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Research Article

Impact of Artisanal Crude Oil Refining Effluents on Interstitial Water of Mangrove Wetlands in Asari-Toru Axis of Sombreiro River, Rivers State, NIGERIA

Davies Ibienebo Chris, Efekemo Oghenetekevwe

[1]Department of Fisheries, Faculty of Agriculture, University of Port Harcourt, P.M.B. 5323, Port Harcourt, NIGERIA
[2]Department of Chemical Sciences, Biochemistry Option, Faculty of Science, Edwin Clark University, Kiagbodo, Delta State, NIGERIA

* Corresponding author: D.I Chris
E-mail: davies.chris@uniport.edu.ng

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Abstract

A comparative study on the water quality of the interstitial water of two creeks in Rivers State was conducted. Temperature, pH, Conductivity, Dissolved oxygen, biochemical oxygen demand, Salinity, and Total dissolved solid were checked with an in-situ hand-held multi-meter (The EZODO Multi-meter). Dissolved oxygen (DO) was measured with a Milwaukee Dissolved oxygen meter while Biochemical Oxygen Demand (BOD) was determined by the 5-day BOD test (APHA, 2005). The temperature ranged between 28.3 to 29.3℃ in the Opro-ama creek and 26.0 -26.8℃ in Buguma creek. The pH value ranged from 6.2 to 6.8 in Opro-ama creek while that of Sa-ama creek was between 6.8 and 6.99. Salinity ranges from 9.1 to 9.5 (ppt) in the Opro-ama creek while Sa-ama creek recorded a range between 11.2 to 12.0 (ppt). The dissolved oxygen was between 1.5 and 2.3 (mg/L) in Okpoka creek meanwhile Sa-ama creek varied between 4.6 and 4.10 (mg/L). The biochemical oxygen demand values were between 1.4 to 2.3 (mg/L) in Opro-ama creek while that of Sa-ama was between 1.9 to 2.4 (mg/L). The conductivity values for the Opro-ama creek were between 10.3 and 10.6 while Sa-ama creek recorded a value of 12.5 to12.6 (µS/cm). There were significant variations ($P<0.05$). It was observed that Sa-ama creek had more impacted water parameters than the Opro-ama creek. The results were that most parameters were not within the permissible limits of WHO, USEPA, and DPR. There is therefore a need for regular environmental impact assessment by authorized regulatory bodies in this region.

Keywords: Physico-chemistry, Artisanal Refining, Interstitial Water, and Creek.

Introduction

In the Niger Delta, the contamination of creeks and rivers with a wide range of chemicals and associated waste has become a major concern over the past few decades, not only due to the threat to public water supplies but also to the damage they cause to aquatic life (Lawal, 2020; Davies et al., 2022). Usually, aquatic organisms such as fish are capable of accumulating heavy pollutants into their living cells at concentrations much higher than those present in their environment, including their water supply and sediment. As a result of their toxicity and accumulative behavior, these contaminants can change the aquatic organism’s diversity and ecosystems in creeks, rivers, and other aquatic environments (Menteş et al., 2019; Akankali et al., 2022). Water’s quality is determined by its physical, chemical, and biological characteristics (Gorde, and Jadhav, 2013). It describes the condition of water and the requirements for one or more biotic species for any human need or purpose for wastewater treatment (Omer, 2019). In most cases, it is used in conjunction with a set of standards against which compliance can be assessed (Neale et al., 2021). Most of the standards used to evaluate water quality are related to the health of ecosystems, the safety of human contact, and the quality of drinking water (Edokpayi et al., 2018). Even when there is no pollution present, the water quality of rivers, streams, oceans, and lakes varies significantly with the seasons and geographic locations (Wang et al., 2019). The observed increases in urbanization, population, and industrialization are all linked to increased water contamination (Koh, 2019). Therefore, waste management is a big issue in most developing nations, including Nigeria.

In recent years, water quality monitoring has become increasingly important for creeks and river water systems that are being significantly polluted by untreated urban effluents such as illegal refinery runoff, atmospheric deposition, and domestic and industrial effluent discharges. The physicochemical characteristics such as dissolved oxygen and the pH of aquatic ecosystems may determine stream water ecosystem integrity (Geissen, et al., 2015). In addition, the growing importance of fish as a source of protein, and the study of the accumulation of different contaminants at trophic levels of the food chain, will help to increase the focus on fish (Odekina, et al., 2021). Therefore, good and safe water quality is essential for sustainable development (Okere et al. 2021). Preventing pollution of water bodies will help to ensure mankind's survival of life of the aquatic organisms in the future (Davies and Ekperusi, 2021).

To determine the level of contamination in wastewater, creeks, rivers, and stream water, physicochemical characteristics and anthropogenic pollutants need to be monitored (Akankali et al., 2022b). As urbanization and industrialization have increased, industrial effluent discharges into stream water have increased as well, leading to increased pollution loads monitored (Altenburger et al., 2019). Poor water quality caused by municipal effluents and industrial discharges may lead to alteration of the hydrogen ion concentration or pH which is one of the vital environmental factors which may result from a high rate of photosynthesis by dense phytoplankton blooms (Chauhan and Sagar, 2013). Therefore, there is a need for the implementation of already establish standards by agencies of government and technical/scientific on how the water will be used (Dillingham, 2018). Because these wastes if not properly managed will later be washed off into nearby rivers. Jaji et al. (2007) observed an increase in water quality parameters in some rivers as a result of improper waste management. Meanwhile, some significant increase in water quality has been reported following indices such as DO, pH, BOD, nitrate, and phosphate studies on the impact of point source pollution from sewage treatment oxidation pond on a receiving stream (Ogunfowokan et al., 2005). Although environmental factors can affect the characteristics of natural water bodies (Davies et al., 2022). The dissolved minerals may affect the suitability of water for a range of industrial and domestic purposes. To know how these systems function, scientists have studied how contaminants are transported and disposed of (Davies and Efekemo 2022).

