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Spatial and temporal variations of physical-chemical parameters of the Akor River in Ikwuano local government of Abia state, Nigeria

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ABSTRACT. Physical-chemical parameters of the Akor River were investigated. The river water was sampled for seven months (February –August) in 2019 and analysed following standard procedures and protocols. The results revealed that there were no significant differences ($P > 0.05$) among all the investigated physical-chemical parameters across stations. Mean values of all the investigated physical-chemical parameters were within Federal Ministry of Environment set standards (2011) except for chemical oxygen demand and pH. Spatiotemporal results revealed that turbidity, total suspended solids, total dissolved solids, and the major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) as well as the major anions (PO_4^{3-}, NO_3^- and SO_4^{2-}), were high during the rainy season months, but water temperature, pH, dissolved oxygen, and biochemical oxygen demand were higher during the dry season months. The percentage of Na^+ contents ranged from 15.85 to 16.39%, indicating that Akor River has excellent irrigation water quality. The Nemerow pollution index varied from 0.59 to 0.63, also indicating that the river water is of good quality. The water quality index results varied from 52.70 to 54.50%, indicating that Akor River has a good water quality status. The result of water pollution index revealed that Akor River status is excellent and capable of sustaining biodiversity as well as crop irrigation.

Keywords: spatiotemporal variations, physical-chemical parameters, surface water, water pollution index

1. Introduction

Water is one of the most essential resources for the survival of man and other living organisms. The capacity of water source, especially surface water body, to sustain its potential depends on human activities within and around it. Surface water bodies have been significantly affected by anthropogenic activities, causing water quality deterioration, decreasing water availability and reducing the carrying capacity of aquatic life (Wang et al., 2012; Zhang et al., 2015; Harding et al., 2019).

Surface water body polluted by anthropogenic activities becomes less suitable or unfit for drinking, domestic uses, crop irrigation, fisheries, or other purposes. Continually drinking water from a polluted water body could cause human population to suffer from different waterborne diseases. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life of people, who always depend on surface water bodies for drinking water and other purposes.

Water bodies supplying drinking water for people have to be of good quality parameters. Assessment of water quality is very important to evaluate the "health" of ecosystems, to control environmental pollution and, hence, to maintain human safety (Anyanwu and Umeham, 2020). Nowadays, water quality is assessed by measuring environmental variables and by freshwater organisms in order to determine the environmental status of the ecosystem (Anyanwu et al., 2019).

Changes in the river water quality due to anthropogenic activities are a cause of growing concern and require monitoring of the surface waters (Parvez et al., 2019). Research has revealed that most of the freshwater bodies globally are increasingly polluted as a result of anthropogenic activities, thus affecting the derivable ecosystem services (Gupta et al., 2005; Anyanwu, 2012; Goldschmidt, 2016; Amah-Jerry et al., 2017). Many studies discussed physical-chemical parameters of rivers around the world (Table 1), but none of them was carried out on the Akor River so far.

The Akor River is subjected to several human activities, including sand mining, lumbering, water

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irrigation of farms and nursery, application of fertilizers and pesticides, extraction of water for drinking and other domestic uses: washing, swimming and food processing. Some of them take place within the watersheds, which could negatively affect the water quality as well as derivable ecosystem services through direct or indirect impacts and discharges or runoffs. Thus, the present study assessed spatial and temporal variation of chemical parameters in the Akor River in Ikwuano Local Government of Abia State.

2. Materials and methods

2.1. Description of study area

The Akor River takes its source from Bende in Abia North and passes through many communities (including Nkanu Nta, Obuoru, and Itunta) before discharging into the Cross River at Itunta. The stretch of the Akor River studied is between Obuoru and Itunta in Ikwuano L.G.A, Abia State; about 2.38 km in length. It lies between latitude of 5°26.854' and 5°28.031'N and longitude of 7°37.860' and 7°38.838'E. The major activities in and around the Akor River are palm oil production, cocoa farming, sand mining, lumbering, rice and cocoa nurseries, rice, cocoa, cassava and vegetable farming as well as others, including bathing, swimming, washing, fishing, and extraction of water for drinking and other domestic uses. For the purpose of this study, three stations were selected based on accessibility and anthropogenic activities.

Station 1 was upstream, located in Obuoru, Ibere (Fig.1). The observed human activities are laundry, swimming, fishing, extraction of drinking water, sand mining, washing of bread fruit, and lumbering. The substrate was sand, and the flow velocity was moderate.

