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Effects of Oil-Based Drilling Mud on Physico-chemical Properties and Water Quality of Tunu Creek, Bayelsa State, Nigeria

[1]Amah, O. K.., [1]Gobo, A .E., [2]Ideriah, T. J. K., [3]Ayotamuno, A.

[1]Institute of Geosciences and Environmental Management, Rivers State University Nkporlu-Oroworukwo, Port Harcourt, Rivers State, Nigeria.
[2]Institute of Pollution Studies, Rivers State University Nkporlu-Oroworukwo Port Harcourt, Rivers State, Nigeria.
[3]Department of Geography and Environmental Management, Rivers State University Nkporlu-Oroworukwo, Port Harcourt, Rivers State, Nigeria.

Corresponding E-Mail: amah.onyedikachi@gmail.com

Abstract

The study examined the effects of oil-based drilling mud (OBM) on physico-chemical properties and water quality of Tunu Creek, Bayelsa State, Nigeria. Surface water samples were collected from an operational drilling rig in the Tunu swamp area of Bayelsa state, where OBM was discharged and analyzed them in the laboratory for the physico-chemical properties of the water samples using standard laboratory methods. The results were compared with the World Health Organization (WHO) and other relevant standards for water quality. Findings showed that pH values of the surface water samples ranged from 5.65 to 6.96, conductivity ranged from 62.5 to 1020.0 µS/cm, salinity ranged from 0.03 – 0.5%, TDS, which ranged 37.5 to 725mg/l, turbidity, which ranged 63.6 to 917 NTU, calcium values ranged from 8.1 to 166.93 mg/l, and the total hydrocarbon content (THC) recorded ranged from 2.70 to 120.02ppm. The water samples also showed high concentrations of heavy metals (chromium – 5.191mg/l, nickel – 0.364mg/l, iron – 4.108mg/l) and PAHs (15.656 – 15.915mg/kg), which pose significant risks to human health and the environment.
The study can be concluded that water quality index of Tunu Creek showed that major contaminant of the water samples emanated from the drilling point as the indices was elevated at the drilling point for some of the parameters such as turbidity, conductivity, TDS, alkalinity, chloride, phosphate, calcium, magnesium, potassium, THC, bicarbonate, carbonate, heavy metals except Pb and Mn. Also, the water quality at closer distance to the OBM was of less quality both at the upstream and downstream of the drilling site. Thus, the water quality is not suitable for human consumption and may pose various health risks. The study recommended that more studies on pollution monitoring should be carried out to regularly determine the physico-chemical status of the surface water to ensure their domestic value. Furthermore, the study should be extended to other creeks of similar value to ensure the level of contaminants present in them.

Keywords: Drilling, Physico-chemical properties, Laboratory, Pollution

Introduction

The oil and gas industry generates significant amounts of waste materials, including drilling mud, which contains various chemicals, including heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs), that pose significant risks to human health and the environment (Feng *et al*., 2019). Disposal of Oil-Based Mud into water bodies can lead to the long-term contamination of the aquatic environment and threaten the sustainability of ecosystems (USEPA, 2016). The physicochemical properties of surface water can provide essential information on the degree of contamination, and the levels of xenobiotic compounds present in the surface water samples can help to identify potential risks to human and environmental health (Feng *et al*., 2019). A comprehensive analysis of the physicochemical properties and xenobiotic levels in water exposed to oil-based drilling mud is necessary to assess the potential risks to human and environmental health and develop effective strategies to minimize the impact of oil and gas drilling on the environment (Feng *et al*., 2019).

The study used standard analytical methods, including Gas Chromatography-Mass Spectrometry (GC-MS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), to analyze the surface water samples for the presence of xenobiotic compounds and heavy metals (Feng *et al*., 2019). The physicochemical properties of the surface water samples were analyzed using standard laboratory methods, including pH, conductivity, and total organic carbon analysis (APHA, 2017).