Materials and Methods

Study Area

The study was carried out along two creeks which are joint tributaries of Sombreroraro Estuary in the Asari-Toru Local Government Area of Rivers State (Figure 1) which is one of the 21 estuaries in the Niger Delta geomorphic unit of Nigeria's extensive (approximately 853 km) coastline (Zabbey et al., 2021). Located Southeast of the Niger Delta between longitude N04^0 48' 14.0" and latitude E006^0 50' 16. These creeks system consists of the main channel and associated feeder creeks linking other communities like Te-ama, Sangama, Abala-ama, Degema, Krakrama, and other riparian communities. Both creeks are village settlements that are situated northwest of Atuka, and southeast of Sama-Naguakiri. This settlement has grown to become a middle town of the Kalabari people in the rivers state of Nigeria. The tidal influence is frequent and vigorous. Pollutants such as artisanal channelization, Illegal refining, and bunkering activities, domestic dumps, sand dredging, and deliberate cutting of mangroves at the community landing corridors around the creeks are presumed to be evenly dispersed in the environment. Fishes like Lutjanidae, Clupeidae, Cichlidae, and, Claroteidae are among the main fish family in this ecosystem but the most common are the Claroteidae which is the silver catfish and tilapias, the tidal mudflats species which include the gobies, periwinkles, crabs, and mudskippers, only to mention a few (Davies and Efekemo, 2022). The mangrove vegetation of the area comprises *Rhizophora racemose*, *R. mangle,* and *R. Harrisoni* (red mangrove). Other mangrove species in the area are Avicennia germinans (white mangrove), *Laguncularia racemosa* (black mangrove), and Conocarpus erectus buttonwood). There are the presence of mangroves associates such as *Acrostichum aureum* (mangrove fern) and *Paspalum vaginatum* (mangrove sedge) around as well (Davies et al., 2021).

Physico-Chemical Parameters

Analysis was carried out for both Opuro-ama and Sa-ama Creeks. All the parameters were determined using recommended standards method by APHA 2340C (2005).

Temperature ($^{\circ}$C)

The temperature was measured in-situ with a mercury-in-glass thermometer. The thermometer was dipped about 15cm into the interstitial water and allowed for 2 minutes to stabilize and the temperature reading was taken and recorded at ^{0}C (degree Celsius).

Hydrogen Ion Concentration (pH)

The pH was determined in-situ with a pocket-sized pH meter (Milwaukee model pH600). The pH meter was inserted 10-15 cm below the interstitial water. The meter was switched on and the pH reading was taken when the probe became stable.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) was measured with the Milwaukee Dissolved oxygen meter (MW 600 Model). The DO meter was stabilized for 10 minutes and the probe of the meter was inserted 10-15 cm below the interstitial water. The meter was switched on and the DO reading was taken when the reading became stable.

Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) was determined by the 5-day BOD test (APHA, 2005). 5ml sample was diluted to 100ml with distilled water. This was poured into two 50ml capacity DO bottles and capped. One of the two test samples was used to determine the initial DO use of the Milwaukee DO meter (MW 600 model). The other test sample was incubated for 5 days at a temperature of 20^{0}C before it was analyzed for DO by the above method.

BOD (mg/l) = Initial DO – Final DO

Salinity

Salinity was measured in-situ with a hand-held multi-meter (The EZODO Conductivity/TDS/Salt/Temp Multi-meter meter) model CTS-406. The probe of the meter was inserted 10-15 cm below the interstitial water and the meter was switched on and allowed to stabilize for 10 minutes. The salinity reading was taken when the reading became stable.

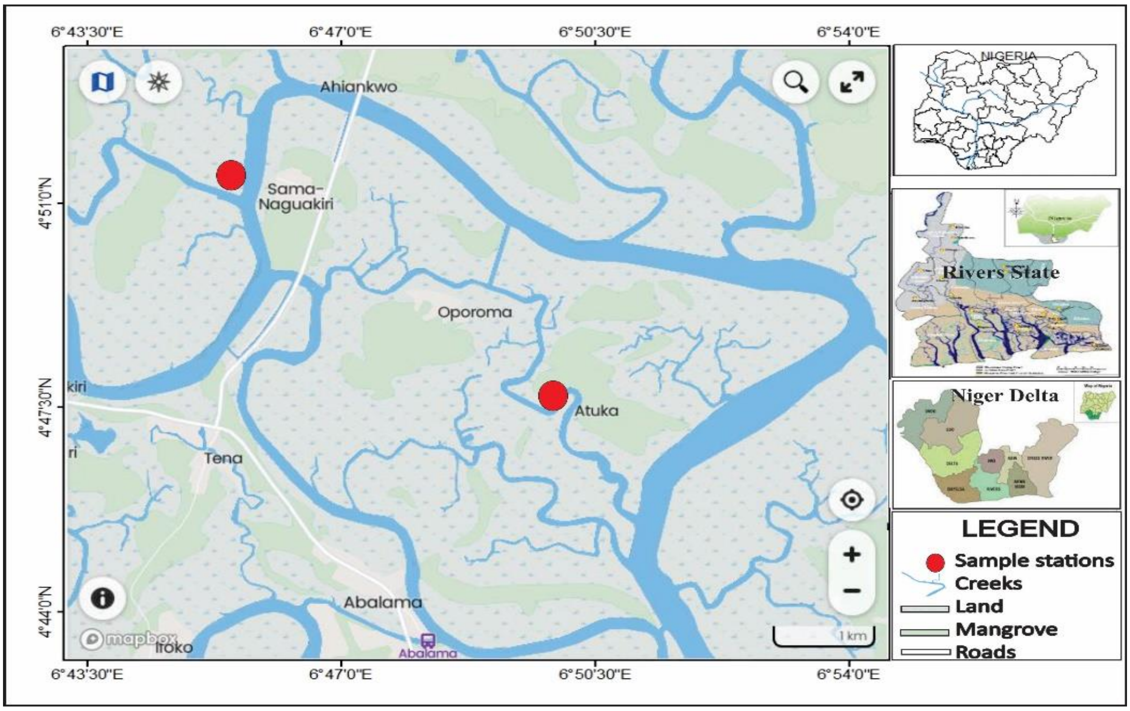

Fig. 1: Showing the Sampling Area.

Conductivity
Conductivity was measured in-situ with a hand-held multimeter (The EZODO Conductivity/TDS/Salt/Temp Multimeter meter) model CTS-406. The probe of the meter was inserted 10-15 cm below the interstitial water and the meter was switched on and allowed to stabilize for 10 minutes. The Conductivity reading was taken when the reading became stable.

Total Dissolved Solid TDS
The total dissolved solid was measured in-situ with a hand-held multi-meter (The EZODO Conductivity/TDS/Salt/Temp Multi-meter meter) model CTS-406. The probe of the meter was inserted 10-15 cm below the interstitial water and the meter was switched on and allowed to stabilize for 10 minutes. The TDS reading was taken when the reading became stable.

Total Suspended Solid (TSS)
Filter paper was dried in an air oven at 105^{o}c, the filter paper was weighed and the weight was recorded. 50ml of the effluent was filtered through the filter paper and the filter paper was dried at 105^{o}c until a constant weight was obtained. The filter paper was allowed to cool to room temperature in a desiccator and re-weighed.
TSS (mg/l) was calculated as the weight of filter paper and residue minus the weight of empty filter paper x 1000 x 20.

