***Original Research Article***

# Impact of Artisanal Refinery Activities on Interstitial and Surface Water Quality Along Ibaka Creek, Rivers State, Nigeria.

## ABSTRACT

The aim of the study was to determine the impact of artisanal refinery activities on interstitial and surface water quality along Ibaka Creek, Rivers State, Nigeria. The temperature, pH, electrical conductivity (EC), salinity and total dissolved solids were measured using a Multi-meter (Manufacturer - Extech EC500; City – Washington). Dissolved oxygen (DO) and Biochemical oxygen demand (BOD) were measured using an Extech multimeter (Manufacturer - Extech EC500**;** City – Washington). All the physicochemical parameters were within the acceptable limit by the (WHO, EPA and SON. The surface and interstitial water in Ibaka Creeks showed variations in EC, TDS, pH, temperature, salinity, BOD, and DO values. However, surface water recorded higher EC (30.04±0.19 µS/m) and TDS (29.87±0.18 mg/L) values, while interstitial water showed a higher pH value of 7.25±0.07 and lower temperature values of 27.94±0.09 °C. Salinity was higher in surface water (0.64±0.15 ppt). Surface water also had a higher BOD value of 3.36±0.02 mg/L and a DO value of 4.61±0.06 mg/L than that in the interstitial water. There were no significant differences ($p<0.05$) in the BOD and pH values between the surface and interstitial water. The other parameters showed significant differences ($p>0.05$). The temporal variation in the physicochemical parameters for the surface and interstitial water in Ibaka Creek showed significant variation across the months. The surface and interstitial water in November recorded the highest values, except for BOD values which were highest in December. The month of February recorded the lowest temperature and pH while April had the lowest DO. Moreover, the salinity and BOD were lowest in March, while electrical conductivity and TDS were lowest in February. Temporal variations showed fluctuation in parameters across the months which was attributed to seasonal changes and anthropogenic influences. Therefore, continued monitoring and assessment are essential to maintain and safeguard the health of aquatic ecosystems and support sustainable management practices.

***Keywords**: Artisanal Refinery; Ibaka Creek; Water Quality; Temporal Variation*

## 1. INTRODUCTION

The Niger Delta region of Nigeria stands as a microcosm of the complex relationship between human activities and the environment, driven by the exploration and exploitation of oil and gas resources[1]. Within the industrial and economic endeavours, a less conspicuous yet pressing concern has emerged,abandoned artisanal refinery sites[2]. These locations, which remain remnants of unregulated oil refining activities, possess the capacity to cause long-lasting ecological harm to the fragile ecosystems of the area [3].

The Niger Delta's rich natural resources and biodiversity have long attracted large-scale oil and gas industries and small-scale artisanal activities aimed at extracting valuable products from crude oil [4]. While these artisanal activities may have provided economic benefits to local communities, they have left a legacy of environmental challenges in abandoned refinery sites that often spill pollutants into the surrounding environment[5].

Estuaries are unique, complex and highly productive marine ecosystems [6]. Due to the intricate and interconnected interactions that occur in these ecosystems, it can be challenging to understand the impacts of disturbance caused by pollution [7]. Furthermore, the dynamic physical, chemical and geological factors in estuaries can make it difficult to assess the impact of human activity on the biotic integrity of these ecosystems [8]. Therefore, it is crucial to conduct a comprehensive and accurate assessment of interstitial and surface water in these estuaries Mangrove Swamp.

The interstitial spaces within mangrove sediments act as a dynamic interface, where water quality interacts with the sediment matrix, influencing nutrient cycling, biogeochemical processes, and the overall health of the ecosystem[9]. Conversely, surface waters serve as the visible interface that connects terrestrial and aquatic realms, mediating the exchange of nutrients and contaminants[5]. Beyond the ecological sphere, the potential repercussions of water quality degradation extend to human health and livelihoods[10]. Communities residing near these mangrove ecosystems are particularly vulnerable to the consequences of abandoned refinery pollution, as water sources are intimately intertwined with daily life activities, including fishing, agriculture, and domestic use[11].

Therefore, an in-depth understanding of the interplay between abandoned refinery sites, water quality, and human well-being is of paramount importance. This study aims to explore the complex effects of abandoned artisanal refinery sites on the quality of both interstitial and surface water in the intricate setting of the Ibaka Mangrove Swamp.

## 2. MATERIALS AND METHODS

### 2.1 Description of Sampling Areas

The study was conducted on the Ibaka waterfront, a tidal mangrove in the Niger Delta, Nigeria (Figure 1). The Ibaka mangrove swamp is situated within the coordinates of 4°43'55.7"N to 4°45'02.5"N latitude and 7°04'07.4"E to 7°04'38.4"E longitude. Three sample stations were selected to form a composite sample, located near mudflat sediment, an abandoned artisanal site, and a densely populated settlement (Plate 3.1a to Plate 3.1c). The area is constantly flooded with waste from animal, human, and domestic sources. Activities in the area generate waste from sewage discharge, refuse, and commercial waste, which are dumped into the tidal river. The study area is also subject to effluent discharge from industries and a densely populated coastal settlement. Surface run-offs from erosion, lumbering, dredging, forestry operations, and domestic sewage contribute to the wide-scale contamination of the swamps. Speed boats frequently traverse the sample stations, polluting and dispersing contaminants across the environment. The sample site is also close to the Creeks, communities like George Ama, Ogoloma and ACT jetty. All three random sample stations are frequently traversed by speed boats either conveying passengers or illegally refined crude products, polluting and caused by disturbances that constantly disperse and regiment the contaminants across the environment.