Several studies have investigated the impact of OBM on surface water quality. For example, a study by Al-Khashman *et al.* (2019) found that the use of OBM in oil drilling activities resulted in elevated levels of heavy metals in sediments and surface water samples. Similarly, a study by Al-Haidarey *et al*. (2020) found that the use of OBM in drilling operations resulted in the accumulation of Polycyclic Aromatic Hydrocarbons (PAHs) in surface water samples. In addition to heavy metals and PAHs, OBM can also contain other xenobiotic compounds, such as alkylphenols and phthalates which can have endocrine-disrupting effects (Sultana *et al*., 2019). These compounds can enter the food chain and pose a risk to human and animal health. Many of the previous studies did not consider the influence of OBM on the physico-chemical properties of surface water in which the present study is focusing at. This study is examining the effects of oil-based drilling mud on physic-chemical properties of Tunu River, Bayelsa State, Nigeria.

Materials and Methods

The study was carried out on Tunu Creek in Ekeremor LGA, Bayelsa State, Nigeria. Ekeremor is one of the eight local government areas (LGAs) in Bayelsa State, Nigeria. It borders Delta State and has a coastline of approximately 60 km on the Bight of Bonny. Its headquarters are in the town of Ekeremor in the northeast of the area. It has an area of 1,810 km^2 and a population of 270,257 at the 2006 census. The postal code of the area is 56. Ekeremor Local Government Area is located on the northwestern end of the State, with its western border forming part of the State's coastline by the Atlantic Ocean. Its northern border is marked by the Forcados River, one of the major distributaries of the Niger River. It is also drained by the Bomadi River. It also comprises of Alabini, Opuokede Creek, Oporomor West and Aleibiri local Government Areas. It covers 21% of the total land area and holds 11.1% of the total population of the State. The area is vastly blessed with natural resources and good soil for agriculture, as well as opportunities for tourism development. The traditional occupation of the people includes fishing, farming, trading, Raffia Palm tapping and distillation, lumbering and canoe carving, salt making, and hunting (Deekor *et al.,* 2022).The specific community in Ekeremor where samples were collected is called Tunu. Tunu is situated nearby to the villages Aghoro and Agge, which lies at 5° 6' 41'' N and 5° 26' 53'' E (Figure 1 & 2).