Chemical Oxygen Demand
This was done using the $KMnO_4$ method, 25ml test sample and blank were set up simultaneously for 4hrs observations. 1ml of 20% Sulphuric acid was added to the test sample and 1ml 0.0125m of $KMnO_4$ was added to both samples and these were left to stand for 4hrs.within this period $KMnO_4$ was added to the test sample because the colour was fading away and the volume of $KMnO_4$ added within this period was recorded. 1ml 10% potassium iodide was added at the end of 4hrs and the resultant solution was titrated within 0.0125m of sodium bisulphate using starch as an indicator. COD was calculated using the formula below:

COD
Because more $KMnO_4$ was used, the titer of the sample was divided by the total volume of $KMnO_4$ used up before subtracting from the blank titer volume. All the samples were repeated in triplicates and the values were recorded *(mg/l = blank titer - test titer x100 used)*

Statistical Analysis
The descriptive statistics and the analysis of variance (ANOVA) were performed with SPSS version 16. Duncan Multiple Range Test at 0.05 was used to separate significant means. The mean and standard error of the mean was the statistical quantities used to manage the data set.

Results
Physco-chemical parameters of the Interstitial Water

The physicochemical parameters of the interstitial water samples collected from the Opuro-ama and Sa-ama creek during the study period are shown in Tables 1 and Figures 2 to 10.

Temperature ($^{\circ}$C)
The temperature ranges from 28.3°C-28.9°C in Opuro-ama creek with the highest mean value of 28.9±0.32 and 26.0°C-26.8°C in Sa-ama creek with the least mean value of 26.4±0.23°C during the study period. Significant differences ($p>0.05$) between the two stations were observed (Figure 2).

Table 1: Physico-chemical parameters of interstitial water from the sample stations and standard regulatory bodies.

Parameters	OPURO-AMA		SA-AMA		WHO (2011)	USEPA (2012)	DPR (2002)
	Range	Mean	Range	Mean			
Temp. (°C)	26.0-26.8	26.4±0.23b	28.3-2.3	28.9±0.32a	28-30	<25	22.32-25
pH	4.4-6.2	5.3 ± 0.06b	3.9-4.5	4.2±0.54a	6.5-8.2	6.5-8.5	6.5-8.5
Sal. (ppt)	9.1- 9.5	9.3±0.21b	11.2-12.0	11.6 ±0.22a	120	-	600
DO (mgL)	4.6-4.10	4.10±0.29a	1.5-2.3	1.9±0.28b	6	7.5	5
BOD (mgL)	1.4-2.3	1.85±0.26b	1.9-2.4	2.16±0.15a	10	5 - 7	10
Cond.(µS/cm^{-1})	10.3-1.6	10.5±0.09b	12.5-12.6	12.6±0.03a	400	200-1000	-
TDS (µS/cm)	14.0-15.4	14.2±0.10 b	15.7-17.0	16.6±0.01a	2000	1000-2000	2000
TSS (µS/cm)	91 - 130.2	111±0.58b	121-127	124±0.05a	30	30	30
COD (µS/cm)	42-79	64.6±0.88b	89- 99	94.0±0.05a	40	-	10

In each row, the mean with a common letter is not significantly different (P>0.05).

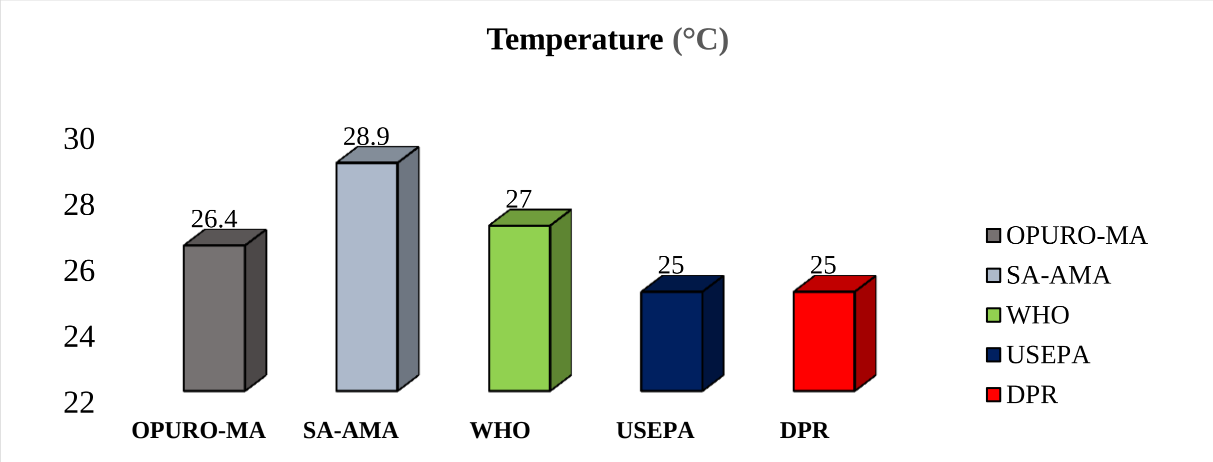

Fig. 2: Mean values of temperature (ºC) in interstitial water as compared to standards.

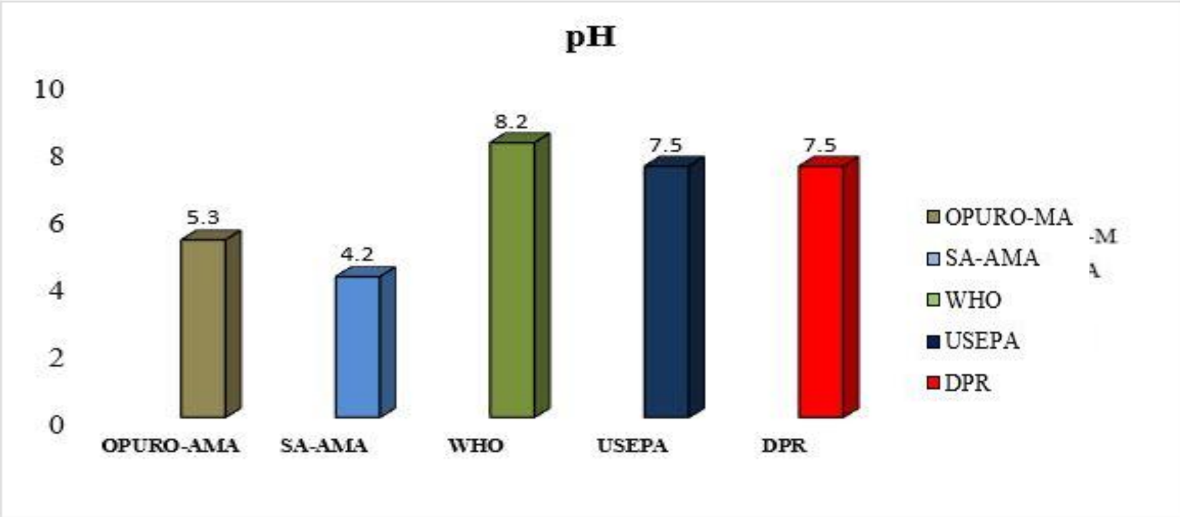

Fig. 3: Mean values of temperature (pH) in interstitial water as compared to standards

Hydrogen Ion Concentration (pH)

The pH values of the interstitial water varied between 4.4-6.2 in the Opuro-ama creek with the highest mean value of 5.3 ± 0.06 and 3.9-4.5 in Sa-ama creek with the lower mean value of 4.2±0.54. A significant difference ($p<0.05$) in the pH value was observed between the two sampled stations (Figure 3).