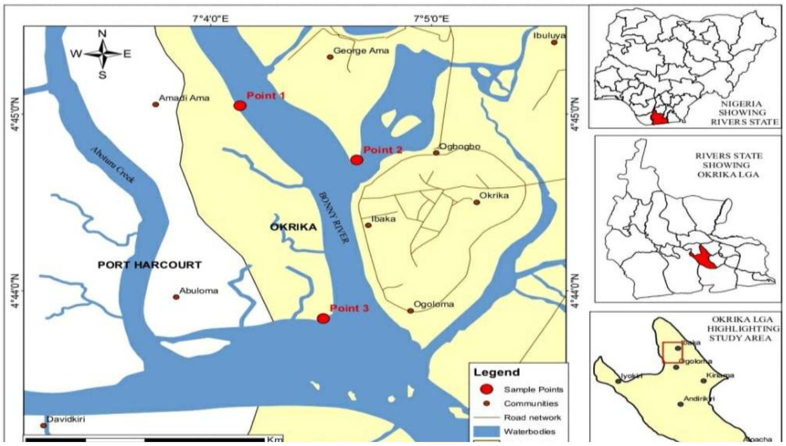

**Fig. 1. Section of the Ibaka sampled stations studied.**

**Plate 3.1:** Showing the sampling sites

### 2.2 Collection of Samples

The analysis investigated the physical and chemical attributes of surface and interstitial water, encompassing pH, salinity, temperature, conductivity, TDS, and DO. The device was activated for self-calibration, followed by air pressure instrument verification via the CAL button. The probe was cleansed with both the sample and distilled water. After 15 minutes, interstitial water was extracted from a trench on the intertidal flat. Readings were captured as the probe entered the sample cell, having stabilized for recording. The temperature was gauged using a mercury-in-glass thermometer. Utilizing a Multi-meter (Manufacturer: Extech EC500; City: Washington), pH, EC, salinity, and TDS were measured, the instrument having been calibrated with EC standards and pH buffers. Both EC and pH observations were logged once stable. Salinity and TDS values were then sequentially collected. For quantifying dissolved oxygen (DO) and biochemical oxygen demand (BOD), an Extech multimeter (Extech EC500; Manufacturer: Washington) was employed. Each sample underwent a triplicate examination.

### 2.3 Statistical Analysis

To determine the average, range, mean, and standard deviations of the examined surface and interstitial water, descriptive statistics were used. In addition, a one-way ANOVA and the significance test were performed on the findings. The statistical evaluation was carried out using IBM SPSS 23 software.

## 3. RESULTS

### 3.1 Physicochemical Parameters of The Interstitial and Surface Water

Table 1 presents the mean physicochemical parameter results for interstitial and surface water in the Ibaka Creeks at the Okrika River sampled site. The highest Electrical Conductivity (EC) concentration (30.04±0.19 µS/m) was observed in surface water, while the lowest was noted in interstitial water (26.80±1.4 µS/m). Surface water exhibited a higher Total Dissolved Solids (TDS) concentration

(29.87±0.18 mg/L), whereas interstitial water displayed the lowest value (22.20±1.12). The highest pH value (7.25±0.07) was recorded in interstitial water, contrasting with the lowest value (22.20±1.12) found in surface water. Surface water registered a higher temperature (28.18±0.06 °C), while interstitial water showed a slightly lower temperature (27.94±0.09 °C). The mean salinity concentration was greater in surface water (0.64±0.15 ppt) compared to interstitial water (0.56±0.01 ppt). Surface water exhibited a higher Biological Oxygen Demand (BOD) (3.36±0.02 mg/L), while interstitial water displayed a lower BOD (3.30±0.07). Dissolved Oxygen (DO) levels were higher in surface water (4.61±0.06 mg/L) than in interstitial water (3.92±0.13 mg/L). The physicochemical parameters of electrical conductivity, total dissolved solids, temperature, salinity, and dissolved oxygenshowed significant differences ($p>0.05$) between interstitial and surface water. However, there were no significant differences ($p<0.05$) between interstitial and surface water concerning biological oxygen demand and pH.

**Table 1. Mean Variation of the Physicochemical Parameters of The Interstitial and Surface Water.**

| **Locations** | **EC (µS/m)** | **TDS (mg/L)** | **pH** | **Temp (°C)** | **Salinity (ppt)** | **BOD (mg/L)** | **DO (mg/L)** |
|---|---|---|---|---|---|---|---|
| **Interstitial** | 26.80±1.4$^{b}$ | 22.20±1.12$^{b}$ | 7.25±0.07$^{a}$ | 27.94±0.09$^{b}$ | 0.64±0.15$^{a}$ | 3.30±0.07$^{a}$ | 3.92±0.13$^{b}$ |
| **Surface** | 30.04±0.19$^{a}$ | 29.87±0.18$^{a}$ | 7.23±0.08$^{a}$ | 28.18±0.06$^{a}$ | 0.56±0.01$^{b}$ | 3.36±0.02$^{a}$ | 4.61±0.06$^{a}$ |
| **(WHO (2011)** | <1000 | 600 | 6.5 - 8.5 | - | - | 10 | 5 – 6 |
| **USEPA (2020)** | 500 | 500 | 6.5 - 8.5 | - | 2 | 3 | 3 - 5 |
| **SON (2019)** | 1000 | 500 | 6.5–8.5 | 22–32 | - | 10 | 3–5 |

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

*EC: Electrical Conductivity, TDS: Total Dissolved Solids, pH: Potential of Hydrogen, Temp: Temperature, Salinity: Salinity level, BOD: Biological Oxygen Demand, DO: Dissolved Oxygen.

*World Health Organization [12]

*United States Environmental Protection Agency [13].

*Standards Organization of Nigeria [14].

### 3.2 Temporal Variation in The Physicochemical Parameters of Surface Water from Ibaka Creeks.

Table 2 shows the temporal variation in Physicochemical parameters (electrical conductivity, total dissolved solids, pH, temperature, salinity, biological oxygen demand, and dissolved oxygen) from the study. The mean electrical conductivity ranged between 29.17±0.00 µS/cm in February to 31.28±0.25 µS/cm in November while the TDS ranged between 29.05±0.11 mg/L in February to 30.58±0.02 mg/L in November. The temperature ranged between 28.04±0.01 °C in February to 28.34±0.11°C in November and mean pH values ranged from 6.84±0.33 in April to 7.59±0.12 in November. Salinity ranged between 0.51±0.00 in March to 0.62±0.10 in November and the BOD ranged between 3.23±0.01 mg/L in March to 3.49±0.01 mg/L in December.The DO range between 4.25±0.02 mg/L in April to 4.88±0.15 mg/L in November. The monthly variation in the mean values of the Physicochemical parameters was significantly different ($P > 0.05$) for electrical conductivity, pH, BOD, DO, and TDS respectively across the months. However, no significant ($P < 0.05$) variation was observed in the mean temperature and salinity values across the months. Temperature and electrical conductivity, salinity, pH, DO and TDS were highest in November while BOD was highest in December. The temperature was lowest in February, pH was lowest in April and DO was in April. Salinity and BOD were lowest in March while the electrical conductivity and TDS were lowest in February.