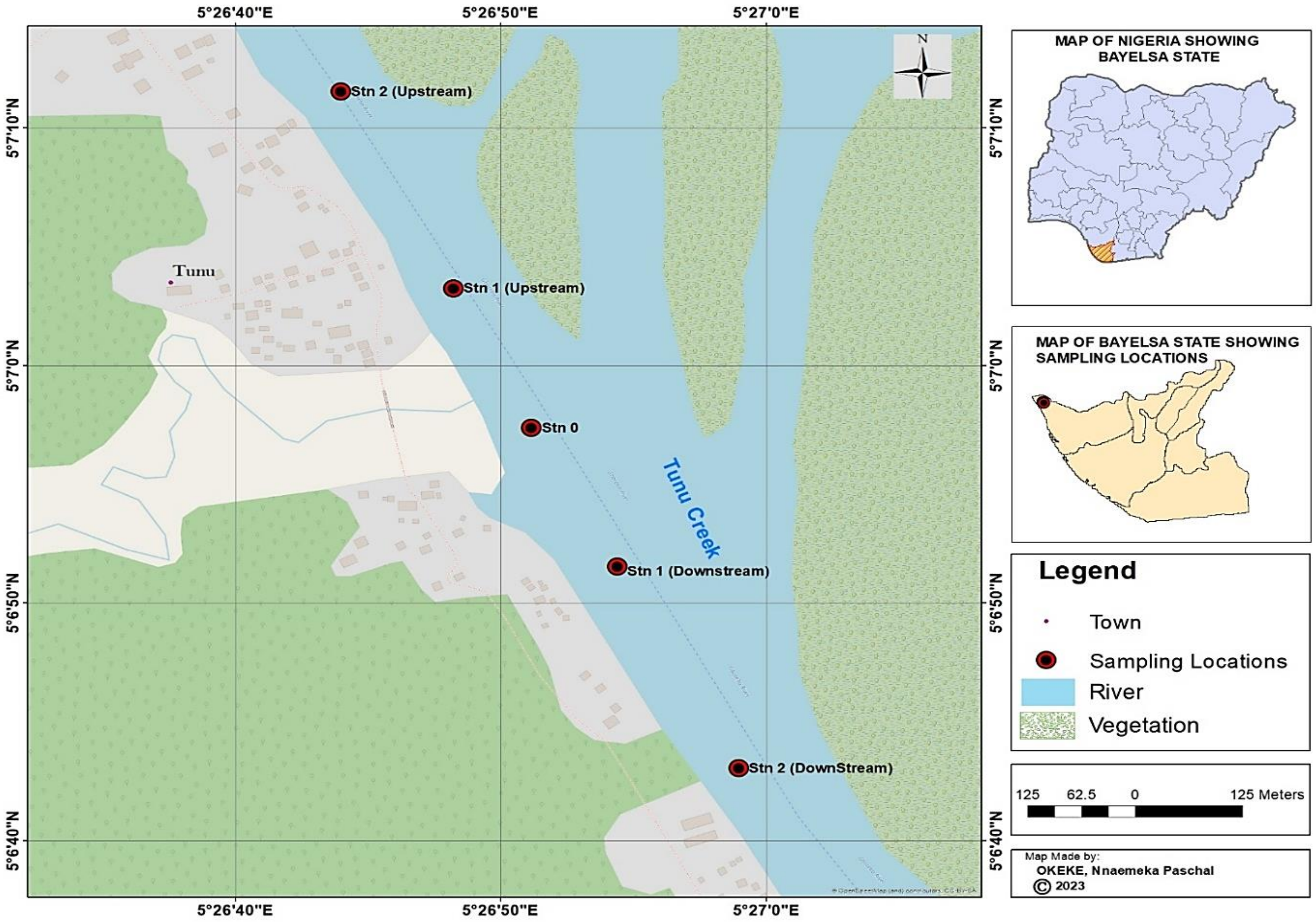

Figure 1: Tunu Creek showing Sampling Points

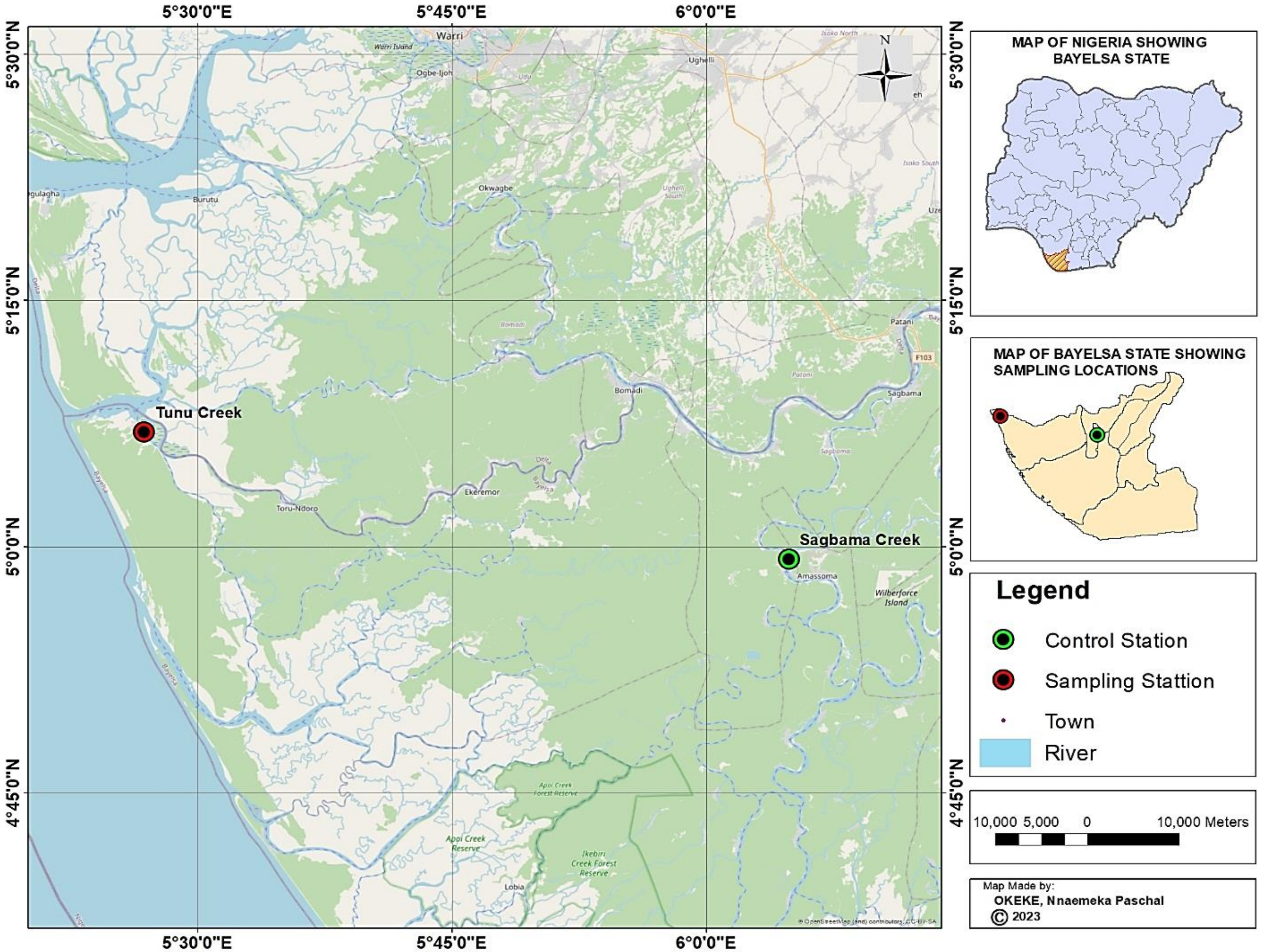

Figure 2: Sagbama Creek (Control Point) and Tunu Creek (Experimental Point)

This research employed an experimental design, which explores the effects of an intervention on specific variables or a population without random assignment. The study is an experimental research study of surface water from Tunu Creek area in Ekeremor LGA of Bayelsa State, Nigeria. The data utilized in this study exclusively comprised primary data collected directly from field samples of water. These samples were meticulously obtained to encompass a wide range of physicochemical parameters, enabling us to thoroughly examine their characteristics in comparison to established reference standards. To capture temporal variations, water samples were collected at different time points throughout the study period.

In this study, water samples which were exposed to oil-based drilling mud in the study area, were collected using appropriate sampling equipment and techniques. Water samples were collected at predetermined depths to capture variations in water quality. The water samples were obtained using a stainless-steel surface water sampler, with 250ml Amber bottles utilized for the analysis of biological oxygen demand (BOD_5). These bottles were then incubated for a period of 5 days at 20^oC, allowing for the assessment of both BOD5 and Dissolved Oxygen (DO) levels (Appendix I). Prior to laboratory examination, the samples designated for BOD_5 analysis underwent fixation with 2ml of Winkler 1 and II reagents. For the