Dissolved Oxygen (mg/L)

Dissolved oxygen values varied between 4.1- 4.6 mg/L in Opuro-ama creek with the highest value of 4.10±0.29 and 1.5-2.3 mg/L for Sa-ama creek with the least mean value of 1.9±0.28. There was a significant difference ($p<0.05$) between the mean values of both stations as seen in Figure 4.

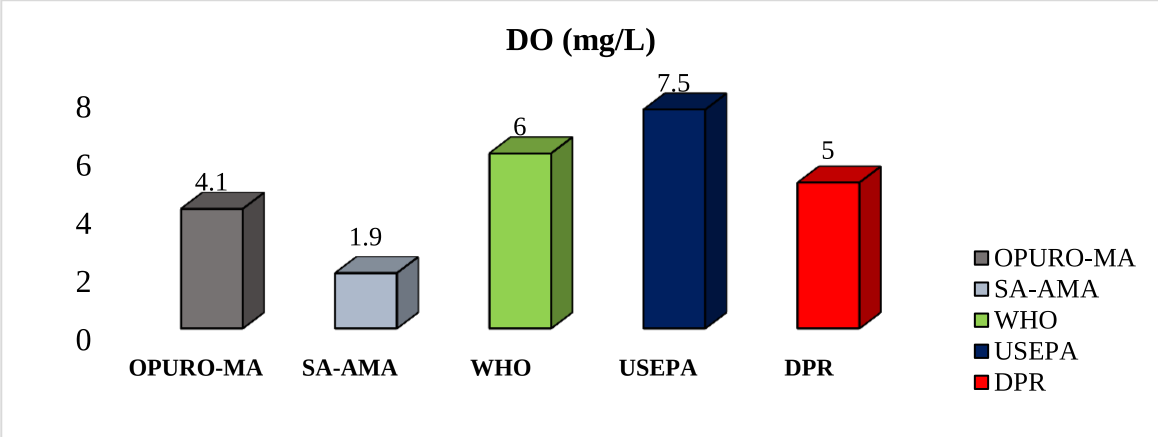

Fig. 4: Mean values of Dissolved Oxygen (Mg/L) in interstitial water as compared with standard organizations

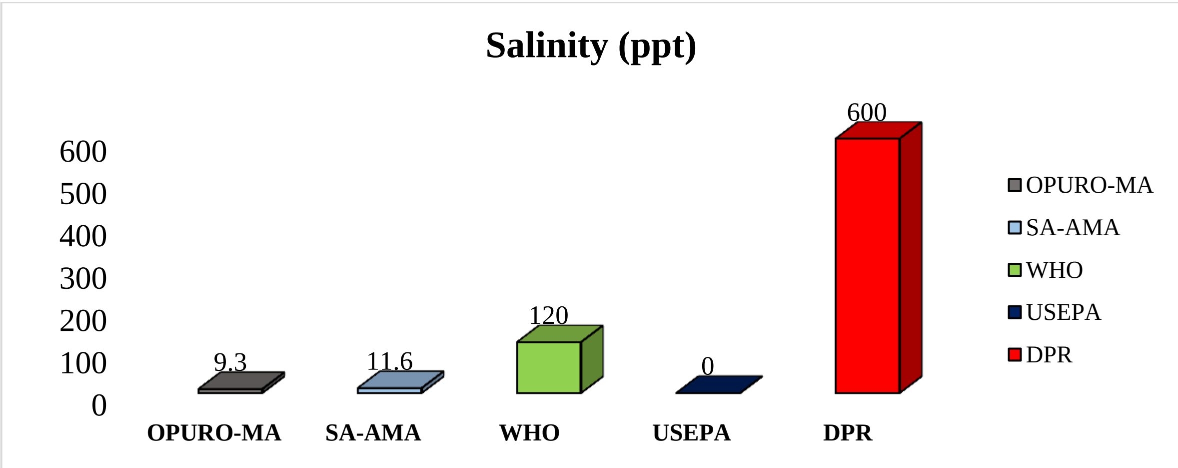

Fig. 5: Mean values of Salinity (ppt) in interstitial water as compared to standards.

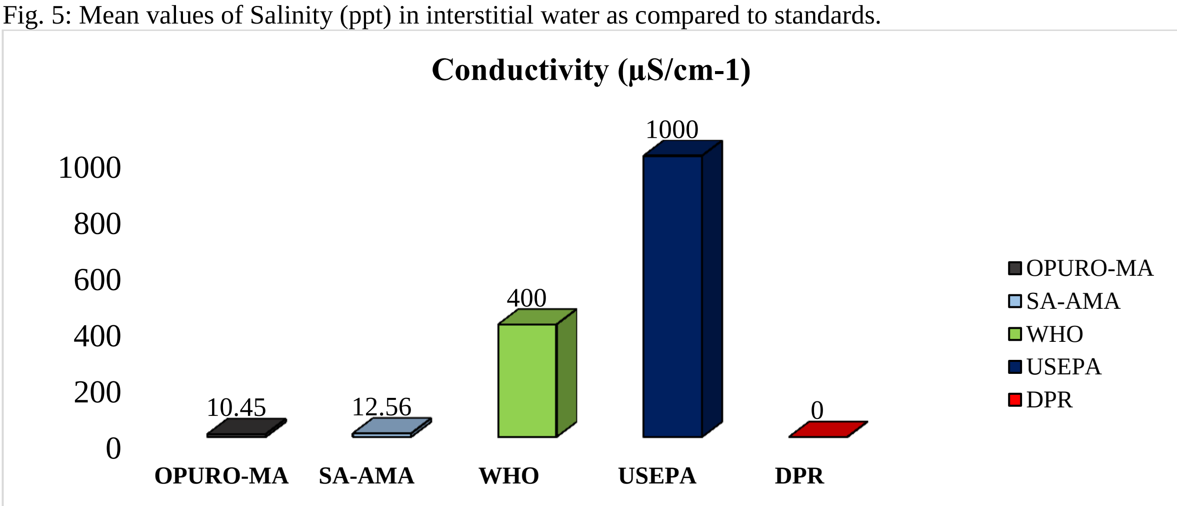

Fig. 6: Mean values of Conductivity $(\mu S/cm)^{-1}$in interstitial water as compared to standards.