**Table 2. Temporal Variation in The Physicochemical Parameters of Surface Water Samples from Ibaka Creeks.**

| Months | EC (µS/cm) | TDS (mg/L) | pH | Temp (ºC) | Salinity (ppt) | BOD (mg/L) | DO (mg/L) |
|---|---|---|---|---|---|---|---|
| **Nov** | 31.28±0.25$^{a}$ | 30.58±0.02 $^{a}$ | 7.59±0.12$^{a}$ | 28.34±0.11$^{a}$ | 0.62±0.10$^{a}$ | 3.43±0.01$^{a}$ | 4.88±0.15a |
| **Dec** | 31.08±0.13$^{a}$ | 30.35±0.21 $^{a}$ | 7.56±0.02$^{a}$ | 28.30±0.11$^{a}$ | 0.60±0.02$^{a}$ | 3.49±0.01$^{a}$ | 4.87±0.03a |
| **Jan** | 29.18±0.08$^{b}$ | 29.27±0.61 $^{a}$ | 7.15±0.14$^{ab}$ | 28.06±0.18$^{a}$ | 0.55±0.08$^{a}$ | 3.32±0.06 $^{b}$ | 4.64±0.11b |
| **Feb** | 29.17±0.00$^{b}$ | 29.05±0.11 $^{b}$ | 7.14±0.01$^{ab}$ | 28.04±0.01$^{a}$ | 0.54±0.00$^{a}$ | 3.35±0.02 $^{b}$ | 4.68±0.04ab |
| **Mar** | 30.09±0.03$^{ab}$ | 30.13±0.01 $^{a}$ | 7.15±0.00$^{ab}$ | 28.26±0.09$^{a}$ | 0.51±0.00$^{a}$ | 3.23±0.01 $^{b}$ | 4.32±0.03bc |
| **Apr** | 29.62±0.00 $^{b}$ | 29.58±0.69$^{ab}$ | 6.84±0.33 $^{c}$ | 28.13±0.27$^{a}$ | 0.56±0.01$^{a}$ | 3.28±0.01$^{bc}$ | 4.25±0.02 c |
| **(WHO (2011)** | <1000 | 600 | 6.5 - 8.5 | - | - | 10 | 5 – 6 |
| **USEPA (2020)** | 500 | 500 | 6.5 - 8.5 | - | 2 | 3 | 3 - 5 |
| **SON (2019)** | 1000 | 500 | 6.5–8.5 | 22–32 | - | 10 | 3–5 |

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

*EC: Electrical Conductivity, TDS: Total Dissolved Solids, pH: Potential of Hydrogen, Temp: Temperature, Salinity: Salinity level, BOD: Biological Oxygen Demand, DO: Dissolved Oxygen.

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### 3.3 Temporal Variation in The Physicochemical Quality of Interstitial water samples from Ibaka Creeks.

Table 3 shows the temporal variation in Physicochemical parameters of the Interstitial water samples (electrical conductivity total dissolved solids pH, temperature, salinity biological oxygen demand, and dissolved oxygen) from Ibaka Creek in Okrika from November 2022 to April 2023. The average electrical conductivity exhibited a range from 28.52±0.30 µS/cm in January to 30.17±0.41 µS/cm in November, while TDS fluctuated between 23.86±2.3 mg/L in February to 30.22±0.16 mg/L in November. The temperature ranged between 27.89±0.47 °C in February to 28.36±0.47°C in November, and the mean pH values varied from 7.08±0.02 in February to 7.55±0.26 in November. Salinity displayed a range from 0.39±0.17 in February to 1.32±0.01 in December, and BOD ranged from 3.19±0.02 mg/L in March to 3.68±0.09 mg/L in December. DO ranged from 3.89±0.16 mg/L in April to 4.80±0.04 mg/L in November. November saw higher values for electrical conductivity, temperature, pH, DO, and TDS, while December recorded higher salinity and BOD. The lowest temperature was in February, pH in February, and DO in April. February had the lowest salinity, while April had the lowest BOD. The lowest electrical conductivity was in January, and the lowest TDS was in February. Monthly variations in mean values of physicochemical parameters for interstitial water samples showed significant differences ($P > 0.05$) in salinity, BOD, DO, and TDS across months. Conversely, no significant ($P< 0.05$) variation was observed in mean electrical conductivity, temperature, and pH values over the months.

**Table 3. Temporal Variation in The Physicochemical Parameters of Interstitial water samples from Ibaka Creeks.**

| `Months | EC (µS/cm) | TDS (mg/L) | pH | Temp (ºC) | Salinity (ppt) | BOD (mg/L) | DO (mg/L) |
|---|---|---|---|---|---|---|---|
| **Nov** | 30.17±0.41$^a$ | 30.22±0.16$^a$ | 7.54±0.27$^a$ | 28.36±0.47$^a$ | 0.61±0.03$^b$ | 3.52±0.02$^a$ | 4.80±0.04$^a$ |
| **Dec** | 29.73±0.60$^a$ | 28.98±0.73$^a$ | 7.55±0.26$^a$ | 28.18±0.26$^a$ | 1.32±0.01 $^a$ | 3.68±0.09 $^a$ | 4.73±0.06 $^a$ |
| **Jan** | 28.52±0.30$^a$ | 23.96±2.93$^b$ | 7.09±0.07$^a$ | 27.90±0.11$^a$ | 0.40±0.24 $^b$ | 3.19±0.06 $^b$ | 4.06±0.26 $^b$ |
| **Feb** | 28.53±0.28$^a$ | 23.86±2.32$^b$ | 7.08±0.02$^a$ | 27.89±0.47$^a$ | 0.39±0.17 $^c$ | 3.21±0.06 $^b$ | 4.09±0.26 $^b$ |
| **Mar** | 28.80±4.54$^a$ | 24.92±2.33$^b$ | 7.09±0.03$^a$ | 28.09±1.83$^a$ | 0.43±a0.0 $^b$ | 3.19±0.02 $^b$ | 3.98±0.15$^c$ |
| **Apr** | 28.75±0.41$^a$ | 24.26±2.38$^b$ | 7.08±0.23$^a$ | 27.93±0.85$^a$ | 0.45±0.35 $^b$ | 3.17±0.05 $^b$ | 3.89±0.16$^c$ |
| **(WHO (2011)** | <1000 | 600 | 6.5 - 8.5 | - | - | 10 | 5 – 6 |
| **USEPA (2020)** | 500 µS/cm | 500 | 6.5 - 8.5 | - | 2 | 3 | 3 - 5 |
| **SON (2019)** | 1000 | 500 | 6.5–8.5 | 22–32 | - | 10 | 3–5 |

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

*EC: Electrical Conductivity, TDS: Total Dissolved Solids, pH: Potential of Hydrogen, Temp: Temperature, Salinity: Salinity level, BOD: Biological Oxygen Demand, DO: Dissolved Oxygen.

