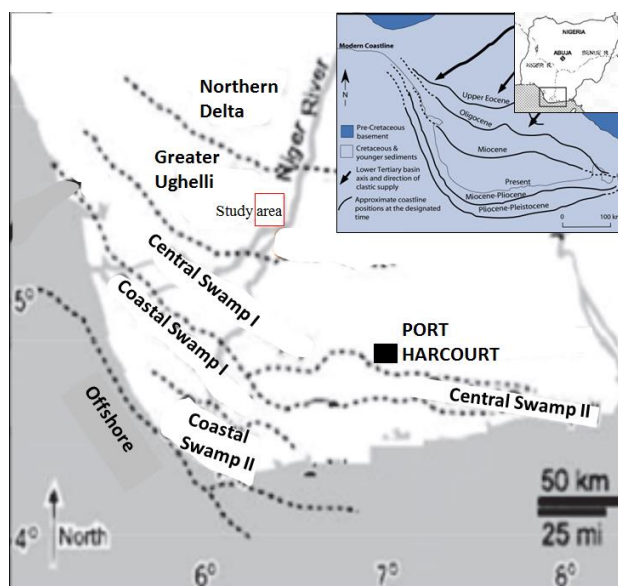


Figure 1. Map of Niger Delta showing the study area (red box) and the major depobelts in the basin

The study area is a flat-lying coastal sedimentary terrain dominated by sandy lowlands. It is drained by a network of streams and rivers whose flow rate is relatively slow due mainly to the flat terrain and close proximity to the sea. These natural water systems run as the tributaries of major rivers (e.g., Warri, Forcados and Niger) that have access to the Atlantic Ocean. Typical of many wells in the area, the candidate well penetrated Tertiary sediments of the Greater Ughelli depobelt. The regional stratigraphy consists of Akata, Agbada, Benin formations, and surficial deltaic plain sands. A detailed discussion of the regional stratigraphy of the Niger Delta is provided in Nwajide [2]. The unconsolidated sand units of the deltaic plain sand and Benin Formation constitute prolific aquifers. Because these aquifers are shallow (usually less than 50 m), it is easy for groundwater to be abstracted through hand dug wells and boreholes. The sandy overburden and unconfined nature of the aquifer system make the risks of groundwater pollution quite high.

3. Materials and method

The study involved field measurements and laboratory analysis. Tests done in the field included pH, total dissolved solids, turbidity, and temperature. Laboratory analysis was carried

out for total suspended solids, chemical and biological oxygen demand, and salinity. Fifteen samples of effluent drilling materials were taken from five different mud pits at the rig site over a three-week period. The weekly sampling approach made it possible for samples from different depths along the well path to be obtained as drilling was going on. The samples were grouped as A to E according to the mud pits and sub-numbered 1 to 3 indicating the week of the sampling (see Table 1). The labelled samples were cautiously transported in ice packs and stored at 4°C before the laboratory analysis for physico-chemical characteristics. The handling and storage of samples followed the ASTM 3856 [3] recommended standard laboratory practices. The results obtained were compared with the Department of Petroleum Resources Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (DPR EGASPIN).

4. Analytical procedure

A suite of best-practice analytical procedures was followed because of the need to test for specific parameters. For the Total Suspended Solids (TSS), the non-filterable residue was extracted from the sample using 0.45µm standard filter paper and then dried to a constant weight at temperatures that ranged from 103°C to 105°C. Samples were analysed for Chemical Oxygen Demand (COD) by digestion in a Hach reactor, and the values read on the automatic display while the Biological Oxygen Demand (BOD) was obtained with the Warburg and Sierp manometric method. The argentimetric method was used to determine the level of concentration of chlorides (salinity) in the samples. The method involves titration in silver nitrate. Also, residual chlorine in samples was determined with the Hach method by reacting hypochlorides with nitrogen, N-diethyl-p-phenylenediamine to get a red colour which is directly interpreted and displayed as values by the digital system

5. Results and discussion

Having prepared the samples for the analysis of parameters of interest as previously discussed, the results of the analysis and recommended limits of each of the parameters as stipulated by DPR, the oil industry regulatory agency are presented in Table 1 and subsequently discussed.