assessment of physicochemical parameters, samples were collected using 2L plastic containers, while those intended for heavy metals analysis were placed in plastic vials and treated with 2% nitric acid to ensure sample integrity during transportation to the laboratory. The water samples were subjected to various standard laboratory analyses to ensure variation in the effects on OBM on water samples. Descriptive statistics were applied for the data analysis.

Results and Discussions

Physicochemical Properties of Surface Water

The physicochemical properties and the permissible limits for drinking water quality according to the Nigerian Standard for Drinking Water Quality (NSDWQ) of the surface water samples from the study area are shown in Table 1. The pH values of the surface water samples range from 5.65 to 6.96, which are within the NSDWQ limit of 6.5 – 8.5. They vary slightly among the different sampling locations, with the lowest value at upstream 100 m and the highest value at downstream. The temperature of the surface water samples ranged from 26.90 °C to 28.00 °C, which is within the NSDWQ limit of 15 – 35 °C. The drilling point had the highest temperature of 28.00 °C, which was higher than the control site at Sagbama. The downstream 300m site had the lowest temperature of 26.90 °C, which was lower than the control site at Sagbama. The value of Electrical conductivity at the drilling point sample has the highest conductivity of 1020 µS/cm, which is slightly above the NSDWQ limit. The upstream and downstream samples have low conductivity values ranging from 65.50 to 94.50 µS/cm, which are well below the NSDWQ limit.