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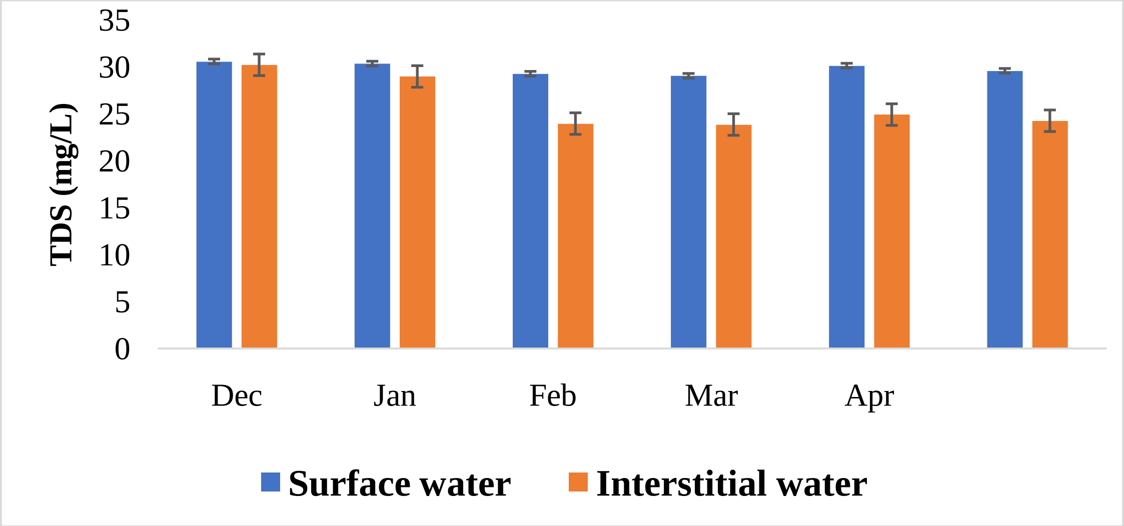