Table 1. Results of physico-chemical analysis of drilling waste samples used in the study.

Sample locations	Parameters	pH	Temp (°C)	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	salinity (mg/L)	Ratio BOD:COD
	DPR limit	8.5	25	10	2000	30	10	10	600	0.8
A1		6.67	29.7	57.1	107.2	73.15	16.03	90.2	44.1	5.6
A2		7.1	29.2	90.1	299.6	101.2	34.07	120.25	205.4	3.5
A3		6.97	29.3	63.1	229.48	78.1	110.2	448.94	115.24	4.1
B1		8.18	29.9	17.03	84.17	19	21.04	130.27	32.06	6.2
B2		10.5	29.1	70.14	1804.7	22	76.15	444.93	1315.75	5.8
B3		7.38	29.13	11	2405	12	94.2	681.42	1778.72	7.2
C1		6.51	30.5	32.06	74	21.04	47.1	230.5	28.05	4.9
C2		7.88	29.03	19.03	235.4	26.05	59.12	305.64	141.3	5.2
C3		8.49	29.13	17.03	42	23.04	17.03	45.1	27.05	2.6
D1		6.97	29.93	7.01	107.22	29.06	12.02	43.1	44.1	3.6
D2		7.38	28.93	8.01	90.1	10	9.02	30.06	48.1	3.3
D3		6.57	29.13	8	86.1	16.03	64.13	240.5	39.1	3.8
E1		7.2	29.8	36.07	142.2	47.1	34.07	91.2	62.13	2.7
E2		6.9	28.9	88.18	193.4	100.2	41.1	107.22	89.18	2.6
E3		7.38	29.4	258.5	289.6	323.6	156.32	515.07	80.16	3.3

5.1. Odour

Odour is mainly attributed to the emissions of volatile organic materials and sulphur compounds [4]. The guideline by DPR specifies that drill site wastes should have no objectionable odour. However, all the samples in the study had odour considered to be objectionable. As a first pass test, an undesirable smell is in itself a pollutant. The wastes, therefore, need to be treated before disposal so that the odour would not circulate further and cause discomfort (such as dizziness, nausea, insomnia, headaches and loss of appetite) to the local populace, degrade air quality, or introduce deleterious materials into the ecosystem especially natural sources of domestic water.

5.2. pH

This is a measure of the acidic or basic (alkaline) nature of a solution and is determined by the concentration of hydrogen ions. The pH of the medium is an important factor that controls neutralization, precipitation, coagulation and other biological processes [5]. Acceptable limits of pH are 6.0 – 9.0 and 6.5 – 8.5 for FME_{env} and DPR respectively. Out-of-limit pH values would impair the natural ecosystem chemical balance as it affects the coagulation of substances and can adversely impact on aquatic life [5]. This is because most organic matter and bacteria thrive best at the neutral or slightly alkaline environment. The pH was measured in the field using a digital pH meter. The results (Figure 2A) ranged from 6.5 to 10.5. A value of 10.5 as obtained in location B2 is significantly above the regulatory standards.