Table 1: Physicochemical Properties of Surface Water Samples

SN	Parameter	Control (Sagbama)	Upstream 300m	Upstream 100m	Drilling Point	Downstream 100m	Downstream 300m	NSDWQ Limit
1.	pH	5.65±0.02	6.69±0.01	6.64±0.02	6.69±0.02	6.71±0.01	6.78±0.1	6.5 – 8.5
2.	Temperature, °C	27.2±0.71	27.6±0.95	27.6±0.85	28.0±0.8	26.9±0.3	27.3±0.5	15 – 35
3.	Turbidity, NTU	124.5±6.36	63.6±1.6	58.0±2.2	917.0±31	66.5±0.9	84.9±1.15	5
4.	Conductivity, µS/cm	62.49±0.25	65.5±0.5	93.5±0.5	1020±26	70±1	94.5±1.5	1000
5.	Salinity, %	-	0.03±0	0.04±0.0	0.5±0.03	0.28±0.25	0.04±0	0.05
6.	TDS, mg/l	37.5±0.14	46.5±0.5	66.0±0.0	725±29	49.5±0.5	67.0±1.0	500
7.	Total Hardness, mg/l	34.05±7.28	27.3±1.1	47.7±0.7	474.4±48	38.85±1.25	79.25±3.15	150
8.	Alkalinity, mg/l	7.52±0.01	30.0±1.0	27.0±1.0	103.5±1.5	22.0±1.0	23.5±1.5	200
9.	Chloride, mg/l	4.91±0.98	2.5±1.5	2.55±1.55	78.25±4.15	2.5±1.5	2.95±1.95	250
10.	Sulphate, mg/l	0±0	7.4±0.8	6.4±1.1	31.1±0.3	5.75±1.05	6.65±0.65	250
11.	Nitrate, mg/l	8.05±0.92	0.5±0.01	0.32±0.03	0.1±0.02	0.645±0.47	0.66±0.36	50
12.	Phosphate, mg/l	5.69±0.73	0.0±0.0	0.0±0.0	2.58±0.44	0.125±0.02	0.07±0.02	6.9
13.	Calcium, mg/l	14.6±2.97	8.1±0.4	16.25±0.85	166.93±1.48	13.055±0.75	27.665±0.73	75
14.	Magnesium, mg/l	19.45±4.31	1.845±0.14	2.37±0.29	3.55±0.25	1.95±0.29	3.245±1.08	50
15.	Sodium, mg/l	0.007±0.01	5.595±0.53	6.69±0.16	19.79±0.34	4.885±0.14	7.53±0.57	200
16.	Potassium, mg/l	-	2.185±0.24	3.02±0.13	8.87±0.12	2.655±0.77	3.39±0.25	12
17.	HCO_3^-, mg/l	-	29.5±0.5	27.0±1	103.5±1.5	21.5±0.5	22.5±0.5	300
18.	CO_3^{2-}, mg/l	-	0.535±0.11	0.45±0.11	1.66±0.17	0.49±0.17	0.36±0.03	60
19.	THC, ppm	-	2.7±0.13	4.5±0.22	120.0±3.76	5.7±0.8	13.5±0.55	0.5

The control sample (Sagbama) has the lowest TDS level of 37.5 mg/l, which is much lower than the NSDWQ limit of 500 mg/l. The drilling point sample has the highest TDS level of 725 mg/l, which is also above the limit. The other samples have TDS levels ranging from 46.5 to 67.0 mg/l, which are within the limit. The salinity of the surface water samples varied from 0.03% to 3.6%, with the highest value recorded at the drilling point and the lowest value recorded at the upstream site (300m). The salinity of the drilling point was 0.5%, which was higher than the upstream and downstream sites. The salinity of the surface water samples exceeded the NSDWQ limit of 0.05% for drinking water, except for the upstream site.
The water sample has a turbidity of 917 NTU at the drill point, which is higher than the NSDWQ limit of 5 NTU. The turbidity decreases as the distance from the drilling point increases, but still above the recommended limit of 5 NTU for drinking water in all the sampling points. The table also showed that the total hardness at the drilling point is 474.4 mg/l, which is higher than the NSDWQ limit of 150 mg/l. However, the upstream and downstream were low, ranging from 27.30 to 79.25 mg/l; these values decrease as the distance from the drilling point increases.
The value of calcium was also high at the drill point with the mean value of 166.93 mg/l, which is higher than the NSDWQ limit of 75 mg/l. The results showed that the calcium values ranged from 14 to 238 mg/L in the water samples and from 8.1 to 166.93 mg/l in the samples, with the highest values at the drilling point and the lowest values at the upstream, 300m away from the drilling point. Total hydrocarbon content (THC) recorded at the drilling point was 120.02 ppm, which is 240 times higher than the NSDWQ limit of 0.5 ppm. The THC upstream and downstream were also high, ranging from 2.70 to 13.45 ppm; these values decrease as the distance from the drilling point increases, however, these values also exceeded the regulatory limit.