**Fig. 2. shows the temporal variation in total dissolved solids in the Surface and Interstitial water**

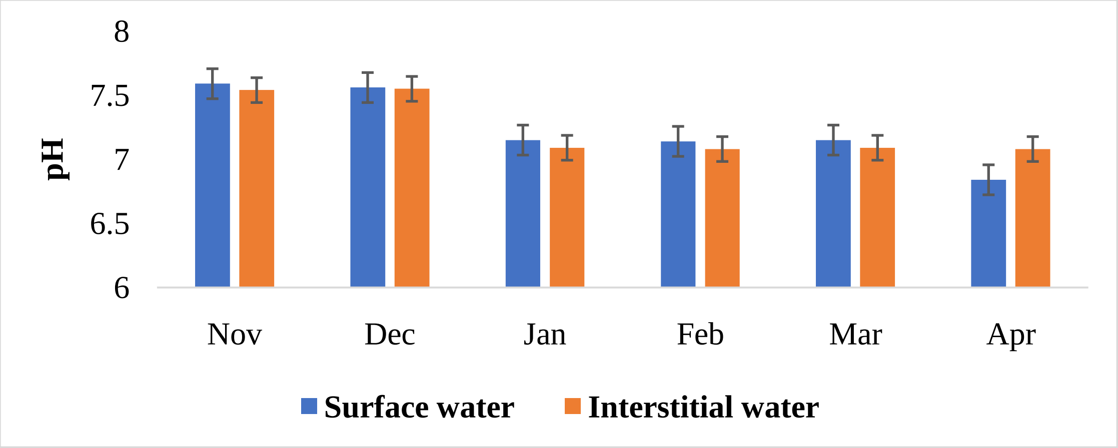

**Fig.3. shows the temporal variation of the Potential of Hydrogen (pH) in the Surface and Interstitial water.**

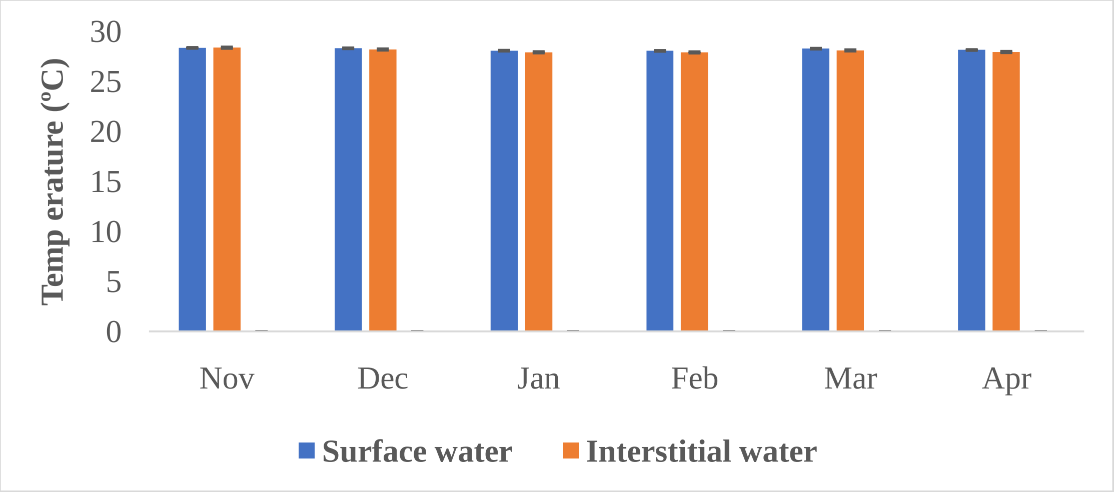

**Fig.4. shows the temporal variation of temperature in the Surface and Interstitial water.**

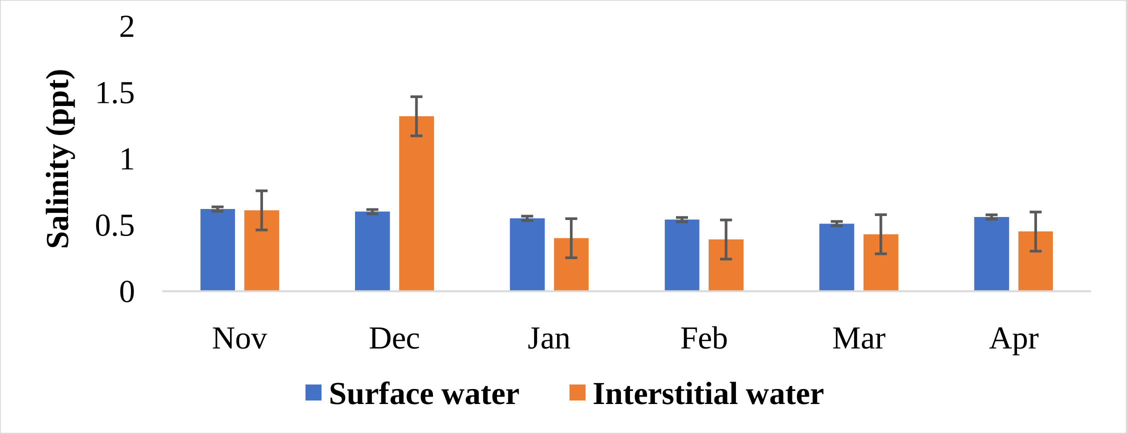

**Fig. 5. shows the temporal variation of salinity in the Surface and Interstitial water.**

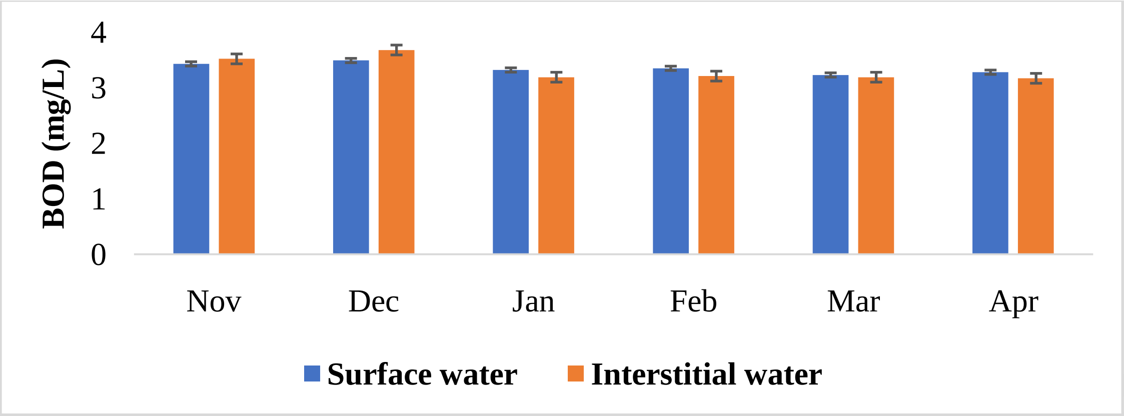

**Fig.6. shows the temporal variation of biological oxygen demand (BOD) in the Surface and Interstitial water.**

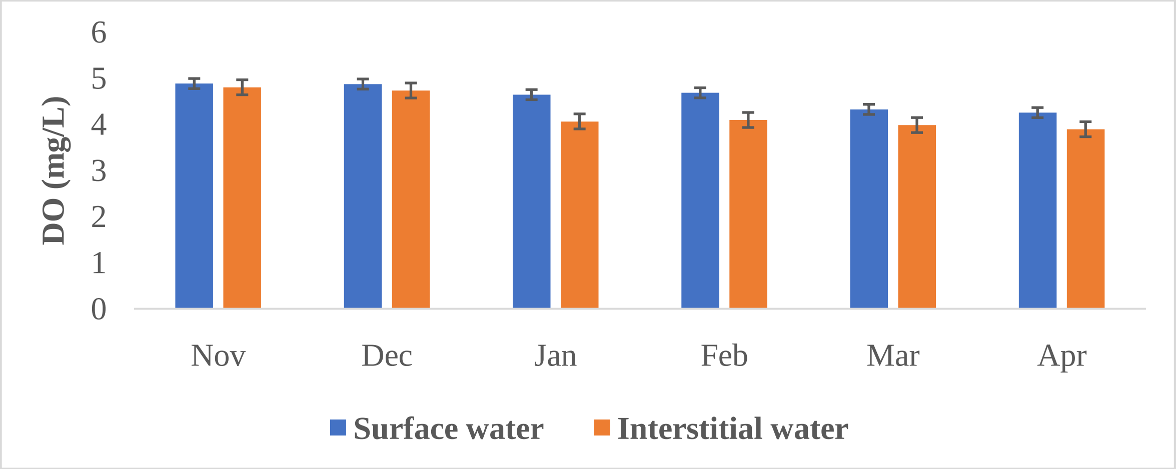

**Fig.7. shows the temporal variation of dissolved oxygen (DO) in the Surface and Interstitial water.**

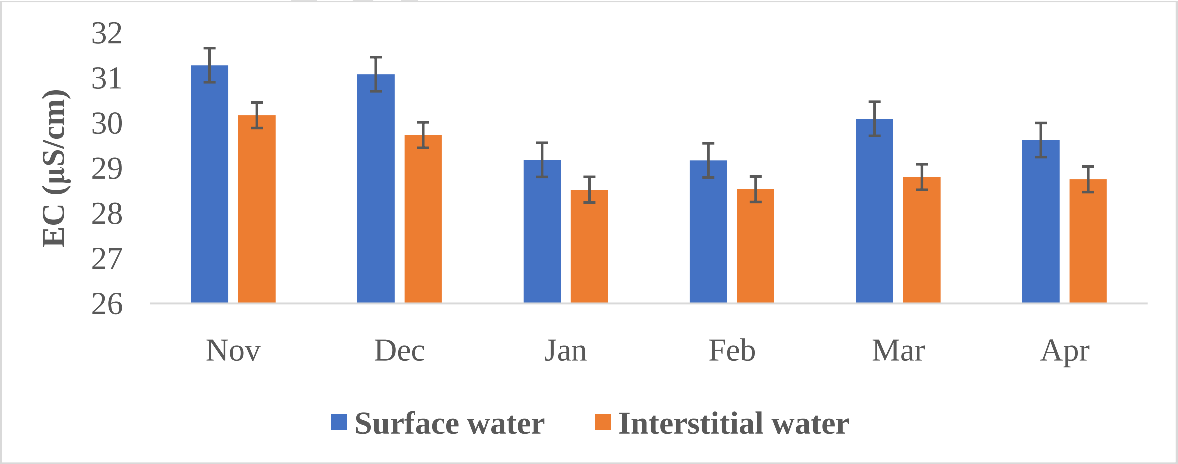

**Fig.8. shows the temporal variation of Electrical Conductivity (EC) in the Surface and Interstitial water.**

# 4. DISCUSSION

## 4.1 Physicochemical Parameters of The Interstitial and Surface Water

The results show the physicochemical parameters of interstitial and surface water in the Ibaka Creeks of the Okrika River sampled site. The study revealed that the electrical conductivity (EC) levels were higher in the surface water compared to the interstitial water. This indicates that the surface water contained a higher concentration of dissolved ions and mineral salts. The elevated EC in surface water may be due to factors like runoff, human activities, or the mixing of seawater [15].

The lower EC in the interstitial water indicates reduced mineral content or dilution due to filtration through sediments. The EC values in this study were within the acceptable limit of <1000, 500 and 1000 respectively set by the World Health Organization [12], the United States Environmental Protection Agency [13] and the Standards Organization of Nigeria [14]. The findings in this study are consistent with those reported by [16]. The low conductivity observed indicates that the water in the study area receives a limited amount of dissolved inorganic substances in an ionized form from its surface catchment areas [17].