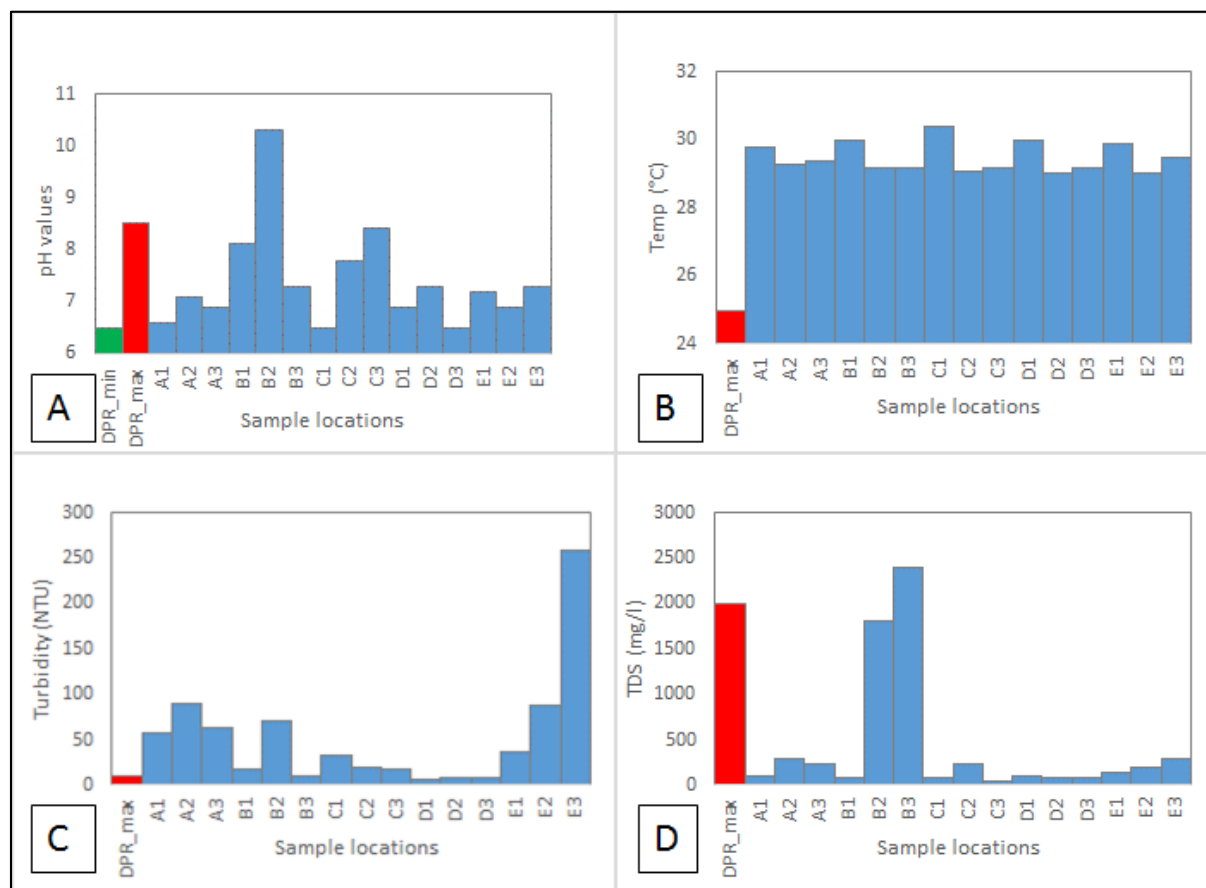


Figure 2. Comparison of pH, temperature, turbidity and total dissolved solids of effluent wastewater at different locations (blue bars) with DPR approved limits (red bar)

5.3. Temperature (°C)

Temperature is one of the major drivers of the interaction of waste materials and the natural environment. It directly affects the reactivity, degradability, and concentration of other physico-chemical parameters. For instance, its impact on the rates of biological processes affects the performance of activated sludge systems [6]. In general, microbial activity increases with increasing temperature until an optimum value is attained, beyond which a decline in microbial activity occurs [7]. Also, the solubility of substances increases with increasing temperature [8]. However, thermal pollution is a problem as it impedes oxygen dissolution and will, therefore, impact negatively on the quality of natural water bodies such as streams and ponds. The DPR approved temperature limit for effluent fluids is 25°C. As shown in Figure 2B, the samples investigated in this study had temperature values of 29.1°C to 30.5°C. These values considerably exceeded the DPR recommended limit [11].

5.4. Turbidity

Turbidity is a measure of the clarity of the fluid under optical inspection. Variations in clarity is an indication of the presence of particles (such as silt and clay-sized sediments, organic matter like algae and plankton) in the fluid. According to Chen *et al.* [9], variations in turbidity helps in understanding the distribution of total suspended solids or sediments (TSS), which by extension would reflect processes like coastal erosion and mobilization of chemicals or pollutants. Turbidity is therefore considered in environmental monitoring because it is a measure of water quality. Excess levels of turbidity can lead to eutrophication challenges in natural water systems [10], the unaesthetic appearance of water, and can expose the populace to gastro-intestinal health risks. Turbidity is usually measured with a nephelometer and expressed in Nephelometric Turbidity Units (NTU). While the DPR allowable limit of turbidity is 10 NTU, results in this analysis revealed values of between 7.0 NTU and 258 NTU. The distribution (Figure 2A) shows that turbidity was consistently higher than DPR recommended limits in all the locations (A, B, C, and E) except in D.