Salinity (ppt)

The salinity values varied significantly different ($p<0.05$) between the Opuro-ama and Sa-ama creeks. The salinity values range from $11.2\%_0$-$12.0\%_0$ to) in Sa-ama creek with the highest mean value of 11.6 $\pm 0.22\%_0$ and from 9.1-$9.5\%_0$ in Opuro-ama creek with the least value of $9.3\pm0.21\%_0$ (Figure 5).

Conductivity $(\mu S/cm)^{-1}$

The electrical conductivity values varied between10.3-1.6$\mu S/cm^{-1}$ in Opuro-ama with the least mean value of 10.45 ± 0.09 and 12.5-12.6$\mu S/cm^{-1}$in Sa-ama creek with the highest mean value of 12.56 ± 0.03. Mean values of conductivity in both creeks were not significantly different ($p>0.05$) as seen in Figure 6.

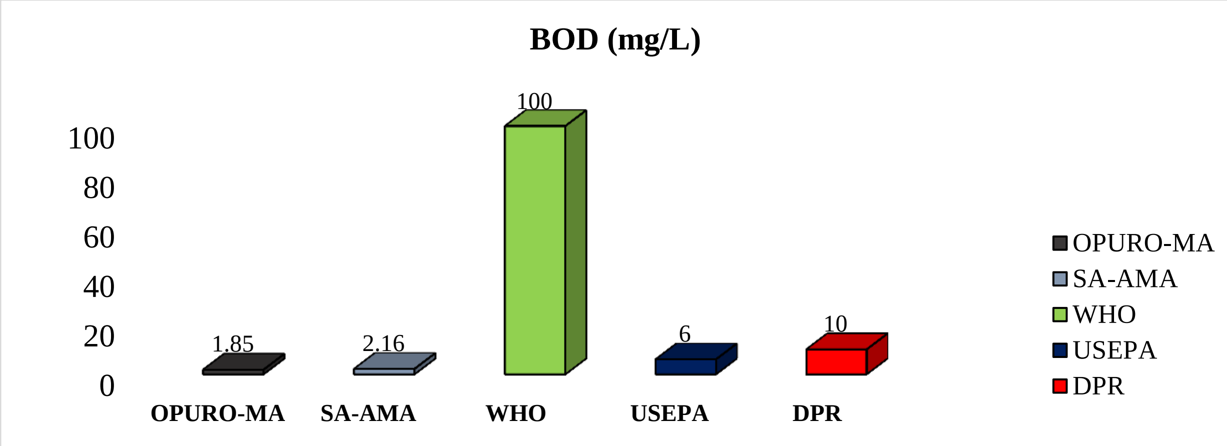

Figure 7: Mean values of Biological Oxygen Demand (mg/L) in interstitial water as compared to standards.

Biological Oxygen Demand (BOD)

The biological oxygen demand values were significantly different ($p<0.05$) between Opuro-ama and Sa-ama creek. The values range from 1.4-2.3 mg/L for Opuro-ama and 1.9-2.4 mg/L for Sa-ama creek with the highest mean value of 2.16±0.15 mg/L recorded in the Sa-ama creek and the least value (1.85±0.26 mg/L) observed in the Opuro-ama creek. (Figure 7).

Chemical Oxygen Demand (mg/L)

The COD values range between 42-79 (mg/L) in the Opuro-ama creek with a mean value of 64.6±0.88 mg/L while the Sa-ama creeks recorded a range between 89-99 (mg/L) with a mean value of 94.0±0.05 mg/L. There was a significantly different ($p<0.05$) across the stations as shown in Figure 8.

The TSS values varied between 91.0-130.2 (µS/cm) for the Opuro-ama creek with a mean value of 111±0.58 and while the values varied from 121-127 (µS/cm) in the Sa-ama creeks with a mean value of 124±0.05. There was a significantly different ($p<0.05$) across the stations (Figure 9).

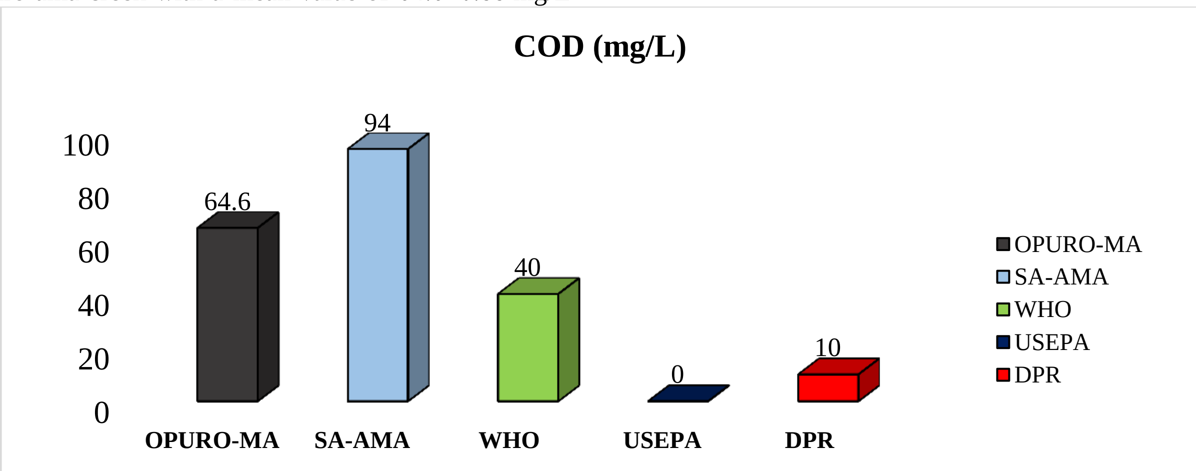

Fig. 8: Mean values of Chemical Oxygen Demand (mg/L) in interstitial water as compared to standards.

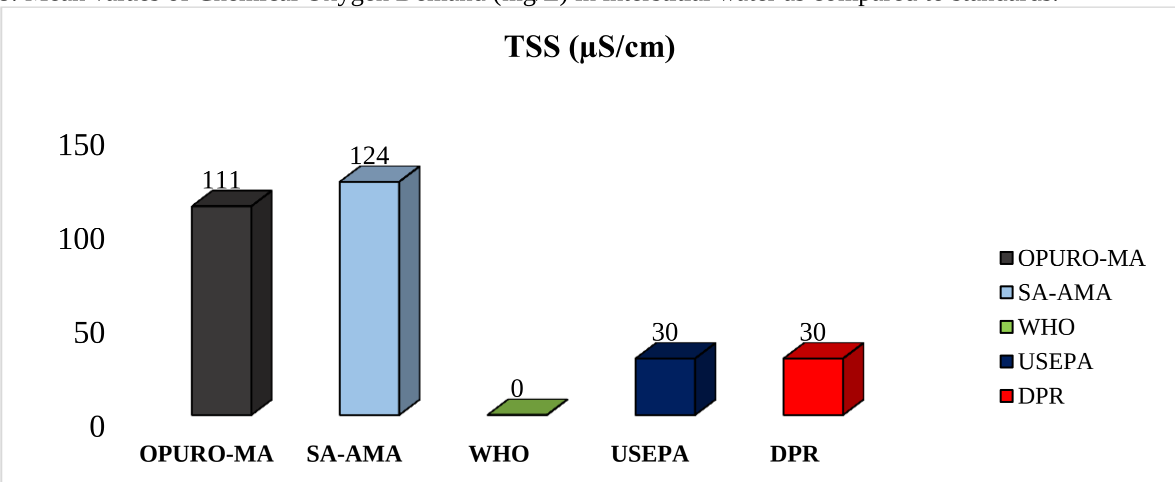

Fig. 9: Mean values of Total Suspended Solids (µS/cm) in interstitial water as compared to standard organizations.