Furthermore, the values exceeded the conductivity levels reported by [17] parameters in the surface water of mini Whuo Stream in Port Harcourt, Rivers State, Nigeria, and those detected by [18] in the Satluj River, Himachal Pradesh, India. The elevated conductivity observed in the creeks could potentially be attributed to the sluggish movement of the stream water and the type of materials being deposited into the stream by human activities daily[19]. These factors likely contribute to the accumulation of dissolved ions or electrolytes, resulting in the higher conductivity values recorded in this study.

Surface water showed a higher TDS concentration compared to interstitial water. TDS represents the total amount of dissolved substances from various sources, including minerals, salts, weathering of rocks, industrial discharges, organic compounds and agricultural runoff [20]. The higher TDS in surface water could be attributed to the accumulation of dissolved substances from various sources, such as natural weathering, anthropogenic inputs, or evaporation [15]. The interstitial water in closer contact with sediments may have lower TDS due to filtration and adsorption processes [21].

The variation in the levels of these TDS in the Surface and interstitial water could indicate a growing level of degrading water quality and pollution in the presence of a water body [15]. Fromthe study, all the above parameters were within the acceptable limits of the World Health Organization. [12], the United States Environmental Protection Agency [13], and the Standards Organization of Nigeria [14] for freshwater ecosystems. This trend in the variation could be attributed to the onset of the rainy (wet) season which would have increased the influx of sediment into the creek [22].

The levels of total dissolved solids (TDS) observed in this study were significantly lower compared to those reported by [22] in the water samples of the Silver River in Bayelsa State, which ranged from 13,050 to 13,500 mg/L. Furthermore, the TDS values in this study were also lower than those observed in the upper reaches of the Orashi River by [39] and a section of the New Calabar River by [22]. The concentration of TDS in water serves as an indicator of water quality and the extent to which pollution has impacted an aquatic environment or coastal ecology.

The interstitial water showed a higher pH value compared to the surface water. pH is a measure of the water's acidity or alkalinity [23]. The higher pH in interstitial water can be influenced by factors such as biological activity, decomposition of organic matter, and buffering capacity of sediments [22] (Agarin *et al.,* 2020). The higher pH in interstitial water also suggests a more alkaline condition, which could be influenced by the presence of alkaline substances [51]. The lower pH in surface water may be due to acidic inputs from atmospheric deposition or organic matter decomposition [24]. The surface water, being exposed to atmospheric gases and potential acid rain, may show slightly lower pH values [25].

The observed values of pH were slightly higher than the acceptable value required for drinking water [12]. The values obtained in this study fell within the same range as those obtained by [17] from Limonite Creek in Ndoni, Rivers State, Nigeria. However, the values obtained in this study were higher compared to those reported by [26] from various locations in the New Calabar River. Regarding the pH values, all the values reported in this research fell within the alkaline range and differed from those reported by other researchers such as [27]. Alkaline water is an indication that the water is disinfected and suitable for use, as noted by [28]. Extreme pH values can impact the taste and sweetness of the water. The efficiency and effectiveness of biochemical reactions within any water body are dependent on pH, as highlighted by [29]. This finding aligns with the results reported by [30].[31] also found a similar pH range for water used for swimming purposes in Abeokuta, Nigeria. However, the pH values observed in surface waterbodies could be attributed to the prevalent soil type in the area or the accumulation of organic materials from runoff. As organic materials decompose, they release carbon dioxide, which combines with water to form a weak acid known as "carbonic" acid.

The recorded pH values for each month in this study fell below the permissible limit (6.5 - 8.5) set by the World Health Organization [12], the United States Environmental Protection Agency [13], and the Standards Organization of Nigeria [14], respectively. [14] confirmed that this pH level in water is suitable for aquatic life. However, the observed seasonal variation contradicts the previous findings of [32] in the Bonny/New Calabar River Estuary, which reported higher pH values during the dry season and lower values during the wet season. The fluctuation in hydrogen ion concentration observed in this study may be attributed to variations in the bicarbonate equilibrium, which can subsequently affect bacterial counts in the river. The pH range variation can also be explained by vegetation decay and the increased influx into the creek channels [28].

The surface water exhibited a higher temperature compared to the interstitial water (27.94±0.09 °C). Temperature variations can occur due to factors like solar radiation, air-water interactions, groundwater inputs, and the thermal properties of sediments [33]. The slight temperature difference between surface and interstitial water could be influenced by solar heating, surface exposure, and potential shading effects from vegetation or structures [34]. Surface water is more exposed to direct sunlight and atmospheric influences, resulting in higher temperatures than interstitial water shielded by sediments.

[35] also reported a similar highest temperature during the dry season compared to the wet season. They attributed the temperature variation in surface waters during the wet season to the amount of rainfall in their study area, as the region experiences a high volume of rainfall with an extended rainy season [32]. The highwater temperature recorded in this study ranged between 27.94±0.09 and 28.18±0.06 ºC. This temperature range could be influenced by factors such as climatic conditions, geographical conditions, or the depth of surface and groundwater, which can impact the physiological and biochemical activities of organisms present in the water sources [36].

The mean water temperature observed during the study period slightly exceeded the standard permissible limits set by the World Health Organization [12] and the Standards Organisation of Nigeria [14]. This finding contrasts slightly with the maximum water temperature of 28 degrees Celsius reported by [37] from various water sources in Nigeria. Additionally, the surface water temperatures recorded in this study exceeded the recommended levels by [12] and the optimal temperature range required for certain aerobic mesophilic bacteria and fungi [29].

Salinity refers to the concentration of dissolved salts in water and is influenced by factors like tidal influence, seawater intrusion, and freshwater inputs. From the results, surface water showed a higher mean salinity related to interstitial water. The higher salinity in surface water suggests the influence of tidal mixing or seawater intrusion, whereas the lower salinity in interstitial water indicates the influence of freshwater inputs or dilution within the sediments [36]. The higher salinity in surface water is likely due to the influence of tidal and seawater intrusion[38]. Evaporation, limited freshwater inputs, and mixing with seawater can increase salinity levels in the surface water [36]. The interstitial water, being closer to groundwater sources and freshwater inputs, may have lower salinity [39].

The salinity values obtained in this study were significantly lower compared to those reported by [22] at Isaka Creek, Bonny River, Nigeria, where a range of values from 4.60 to 1.67 was recorded. These findings also align with the salinity imbalance identified during the reconnaissance survey conducted by [40]. It should be noted that [38] reported a higher salinity value of 13,000 ppm from Gwagwalada, which supports the presence of salinity imbalance observed in the reconnaissance survey by [40]. [41] also noted an increase in salinity downstream, attributing it to the proximity of the sample stations to the estuary and the sea. Furthermore, [39] reported higher salinity values during different seasons.