5.5. Total dissolved solids (TDS)

Total dissolved solids describe the presence of inorganic salts (e.g., calcium, magnesium, sodium, chlorides, sulfate, and carbonate) and some organic matter in the solution. The method of determining TDS was the measurement of specific conductivity with a conductivity probe that detects the presence of ions in water. Conductivity measurements were converted into TDS values by means of a factor that calibrated for the samples. Figure 2D shows that the minimum recorded value of TDS is 42 mg/l while the maximum is 2405 mg/L. The values of 2405 mg/L recorded in B3 sample is above the DPR recommended limit of 2000 mg/l. Nall and Sedlak [12] noted that elevated levels of TDS could result in scales and corrosion of industrial cooling towers and piping fixtures. High TDS effluents can cause changes in the levels of salinity and ion concentrations thereby constituting a significant hazard of toxicity and mortality to flora and fauna in discharge areas.

5.6. Total suspended solids (TSS)

This is a measure of particles in the fluid that would not pass through the 2.0 µm filter. If allowed, these particles settle as sediments. Spent drilling mud and rock cuttings can be carried by storm water into water bodies causing elevated values of TSS. Higher values of TSS may increase the temperature of the fluid as the particles absorb light and heat with the implication of decreasing the amount of dissolved oxygen [13-14]. DPR recommended limit for TSS is 30 mg/l. However, results of the analysis (Figure 3A) indicated values of between 10 mg/l and 324 mg/l. Out of the 15 samples analysed, 9 were found to be within the acceptable limits. The recorded maximum value of 324 mg/l in E3 is more than ten times above the acceptable limit. Such a high amount of sediment load if unchecked would affect coagulation and filtration and also lead to siltation of natural water systems.