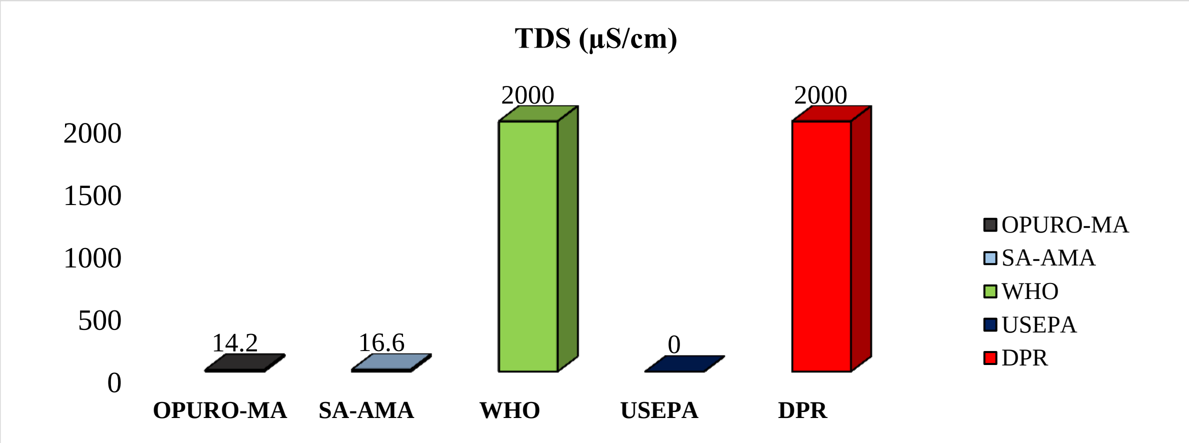

Fig. 10: Mean values of Total Dissolved Solids (µS/cm) in interstitial water as compared to standard organizations

Total Dissolved Solids (µS/cm)

The TDS values varied between 14.0-15.4 (µS/cm) for the Opuro-ama creek with a mean value of 14.2±0.10 and the Sa-ama creeks recorded a range of 15.7-17.0 (µS/cm) with a mean value of 16.6±0.01. There was a significantly different ($p<0.05$) across the stations. This is represented in Figure 10.

Discussion

Temperature (°C)

Changes in the temperature of any environment can affect all life processes either positively or negatively. It is an important factor that also affects the solubility of gases and salts in water (Hart and Zabbey 2005). In the present study, it was observed that the interstitial water temperature fluctuated and the ranged was between 28.29°C and 29.4°C in Opuro-ama creek and 26.0°C and 26.8°C in Sa-ama creek. The values were significantly different for both creeks. The values are within the WHO (2011) limits of 28-30°C for aquatic life but were above the stipulated values for USEPA (2012) which is <25°C and DPR (2002) value of 22.32-25°C. The variation could be attributed to the combination of various environmental factors that govern many physiological and biological processes of these creeks. Zabbet et al., 2021 reported that human activities around the creek such as deforestation of the mangrove trees may have resulted from direct heat from sunlight on the sediment. Phung et al., (2015) reported a similar trend in the New

Calabar River and high temperatures ranging from 28 and 32°C which were recorded in the Lagos Lagoon (Ajao and Fagade, 2002). A similar range of results was also reported by Hart and Zabbey (2005) in Woji creek (25.8 to 30.4°C). Temperature affects physical, chemical, and biological processes in water bodies, therefore, the need to be concerned about the increase in the values which may be linked to the activities and their effluence in the study area which may also have caused the variation (Davies and Efekemo 2022). Ogbonna (2014) recorded a similar result in selected rivers in Port Harcourt Metropolis in the Niger Delta of Nigeria. The difference in temperatures in the study area was due to the enormous activities going on in the stream as well as its morphometric characteristics. An increase in temperatures has been reported by Ayode and Olusegun (2012) in the Ogbere River to be caused by a large number of suspended particles from the anthropogenic activities such as domestic wastes and another effluence from illtreated waste

Hydrogen Ion Concentration (pH)

The pH range of the interstitial water from Opuro-ama creek had a mean value of 5.3 while Sa-ama creek has 4.2, both creeks were was below the permissible limits as stipulated by WHO (2011), USEPA (2012), and DPR (2002) respectively. This difference could be attributed to the high density of leaf litter around the sediment and the subsequent decay which could have contributed to the slightly acidic nature of the interstitial water from Opuro-ama creek (Davies et al., 2021). This agrees with Akankali and **Davies** (2021) who stated that pH could also be influenced by the acidity of the bottom sediment and biological activities in the sediment. The pH range from Opuro-ama Creek interstitial water agrees with the pH of brackish water bodies as reported by Davies and Okonkwo, (2021). The pH influences may also be attributed to the activities and how it interferes with the biodiversity of aquatic organisms. Sharifinia et al. (2013) obtained pH results ranging from 8.07 – 8.46 in the wet season and 6.77 – 8.33 in the dry season in water samples from Ondo State coastal water which is not similar to pH results obtained in this study. The fluctuations observed in the pH values may influence the function of virtually all enzymes, hormones, and proteins which controls all aspects of metabolism, growth, and development (Oluwagboun and Komi, 2022).