BOD is a measure of the amount of oxygen consumed by microbial decomposition of organic matter and increased microbial activity due to inputs from surrounding land, including anthropogenic sources like sewage discharge, dredging activities and agricultural runoff [37]. The surface water exhibited a higher biological oxygen demand (BOD) compared to the interstitial water. The interstitial water, being in contact with sediments, may have lower organic matter content and hence lower BOD [32]. The values were below the 5 to 6 mg/L standard by the World Health Organization[12]. [15] reported BOD values ranged between 2.47mg/L and 4.44mg/L as compared with 3.30 mg/L and 3.36mg/L in this study.

The decomposition process, which consumes oxygen, deprives other aquatic organisms of the vital oxygen they require for survival [32]. In this scenario, the presence of a large bacterial population increases the oxygen demand, resulting in high levels of biochemical oxygen demand (BOD). As the waste is either consumed or dispersed in the water, the BOD levels will gradually decrease. However, during this process, the oxygen-depleted environment can be detrimental to the survival of water, fish, and other aquatic organisms [36] (Dickey et al., 2021). Notably, the recorded BOD levels of the surface and interstitial water samples were within the EU guidelines of 3.0 to 6.0 mg/L (BOD) recommended for the protection of fisheries, aquatic life, and domestic water supply.

Dissolved Oxygen (DO) represents the concentration of oxygen dissolved in water and is essential for aquatic life [33]. Surface water showed higher DO levels compared to interstitial water. The higher DO in surface water could be attributed to atmospheric oxygen exchange, photosynthetic activity, and surface agitation [40]. The higher DO in the surface water can also be attributed to reaeration from atmospheric oxygen, photosynthetic activity, and mixing with the atmosphere, while the interstitial water, being in closer contact with sediments, may have reduced oxygen and air-water interactions and availability due to microbial respiration and limited exchange with the atmosphere [33].

The observed variation in the mean dissolved oxygen (DO) levels in the water samples may indicate the presence of a high bacterial population that consumes the available dissolved oxygen. Additionally, the decreased DO levels in this water body could be attributed to runoff from the abattoir and related activities, as noted by [22]. This finding aligns with the report by [25], stating that DO plays a crucial role in oxidizing both organic and inorganic substances, thereby preventing them from becoming a nuisance to consumers. While dissolved oxygen may not pose a direct health hazard to humans, it can interact with other chemicals in the water, potentially affecting aquatic organisms, as suggested by [33].

In contrast to the present findings, [25] observed low levels of dissolved oxygen (DO) in the upstream and downstream areas during the rainy season, with values of 2.1 and 3.8 mg/L, respectively. These values further decreased to 1.7 mg/L upstream and 1.2 mg/L downstream during the summer. Similarly, [42] reported variable average DO concentrations in the Pipraghat region of the Gomti River, ranging from 0.00 to 5.4 mg/L, mainly due to the inflow of urban drains into the river. Conversely, [41] found higher average DO concentrations upstream compared to downstream of the Han River.

The results indicate significant differences ($p>0.05$) between interstitial and surface water for electrical conductivity, total dissolved solids, temperature, salinity, and dissolved oxygen. However, no significant differences ($p<0.05$) were observed for biological oxygen demand and pH between interstitial and surface water. These variations may be influenced by local factors such as sediment characteristics, hydrological dynamics, and interactions between water and sediment interfaces [33].

### 4.2Temporal Variation in The Physicochemical Parameters for the Interstitial and Surface Water from Ibaka Creeks.

The results in Tables 2 and 3 present the temporal variation in various physicochemical parameters including electrical conductivity (EC), total dissolved solids (TDS), pH, temperature, salinity, biological oxygen demand (BOD), and dissolved oxygen (DO) from the studied area.The higher electrical conductivity (EC) values of the surface water in November indicate a higher concentration of dissolved ions and minerals in the water [43]. This increase could also be attributed to factors such as increased runoff, sediment erosion, or changes in the water source [44]. Meanwhile, the higher electrical conductivity values of the interstitial water samples in November indicate a higher concentration of dissolved ions and minerals in the interstitial water [44]. This increase in interstitial water could be attributed to factors such as increased runoff, sediment erosion, or changes in water composition due to natural or anthropogenic influences [20].

The electrical conductivity values obtained in this study were lower than those reported in Bayelsa State, Nigeria by [17]. Also, lower values were observed in Eliozu, Obo/Akporin Rivers State by [33]. However, they were within the values observed reported by [26] in Onyima Creek, in Rivers State. On the other hand, this study's electrical conductivity values were higher than those observed at effluent discharge points along the mangrove stretch of New Calabar River, Rumuolumeni, Port Harcourt, and Rivers State [28]. This observation in these results aligns with the findings of [48].

TDS represents the total amount of dissolved substances in water [41]. TDS represents the total amount of dissolved substances in water, including minerals, salts, and other organic and inorganic compounds [28]. The higher TDS values in November for the surface and interstitial water suggest an accumulation of dissolved substances, including minerals and salts, possibly due to increased runoff or inputs from surrounding land areas [26] which could be influenced by factors such as rainfall, agricultural activities, industrial discharges, or other inputs.

The TDS values obtained in this study are lower compared to those reported by [33] in Mouri River, Bangladesh, [15] in Eagle Island Creek, Niger Delta, Nigeria, and [46]) in Opuro-ama Waterfront, Rivers

State, Nigeria. However, this study's measured values are higher than those observed in Elelenwo River, Rivers State, Niger Delta, Nigeria [49].

The observed variation in pH values for the surface water could be influenced by factors such as biological activity, organic matter decomposition, or changes in the water source [48]. The higher pH values in the surface water indicate a more alkaline condition, while the lower pH values suggest a more acidic condition [47]. The higher pH values for the interstitial water indicate a more alkaline condition, while the lower pH values suggest a more acidic condition [38]. The observed variation in the interstitial water pH values could be influenced by factors such as biological activity, organic matter decomposition, or changes in water chemistry [45].

[26] stated that aerobic organisms responsible for breaking down organic waste generate carbon dioxide, which dissolves in water and forms carbonic acid, making the water acidic. The pH level in aquatic environments is crucial for various human activities, including industry, domestic use, and physiological processes. Changes in aquatic pH are often attributed to the presence of industrial contaminants pollutants, and agents, as well as the photosynthesis and respiration of algae that thrive on these contaminants [33].