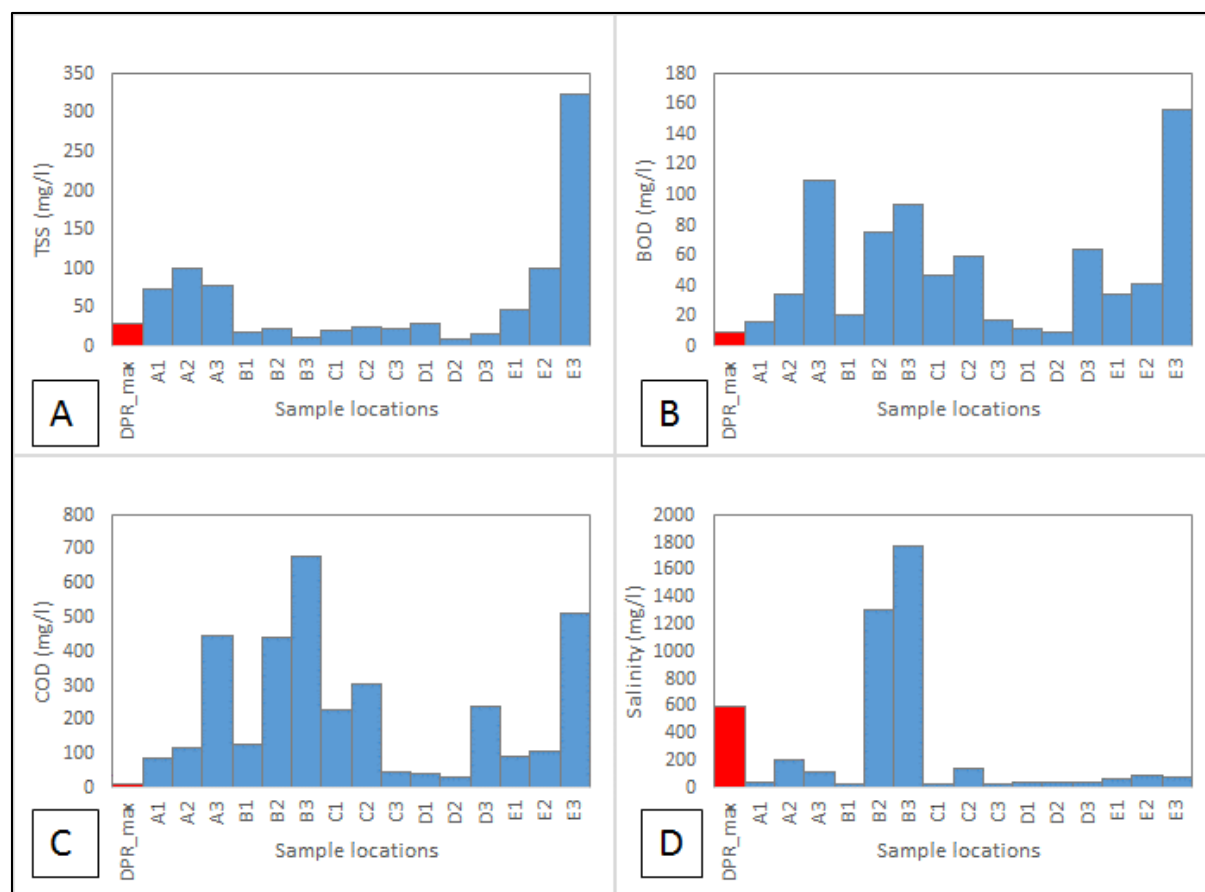


Figure 3. Comparison of TSS, BOD, COD, and salinity of effluent wastewater at different locations (blue bars) with DPR approved limits (red bar).

5.7. Biological oxygen demand (BOD)

Microorganisms (e.g., bacteria) need oxygen for the decomposition of organic wastes. The amount of oxygen consumed by these waste-decomposing bacteria is the biological oxygen demand [15]. Where there are large quantities of organic waste to be broken down, oxygen demand will also be high because a greater population of bacteria will be involved [16]. High amounts of BOD will be interpreted in many cases as evidence of pollution from organic materials. In this wise, the DPR approved limit of BODs is 10 mg/L. For the effluent wastewater samples analysed in the study, the concentration values of BODs (as shown in Figure 3B) widely varied and range from 9 mg/L to 156 mg/L. Only the D2 sample with a value of 9 mg/l is within the DPR recommended limit. On the basis of the recorded BOD results of the other 14 samples, the effluents pose significant pollution hazard to the environment.

5.8. Chemical oxygen demand (COD)

As an index of pollution, the chemical oxygen demand measures the amount of dissolved oxygen consumed in the chemical oxidation of organic matter to carbon dioxide and water under specific analytical conditions. This helps in the assessment of wastes for biologically-resistant organic components and toxins. The inference is that higher amounts of COD is an indication of higher levels of oxidizable organic material in the sample and will, therefore, deplete the levels of dissolved oxygen. For the effluent wastewater samples that were analysed in this study, the values of COD ranged from 30 mg/l to 681 mg/L (see Figure 3C). This contravenes the DPR approved limit of 10 mg/L.

5.9. Ratio of BOD to COD

By comparing the values of BOD to COD, the biological degradability of wastes can be assessed [17]. This ratio-based survey indicates the proportion of the total organic matter that can be decomposed by biological processes [18]. In a study aimed at achieving safe and sustainable treatment options for organic matter in the environment, Samudro and Mangkoedihardjo, [19] zoned BOD/COD ratios into toxic, biodegradable and acceptable or stable. Highly biodegradable wastes have BOD to COD ratios of not less than 0.8 [20-21]. In Figure 4A, data in this study show that BODs are lower in value than the corresponding CODs for the same sample. A plot of the BOD to COD ratio (Figure 4B) indicates that the values are in excess of 0.8. This suggests that the wastes are biodegradable.