Dissolved Oxygen (Mg/L)

Oxygen plays a very important role in any living ecosystem and the amount of dissolved oxygen in water depends on the temperature of the environment and the surface area exposed (Kannel et al., 2011). In the present study, the highest value of DO was reported in the Opro-ama creek which varied from 1.4 to 2.3 Mgl^{-1} while the least value was from 1.5 to 2.3 Mgl^{-1} in the Sa-ama creek. There was a significant variation in the values of the dissolved oxygen in the interstitial water between the two creeks. The values were lesser than the acceptable limit of 5mg/L reported by WHO/USEPA/DPR (2012). A decrease in dissolved oxygen levels may indicate a polluted environment where bacteria are thriving and using up the oxygen (Liu et al., 2021). This agrees with Akankali et al., (2022) who stated that the decrease in dissolved oxygen levels may be due to the microorganisms using oxygen to break down large plants. Boyd et al., (2019) also stated that a large number of aquatic plants rotating in the water also reduces dissolved oxygen levels. A similar result has been reported for both creeks by Davies et al. (2022) on the water from a polluted mangrove swamp in Rivers State. The results from Opuro-ama Creek agree with the temporal variations of physicochemical parameters of interstitial water reported by Ansa et al., 2007. Similarly, the dissolved oxygen values in the Shiroro Lake varied between 2.3 mg/l in bottom water samples and 12.0 mg/l in surface water samples (Sikoki and Veen, 2004). The dissolved oxygen may not pose a direct health risk to humans, but it can affect other chemicals in the water, thereby affecting the aquatic environment (Davies and Efekemo 2022). Akankali et al. (2022) reported that high organic matter content from human feces, rotten household waste, sawmill waste, and plant material that has flowed into these streams can also be reported with low DO records. In addition, DO may have been consumed by the impact of oxidation of nitrogen-containing substances in water from rivers. Akankali et al. (2022). There is an inverse relationship between salinity, temperature, and dissolved oxygen (Lipizer et al., 2014). The DO solubility in water is more affected by salinity and temperature (Verberk et al., 2020). In addition, the presence of decaying organic matter can also cause low oxygen levels, resulting in the emission of toxic gases such as hydrogen sulphide and methane (Hamoda and Alshalahi, 2021). In both creeks, the values didn't reach the minimum value (5mgl-1) for most aquatic animals, required for a normal life cycle ((Motasim, 2017).

Salinity (ppt)

Salinity is one of the key factors that significantly influence the abundance and distribution of organisms in estuaries and freshwater areas. It also interferes with osmoregulation and fish egg development. In estuarine and freshwater environments, salinity is one of the most important elements that determine the quantity and distribution of species (Day et al., 2012).

The salinity value from the study was highest (11.6 $\pm 0.22‰_0$) in the Sa-ama creeks while the lowest value ($9.3 \pm 0.21‰_0$) in Opuro-ama creek. The fluctuations in values can be due to reduced wastewater mixing and emissions of industrial and household waste (Popa et al., 2012). Komi and Sikoki (2013) assumed that the salt content of the Andoni River system is affected by the amount of precipitation and the amount of water discharged into the body of water. This is not uncommon in estuaries, which are famous for their unstable environment (Venberg and Venberg, 1981). However, the difference in salinity between the two creeks is due to fluctuations caused by sharp increases in salinity at different times and seasons (Hossain et al., 2019), or due to human activity like contamination and effluence from illegally refined crude oil observed around the environment along the creeks. Although the salinity gradients of both creeks deviate from normal brackish water conditions, lower salinity may be due to reduced effects of anthropogenic activity around the rivers, Similar observations were made by Logozzo et al. (2021) on the photochemical and microbial degradation of chromophore solutes under floodplain conditions. However, the difference in salinity of the two creeks could be due to the variation caused by a sudden rise in salinity at different times and seasons or attributed to the pollution caused by human activities exemplified by the domestic waste and other illegal activities along the Opuro-ama Creek.

The relatively higher salinity around the Sa-ama creek could also be explained by its location within a mangrove swamp. Mangroves, besides supplying ecosystem goods, also provide ecological services for man and other ecosystems, such as coral reefs, adjacent flats, and seagrasses in the seascape (Moberg and Ronnback, 2003; (Ferreira et al., 2011). These services include protection of the shoreline against erosion, a breeding ground for many commercial fish stocks, and the maintenance of water quality (Kitheka, 1997), including salinity (Ronnback, 1999). Considering that more waste effluence was observed at this Sa-ama creek than at the Opro-ama creek, salinity ought to be higher than at Opro-ama creek but because inflowing tidal water should be diluted due to mixing with outflowing water (Bhuiyan and Dutta, (2012). A trend of rising salinity gradient nearly emerged numerically from both stations, although it may have been affected by the discharges recorded from comparatively incredible affluence along the creeks. This is consistent with Zabbey (2012), who reported similar trends in spatial and temporal variation in salt content in the interstitial water quality of the soft-bottomed plains of Bod Creek in the eastern Niger Delta.

Electrical conductivity (µS/cm)$^{-1}$

The conductivity obtained from Sa-ama Creek which ranges between 12.5 - 12.6 µS/cm^{-1} was higher than that reported in the Opuro-ama Creek with a range value of 10.3 to1.6 µS/cm^{-1}. Nevertheless, the mean value of the electrical conductivity for both creeks was within the acceptable limit of 400 µS/cm^{-1} and 1000 µS/cm^{-1} by WHO, (2011), and USEPA (2012). These variations observed from both creeks could be attributed to the fact that the conductivity is directly proportional to the number of salts dissolved in each water and most water bodies show significantly high conductivity values when more dissolved salts are present in them.

The conductivity from Sa-ama Creek agrees with what Smith (1996) reported on the mangrove sediment in the clarence River, Sikoki and Veen (2004) reported extremely low values of 3.8-10.0 µScm-1 in the Shiroro Reservoir which was a freshwater in Nigeria. Form this study, the observed conductivity of the interstitial water from both Creeks conformed with Hogan and Ward (1998) who reported that the conductivity of most water bodies ranges from 10-1000 µscm^{-1} and may exceed 1000 µscm$^{-1,}$ especially in polluted waters, or those receiving large quantities of land run-off. The higher mean electrical conductivity value in the Sa-ama Creek could be attributed to the impact of the anthropogenic activities found around the creek. The higher mean electrical conductivity value in the Sa-ama Creek could be because of the presence of materials that ionize when washed into the water. Discharges to rivers can also change the conductivity depending on their make-up. A failing sewage system or dumpsite would raise the conductivity because of the presence of chloride, phosphate, and nitrate while in the Opra- ama creeks, the effluence from the illegally refined oil spill flowing into the creek from nearby illegal refining sites could lower the conductivity as well.

Biological Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is a significant marker of water quality, which measures the quantity of oxygen consumed by microorganisms during the degradation of organic matter (Huang et al., 2021). The Dissolved oxygen values range from 1.4 to 2.3 Mgl^{-1} for Opro-ama and 1.9 to 2.4 Mgl^{-1} in Sa-ama creek. These values were far lesser than the acceptable limit of 5mg/L recommended by USEPA (2012) for aquatic life. There were significantly different BOD values for Opuro-ama and Sa-ama creeks. The decline and variations observed might be attributed to the level of pollution by anthropogenic activities along the Opuro-ama Creek (Gautam et al., 2021). The BOD values from Sa-ama Creek were lower than what Unimke et al., (2014) reported for the Imo River Estuary of the Niger Delta mangrove ecosystem.