Table 4.5: Water Quality Index of the Surface Water in the Study Area

SN	Parameter	Sub-Index (%)				
		Upstream 300m	Upstream 100m	Drilling Point	Downstream 100m	Downstream 300m
1.	pH	1.12	0.82	1.12	1.24	1.65
2.	Turbidity	254	232	3668	266	339
3.	Conductivity	0.007	0.009	0.102	0.007	0.009
4.	TDS	0.019	0.026	0.290	0.020	0.027
5.	Total Hardness	0.121	0.212	2.108	0.173	0.352
6.	Alkalinity	0.012	0.011	0.041	0.009	0.009
7.	Chloride	0.004	0.004	0.125	0.004	0.005
8.	Sulphate	0.012	0.010	0.050	0.009	0.011
9.	Nitrate	0.020	0.013	0.004	0.026	0.026
10.	Phosphate	0.000	0.000	5.419	0.273	0.147
11.	Calcium	0.144	0.289	2.968	0.232	0.492
12.	Magnesium	0.074	0.095	0.142	0.078	0.130
13.	Sodium	0.014	0.017	0.049	0.012	0.019
14.	Potassium	1.521	2.097	6.160	1.847	2.354
15.	HCO_3^-	0.033	0.030	0.115	0.024	0.025
16.	CO_3^{2-}	0.015	0.013	0.046	0.014	0.010
17.	THC	1080	1780	48008	2280	5380
18.	Chromium	0	0	207640	10920	0
19.	Nickel	43125	82625	91000	30375	0
20.	Iron	2927.8	2951.1	2495.6	3515.6	4563.9
21.	Manganese	0	0	57.6	3.8	41.8
22.	Lead	0	0	0	0	0
23.	**Water Quality Index**	**370.30**	**684.43**	**2757.43**	**370.10**	**80.72**

Discussion of Findings

The results of the physicochemical analysis of the surface water samples showed that the drilling activity had a significant impact on the water quality parameters. The pH, temperature, turbidity, conductivity, salinity, TDS, total hardness, alkalinity, chloride, sulphate, nitrate, phosphate, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, and total hydrocarbon content (THC) were measured and compared with the Nigerian Standard for Drinking Water Quality (NSDWQ) standards. The results revealed that the water quality at the drilling point and the downstream locations was poor and exceeded the permissible limits for most parameters. The water quality at the upstream locations was relatively better and within the NSDWQ standards for most physicochemical parameters.

The pH is an important indicator of the acidity or alkalinity of water and affects the solubility and availability of nutrients and metals in water. From the result of the laboratory analysis of the water samples from the creek in the study area, pH of all the samples was mostly satisfactory when compared with stipulated tolerable limits of 6.5 – 8.5 set by Nigeria Standard for Drinking Water Quality. However, the pH values at all the locations were lower than 7, indicating that the water was slightly acidic and corrosive. The pH values could be attributed to the presence of acidic components in the oil-based mud, such as fatty acids, organic acids, and sulphur compounds (Yang *et al.*, 2023). There is no legally enforceable standard for drinking water pH levels because pH is considered an aesthetic water quality. However, various environment protection bodies such as the U.S. Environmental Protection Agency (EPA), World Health Organization (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ) recommend a pH between 6.5 and 8.5 for drinking water.

The temperature is another important parameter that affects the physical, chemical, and biological processes in water. The NSDWQ standard for temperature is 15–35°C. The results showed that the temperature values ranged from 26.90 to 28.00 °C, with the highest value at the drilling point and the lowest value at the downstream. The high temperature values could be attributed to the heat generated by the drilling operation, the friction of the drill bit, and the flaring of associated gas (Lusweti *et al*., 2022).