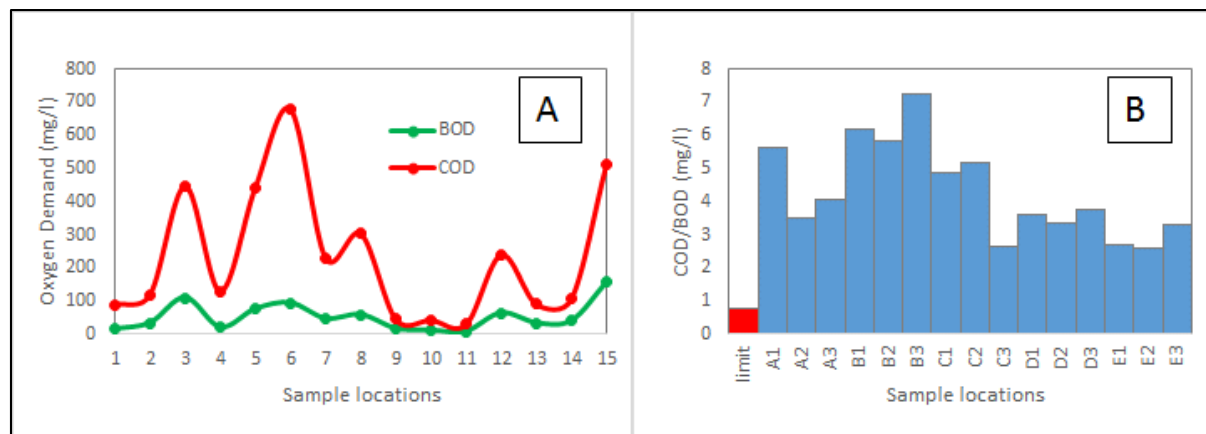


Figure 4. Comparison of BOD and COD data. As expected, in (A), BOD values (green plot) trend lower than the corresponding COD (red plot). The resulting ratios of BOD to COD plotted in (B) are considerably above 0.8 limits (red bar). The inference is that the wastes are highly polluted and biodegradable.

5.10. Salinity

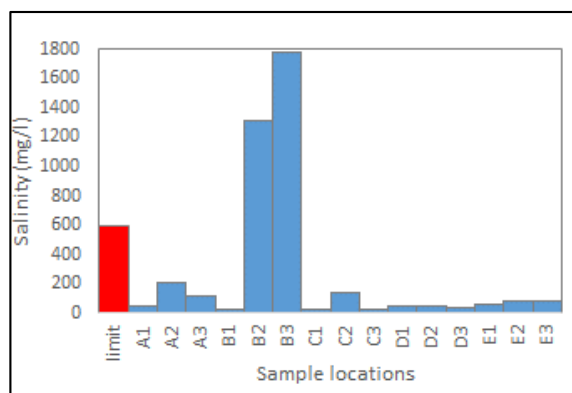


Figure 5. Variation of salinity in effluent wastewater. Except in samples B2 and B3, the values are generally low and in compliance with regulatory standards

One of the characteristics of coastal environments is the ability of aquatic species to tolerate adverse conditions including high salinity [22-23]. As a result of this, many industrial processes exploit marine ecosystems as natural receptacles of wastes of all sorts including those with elevated concentrations of salt. In the tested samples, values of salinity (as chloride) ranged from 27 mg/L to 1779 mg/L (Figure 5). The results in B2 and B3 are abnormally high and above the DPR approved limit of 600mg/L. Considering that 15 samples were analysed and 13 of these were in compliance with the DPR limits, the salinity of the drilling wastes does not constitute a significant threat to the environment.

However, chronic salt stress can severely degrade the environment [24-25]. In particular, salinity adversely impacts on biological degradation processes due to reduced microbial activities. It also inhibits the growth and production of biomass by wetland plants and equally affects the assimilation of nitrogen and phosphorus [26-28]. High levels of salt concentration in the environment can affect and deteriorate the quality of freshwater.

6. Summary and conclusion

The study shows the physico-chemical characteristics of effluent materials from drilling operations in the oil field under consideration and the environmental significance of the parameters. The wastes, in most cases, are additives in drilling muds as well as in-situ reservoir properties that were flushed to the surface by the circulating drilling fluids. Although some of the identified chemical components can be naturally degraded by microorganisms in the environment, they, however, constitute significant risk if the quantity is in excess of what the natural process can easily decompose, a baseline being the respective DPR approved limits. As shown in the table of values (Table 1), the waste materials require treatment before disposal, as most of the tested parameters such as pH, temperature, turbidity, BOD and COD have values that are above the acceptable regulatory limit. At such high concentrations, the risk of pollution is significantly high. Therefore, the waste materials need to be treated before disposal into the natural environment.

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