The variation may be associated with the relatively stable level of pollution he observed in the River Estuary (Sun et al., 2018). This agrees with Oyewo and Don-Pedro, (2003) who stated that variation in the water quality also affects the physicochemical composition of the ecosystem and the physiological processes of aquatic life. The quality of BOD in aquatic surroundings is crucial for the productivity, survival, and assistance of aquatic organisms living in them. The physicochemical parameters of any river offer dietary stability and additionally govern the biotic relationships among the organisms and their surroundings (James et al., 2013). The low BOD values in this study agree with Hawramia et al. (2018) whose prescribed value was found in the surface water in all of their study. This concentration was higher than the concentration reported by Chen et al. (2010) This may be attributed to the various water resources used in the study. This agrees with Venkiteswaran et al. (2007) who reported that in a water body, there is a finite amount of dissolved oxygen that fluctuates with the aquatic ecosystem's diurnal cycle.

Chemical Oxygen Demand (µS/cm)

The measure of chemical oxygen demand determines the amounts of organic matter found in a water body. This makes it a useful indicator of organic pollution in surface water (Hawramia et al. (2018). In the present study, the chemical oxygen demand values which range between 42 to79 µS/cm in the Opuro-ama creek and 89 to 99 µS/cm in the Sa-ama creeks were above the acceptable limit of 40 $\mu S/cm^{-1}$ and 10 $\mu S/cm^{-1}$ by WHO, (2011), and DPR (2002). There were significant variations between both creeks. In the conjunction with the biological oxygen demands test, the chemical oxygen demand test helps indicate toxic conditions and the presence of biologically resistant organic substances (Barakat et al., 2018). In the assessment between the Opuro-ama creek and Sa-ama creek value of chemical oxygen demand, Sa-ama creek shows a higher deviation which refers to the lower quality of the creek's chemical oxygen demand. The amount of chemical oxygen demand determines the quantities of organic matter found in a water body. Therefore, it makes chemical oxygen demand is a useful indicator of organic pollution in this creek (Lokhande et al., 2011). (Dienye and woke 2015) stated that chemical Oxygen Demand (COD) was generally higher than standards allowed to be discharged into the Nigerian inland waters comparing his result values which were greater than 40 mg/l and therefore indicated a higher degree of pollution in the water body.

Total Suspended Solids (µS/cm)

The total suspended solids are made up of carbonates, bicarbonates, chlorides, phosphates, nitrates from alkali and alkaline earth metals, organic matter, salt, and other elements (Singh et al., 2015). From this study, the mean value for TSS in the Opuro-ama creek was 111±0.58 µS/cm while the mean value for Sa-ama creeks was 124±0.05 µS/cm. the values were above the acceptable limit of 30 $\mu S/cm^{-1}$ by USEPA (2012), and DPR (2002). Therefore, it could be said that these creeks' water with high suspended solids is not suitable for fish growth (Lodh et al., 2014). This indicates the reliability of the relationships which suggests that the total suspended solids can be used to predict the levels of pollution by the parameters investigated and possibly proffering a preventive measure before the detailed investigation of this creek in a polluted environment like this (Waziri and Ogugbuaja, 2010). Compared to other studies, the high TSS in this study could po a consequence of the contagious spread of sewage water and pollution caused by nearby activities (Nafi'Shehab et al., 2021). An increase in TSS caused by anthropogenic pollutants may result in eutrophication of water bodies, which in turn may lead to decreased light transmission and thus a reduction in overall productivity (Mazurkiewicz et al., 2020).

Total Dissolved Solids (µS/cm)

Total Dissolved Solids have great importance in water and wastewater treatment because it normally represents the number of organic solids in water. It helps assess the amount of biologically inert organic matter. TDS plays a major role in determining the color and electrical conductivity of the water (Vasistha and Ganguly, 2022). In addition to indicating the salinity of water, total dissolved solids (TDS) can also serve as an indicator for rapid plankton growth and sewage contamination (Das et al., 2018). The study revealed that the Total Dissolved Solids (TDS) values varied between 14.0-15.4 for Opro-ama and 15.7-17.0 for Sa-ama creeks these values were within the acceptable limit of 200 $\mu S/cm^{-1}$ by WHO, (2011) and DPR (2002). The TDS value is very important in assessing good water quality. There is no serious health effect associated with TDS absorption in water as reported by some regulatory agencies like (USEPA, 2012; DPR 2002; WHO, 2002) who recommended a maximum TDS value of 500mg/l for a drinking water. Although the TDS concentration in a body of water can be affected by various factors (APHA 2005).

Increases in TDS can also result from runoff from roads that have been salted in the winter. Organic matter from wastewater that is not treated from the affluence around the creeks may contribute to higher levels of nitrate or phosphate ions (Davies and Efekemo (2022). When the TDS concentrations are high, especially due to dissolved salts, different forms of aquatic life may be affected as well and the high level of salts generated may lead to dehydration of the skin of animals (Hawramia, et al., 2018). The values were below what Sharma et al., 2015 reported in the Limnological study of water quality parameters of Dal Lake where the TDS values were typically found to be between the range of 50 to 250 mg/L. This could be attributed to the hardness of the water or the high level of salinity, in those areas.

Conclusion

In conclusion, the pollution resulting from the impact of this illegal crude oil activity and other associated waste in these creeks has altered the Physico-chemical parameters of the water and might hurt the fishery of this natural water body. It was observed that Sa-ama creek had more impacted water parameters than the Opro-ama creek. From the results, most of the parameters for both creeks were not within international and local limits for fish production and domestic water use WHO, (2011); USEPA, (2017) and DPR (2002). A few exceptions were observed in some parameters as well. Therefore, this obvious evidence of severe contamination in the water quality of the Opro-ama and Sa-ama rivers has affected the Physico-chemical parameter of these creeks as attributed to the illegal crude oil activity and other associated waste observed in the study. Since there is a dearth of information on the impact of anthropogenic activities on the physicochemical characteristics of these creeks in the Asari Toru Local Government of Rivers State. Therefore, to safeguard the fishery, the aquatic environment, and the host community, there is a need for proper and frequent environmental monitoring and assessment by authorized regulatory bodies in the rivers state of Nigeria. This will prevent more future impact and exposure which may endanger the lives of the aquatic organisms therein. The remediation of the creeks and implementation of already established laws to prohibit the direct and indirect disposals and discharge of mistreated, untreated, and wrong disposal partners of any form of waste from large industries to traditional activities.

Conflict of Interest / Author Contributions

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This manuscript covers research conducted by both authors. Both authors conducted the fieldwork, the second author performed the statistical analysis and prepared reports while the first author was responsible for the writing of the manuscript for publication. The main concept and methodology were generated and academically supervised by both authors.

Data Availability Statement

The authors confirm that the data that supports the findings of this study are available within the article.

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