The turbidity is a measure of the clarity or cloudiness of water and reflects the presence of suspended solids, colloids, and microorganisms in water. The sampled water was observed to be turbid with a mean turbidity of 917 NTU at the drill point, which is 183 times higher than the NSDWQ limit of 5 NTU. The turbidity decreases as the distance from the drilling point increases, however, it was still above the limit in all the sampled points. The high turbidity values could be attributed to the presence of drill cuttings, oil droplets, clay particles, and organic matter in the water (Lusweti *et al*., 2022). It indicates the presence of suspended solids in the water, which can affect the aesthetic quality of the water. It reduces the effectiveness of disinfection and increase the risk of microbial contamination in the water. Hawkins and Mann (2007) reported that the occurrence of suspended particles, sediment, carbon-based substance, inorganic material, and other invisible living things increases turbidity. Highly turbid water reduces light penetration to the wells, therefore affecting the level of photosynthesis aquatic plants. This also increases water temperature, due to absorption of sunlight.

Electrical conductivity is a measure of the ability of water to conduct electric current and reflects the presence of dissolved ions in water. The conductivity upstream and downstream were low, ranging from 65.5 to 94.5 µS/cm, while the water is highly conductive at the drilling point, which exceeds the permissible limit of 1000 µS/cm for NSDWQ. This indicates that the water was saline and polluted. The high conductivity values could be attributed to the presence of dissolved salts, metals, and organic compounds in the water (Zhiqiang *et al*., 2018). According to Christine *et al*. (2018), the presence of a slightly high value of electrical conductivity in the water sample shows the presence of contaminations due to high dissolved ions, because electrical conductivity is directly proportional to the total dissolved solids. High conductivity can affect the taste, odour, and corrosiveness of water. It indicates the contamination of water by the drilling activities in the study location.

The high EC at the drilling point, which indicates the presence of dissolved salts in the water, was also reflected by the high TDS at the drill point, which is above the NSDWQ limit of 500 mg/L. Table 4.4 showed that the TDS at the drilling point is 725 mg/l, which is higher than the NSDWQ standard, indicating that the water was polluted and had a high mineral content. TDS upstream and downstream were low, ranging from 46.5 to 67.0 mg/l. The TDS is a measure of the total amount of dissolved solids in water and reflects the concentration of organic and inorganic substances in water. The high TDS values could be attributed to the presence of dissolved solids, such as salts, metals, and organic compounds, in the water (Yang *et al*., 2023). High TDS can reduce the clarity and aesthetic quality of water. It can also affect the aquatic life by changing the water chemistry and reducing the oxygen availability.

Salinity is a measure of the concentration of dissolved salts in water. The result on salinity at the drilling point was 10 times higher than the NSDWQ limit of 0.05%. The salinity further declined with increasing distance, which showed that the drilling activity is the major source of surface water contamination in the study area. The high salinity values could be attributed to the presence of dissolved salts, such as sodium chloride, calcium chloride, magnesium chloride, and potassium chloride, in the water. High salinity can cause dehydration, hypertension, and kidney problems in humans. It can also affect the aquatic life by altering the osmotic balance and metabolic processes (Özkan & Kaplan, 2019).

Water hardness recorded varied between 27.30 mg/l and 1297.3 mg/l in all the sampled points (Table 2). These values satisfy the NSDWQ limit of 150 mg/l except for the drilling point, which records 1297.3 mg/l and 474.40 mg/l respectively. The total hardness upstream and downstream were low, and the values decrease as the distance from the drilling point increases. Total hardness is a measure of the concentration of calcium and magnesium ions in water. The high total hardness values at the drilling point can be attributed to the presence of calcium and magnesium ions, which could originate from the dissolution of carbonate and sulphate minerals, the leaching of drilling mud additives, and the contamination of crude oil. High hardness can cause scaling and clogging of pipes and appliances and increase the soap consumption. It can also affect the aquatic life by altering the pH and buffering capacity of water (Lusweti *et al*., 2022).