The temperature for interstitial water also ranged between 28.89°C in February to 28.36°C in November. The fluctuations in temperature could be influenced by seasonal changes, solar radiation, or water flow dynamics [48]. The slight fluctuations and variations in temperature across the months suggest relatively stable thermal conditions within the surface and interstitial water in the studied area [32]. [21] reported that the temperature variations may also be influenced by seasonal changes, solar radiation, or water mixing processes. The changes observed in the temperature of the water bodies could lead to corresponding alterations in the physicochemical properties of the water, which are driven by the physiological adaptations of the organisms inhabiting the area [28]. Furthermore, temperature influences the ecological factors and conditions that determine the successful adaptation of both living and non-living species to their environment. The presence of dissolved gases, such as oxygen, in water bodies can have beneficial and detrimental effects on aquatic organisms' migration, reproduction, growth, and survival [21]. Additionally, temperature directly influences organisms' normal behaviour and lifestyle within an aquatic ecosystem [26].

Salinity represents the concentration of dissolved salts in water. The higher salinity values in November may be attributed to factors such as seawater intrusion, tidal influence, or changes in freshwater inputs [56]. The lower salinity values in March indicate a dilution effect, potentially caused by increased freshwater inflow or precipitation [36]. The higher salinity for interstitial water values in December suggests increased saltwater intrusion or higher evaporation rates, while the lower values in February indicate dilution due to freshwater inputs or other factors [33].

The salinity measurements obtained in this study were higher than those recorded in the Borokiri Section of Bonny River Estuary, in the Niger Delta by [49], and the Okpoka Creek, Rivers States in the Niger Delta by [22] at their respective sampling locations. Salinity plays a crucial role in environmental conditions as it affects the suitability of water for various purposes and influences the diversity of plant and animal species inhabiting the aquatic environment. According to [38], the salt content of Opro-ama and Sa-ama Creek is influenced by precipitation and water discharge into the water body, which is a common characteristic of estuaries known for their dynamic nature [50]. However, the observed variations in salinity between the studies could be attributed to fluctuations caused by significant increases in salinity during different times and seasons [32], as well as human activities such as contamination and effluence from illegal crude oil refining activities observed in the surrounding environment of the Creeks.

Although the salinity gradients in the studied creek deviate from typical brackish water conditions, lower salinity levels could be attributed to reduced anthropogenic influences around the rivers. Similar findings were reported by [43] regarding the photochemical and microbial degradation of chromophore solutes in floodplain conditions. However, the difference in salinity observed in the study site could also be attributed to variations caused by sudden increases in salinity at different times and seasons[55], or the pollution resulting from human activities, including domestic waste and other illegal practices along Ibaka Creek.

Biological Oxygen Demand (BOD) is a measure of the amount of oxygen consumed by microorganisms during the decomposition of organic matter[53]. Whereas, the biological oxygen demand (BOD) values for interstitial water ranged from 3.19±0.02 mg/L in March to 3.68±0.09 mg/L in December. The higher BOD values for the surface and interstitial water in December suggest increased organic pollution or inputs of organic material into the interstitial water, possibly due to changes in land use, anthropogenic activities, or seasonal factors [54].

Dissolved Oxygen (DO) values for the surface water ranged from 4.25±0.02 mg/L in April to 4.88±0.15 mg/L in November. DO represents the concentration of oxygen dissolved in water and is essential for aquatic life [40]. The fluctuations in DO levels for surface water could be influenced by factors such as temperature, photosynthesis, respiration, or water flow dynamics. DO values for interstitial water ranged from 3.89±0.16 mg/L in April to 4.80±0.04 mg/L in November. The fluctuations in DO levels for interstitial water could be influenced by factors such as temperature, photosynthesis, respiration, or changes in water circulation patterns [22].The higher DO values in November suggest favourable conditions for aquatic organisms, while the lower DO values for the surface water in April indicate potential oxygen depletion or reduced oxygen supply, possibly due to increased organic matter decomposition or reduced oxygen supply [57]. The monthly variations in the physicochemical parameters of the surface and interstitial water samples showed significant differences in salinity, BOD, DO, and TDS across the months, indicating temporal changes in water quality. Similar results were reported by [38]in a Mangrove Wetland, of Sombrero River, Rivers State. However, no significant variations were observed for electrical conductivity, temperature, and pH values, suggesting relatively stable conditions for these parameters. The results also agree with [12]reported similar findings on the physicochemical parameters of the Tin Can Island Creek in Lagos state, Nigeria.

This finding is consistent with the findings of [12], who suggested that the decrease in dissolved oxygen levels could be attributed to microorganisms utilizing oxygen to break down organic matter from plants. A similar trend was observed in both creeks by [46] in a study on water from a polluted mangrove swamp in Rivers State. [23]also noted that a high abundance of aquatic plants in the water can contribute to lower dissolved oxygen levels. The results obtained from Opuro-ama Creek align with the temporal variations in physicochemical parameters of interstitial water reported by [25]. Additionally, the dissolved oxygen values in Shiroro Lake ranged from 2.3 mg/l in bottom water samples to 12.0 mg/l in surface water samples, as [35] reported. While dissolved oxygen may not pose a direct health risk to humans, it can impact other chemical processes in the water, thus affecting the aquatic environment [38].

Decaying organic matter can also contribute to low oxygen levels, releasing toxic gases such as hydrogen sulfide and methane [32]. In both creeks, the recorded dissolved oxygen values did not meet most aquatic organisms' minimum requirement (5 mg/l) to support their normal life cycle [50]. [15] reported that the high organic matter content from sources such as human faeces, decomposing household waste, sawmill waste, and plant material flowing into these streams can contribute to low dissolved oxygen levels. Furthermore, the consumption of dissolved oxygen may be influenced by the oxidation of nitrogen-containing substances in water from rivers, as highlighted by [51]. There is an inverse relationship between salinity, temperature, and dissolved oxygen and the solubility of dissolved oxygen in water is significantly affected by salinity and temperature **[52]**.

## 5. CONCLUSION

In conclusion, the present study investigated the physicochemical parameters of interstitial and surface water in the Ibaka Creeks of the Okrika River sampled site. The results revealed notable variations in the physicochemical parameters between interstitial and surface water, which can be attributed to various factors such as runoff, anthropogenic inputs, sediment interactions, and atmospheric conditions. The study compared the physicochemical parameters of interstitial and surface water in Ibaka Creeks. Surface water had higher electrical conductivity (EC) and total dissolved solids (TDS), indicating increased mineral content, possibly due to runoff or anthropogenic inputs. Interstitial water showed higher pH, suggesting more alkaline conditions near sediments. Temperature and salinity variations were influenced by solar radiation and tidal effects. Biological oxygen demand (BOD) and dissolved oxygen (DO) varied, indicating organic matter decomposition and microbial activity. General, parameters generally fell within acceptable limits set by regulatory bodies. Temporal variations showed fluctuation in parameters across months, possibly due to seasonal changes and anthropogenic influences. Continued monitoring and assessment are essential to maintain and safeguard the health of aquatic ecosystems and support sustainable management practices.

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