The total hardness was confirmed by the high calcium content of the water at the drilling point. Calcium is a measure of the concentration of calcium ions in water. Calcium ions can come from natural sources, such as rocks and soil, or from human activities, such as mining, agriculture, and industry. Calcium ions affect the water quality by increasing the hardness of water. The value of calcium was high at the drill point with the mean value of 166.93 mg/l, which is higher than the NSDWQ limit of 75 mg/l. The high calcium can cause scaling and clogging of pipes and appliances and increase the soap consumption. High calcium also affects the aquatic life by altering the water chemistry and reducing the availability of other nutrients, such as phosphorus and iron.

Total hydrocarbon content (THC), which is a measure of the concentration of petroleum hydrocarbons in water, was observed to be higher than the regulatory limit in all the sampled locations. Petroleum hydrocarbons can be toxic, carcinogenic, and mutagenic to humans and aquatic life. They can also affect the water quality by creating oil slicks, reducing the light penetration and oxygen availability, and altering the water chemistry. Table 4.4 showed that the THC at the drilling point is 120.02 ppm, which is 240 times higher than the NSDWQ limit of 0.5 ppm. The high THC values could be attributed to the presence of hydrocarbons, which could originate from the contamination of crude oil, the leaching of drilling mud additives, and the degradation of organic matter. The THC upstream and downstream were also high, ranging from 2.70 to 13.45 ppm; these values decrease as the distance from the drilling point increases.

Other parameters measured in the water samples such as alkalinity, chloride, sulphate, nitrate, phosphate, magnesium, sodium, potassium, bicarbonate, and carbonate, were all within the NSDWQ limits at all locations. In addition, some of these parameters show slight variations at different distances from the drilling point, which indicates that drilling activity influences the water quality of the surface water.

The result, however, does not explicitly mention the potential health risks of the drilling activities, but some of the parameters that exceed the NSDWQ limits are known to cause adverse effects on human health and the environment. The results suggest that the surface water in the study area is not suitable for drinking and may pose health risks to the consumers. The water is also not favourable for aquatic life and may cause ecological imbalance in the water body. The results indicate that the surface water in the study area is adversely affected by the discharge of oil-based drilling mud and other drilling activities.

The Water Quality Index table also confirms that the water was contamination and therefore, unfit for consumption.

The WQI was computed with reference to NSDWQ standards. From the values obtained, the WQI for the water samples ranged from 80.72% to 2,757.43%. The WQI table showed that major contaminant of the water samples emanated from the drilling point as the indices was elevated at the drilling point for some of the parameters such as turbidity, conductivity, TDS, alkalinity, chloride, phosphate, calcium, magnesium, potassium, THC, bicarbonate, and carbonate. However, the major contaminations in all the water samples were the THC and all the heavy metals (as shown by their very high values) except lead and manganese. The WQI result indicates that the water quality is not suitable for human consumption and poses various health risks.

According to the World Health Organization (WHO, 2017), the consumption of contaminated water can cause various diseases, such as diarrhea, cholera, typhoid, dysentery, hepatitis, giardiasis, cryptosporidiosis, and cancer. The consumption of water with high levels of THC and heavy metals can also cause various adverse effects, such as skin irritation, inflammation, respiratory problems, immunological disorders, neurological disorders, reproductive disorders, developmental disorders, and cancer (ATSDR, 1995; IARC, 2010). Therefore, the water quality should be improved by using appropriate treatment methods, such as coagulation, flocculation, sedimentation, filtration, disinfection, and reverse osmosis, to remove the contaminants and ensure the safety of the water (WHO, 2017).

Conclusion and Recommendations

The study can be concluded that water quality index of Tunu Creek showed that major contaminant of the water samples emanated from the drilling point as the indices was elevated at the drilling point for some of the parameters such as turbidity, conductivity, TDS, alkalinity, chloride, phosphate, calcium, magnesium, potassium, THC, bicarbonate, carbonate, heavy metals except Pb and Mn. Also, the water quality at closer distance to the OBM was of less quality both at the upstream and downstream of the drilling site. Thus, the water quality is not suitable for human consumption and poses various health risks. The study recommended that more studies on pollution monitoring should be carried out to regularly determine the physico-chemical status of surface water to ensure their domestic value. The water quality should be improved by using appropriate treatment methods, such as coagulation, flocculation, sedimentation, filtration, disinfection, and reverse osmosis, to remove the contaminants and ensure the safety of the water. Furthermore, the study should be extended to other creeks of similar value to ensure the level of contaminants present in them.

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