Station 2 was located in Itunta near the bridge about 1.39 km downstream of Station 1 (Fig.1). There was a less active sand mining site, cocoa and rice nurseries and large expanse of cocoa farms. Other activities were laundry, fishing, swimming, and extraction of drinking water. It was open, vegetated and wadeable with relatively high velocity, and the substrate was also sand.

Station 3 was also located in Itunta Ibere about 0.99 km (990 m) downstream of Station 2 (Fig.1). Sand mining, vegetable cropping and cocoa farming activities were observed at this station. It was open vegetated with relatively high velocity and sandy substrate.

2.2. Water sampling

Sampling for water parameters was carried out at the three stations at monthly intervals between February and August 2019. The sampling period covered dry season, onset of rain and peak of rainy season. The collected water samples were taken with sterile one (1 litre) plastic containers. The containers were rinsed three times with the water samples to be collected at the site before collection was made.

Water temperature and pH were measured by digital pH meter/ thermometer (Hach EC 20),

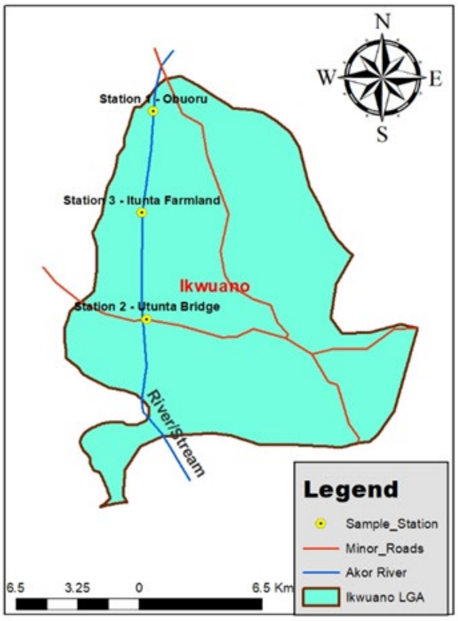

Fig.1. Map of study area with sampling points.

electrical conductivity was measured by Hach CO 150 conductivity meter. To determine total dissolved solids (TDS) and total suspended solids (TSS) content, gravimetric method was used. Turbidity was determined by Jenway 6035 Portable Turbidimeter. To determine dissolved oxygen (DO) content and biochemical oxygen demand (BOD), Winkler method with azide modification was used. Chemical oxygen demand (COD) was determined using open reflux method. NO_3^- was analyzed using Hach DR 1900 spectrophotometer. SO_4^{2-} was determined by turbidimetric method. PO_4^{3-} was determined by the stannous chloride method. K^+ was determined by flame photometry while other major cations (Na^+, Ca^{2+}, and Mg^{2+}) were analyzed using atomic emission spectroscopy.

2.3. Water pollution index

Pollution index of the Akor River was evaluated using Nemerow pollution index (NPI) as described by Anyanwu and Umeham (2020):

$$\mathrm{NPI} = \sqrt{\frac{\left(\frac{C_i}{L_i}\right)_M^2 + \left(\frac{C_i}{L_i}\right)_R^2}{2}} \quad (1),$$

where NPI is the pollution index for a specified water quality purpose; C_i is measured water quality parameter; L_i is the standard water quality parameter for each parameter of specified water quality purpose; $\left(\frac{C_i}{L_i}\right)_M$ is C_i/L_i maximum, and $\left(\frac{C_i}{L_i}\right)_R$ is C_i/L_i average.

The percentage of sodium (%Na) was evaluated as described by Al-Othman (2019) using:

$$\%\mathrm{Na} = 100 \cdot \frac{Na}{(Ca + Mg + K + Na)} \quad (2),$$

where Ca is Ca^{2+} concentration; Mg is Mg^{2+} concentration; Na is Na^+ concentration, and K is K^+ concentration. The quantities of all ions are expressed in mg/L.

The water quality index (WQI) was calculated as described by Anyanwu and Umeham (2020) using:

$$WQI = \frac{\sum q_i \cdot W_i}{\sum W_i} \quad (3).$$

The quality rating scale for each parameter q_i was calculated using the following expression:

$$q_i = 100 \cdot \frac{V_n}{V_i} \quad (4),$$

where V_n is the actual amount of nth parameter, and V_i is the standard (Table 2).

Relative weight (W_i) was calculated by a value inversely proportional to the standard of the corresponding parameter:

$$W_i = \frac{1}{V_i} \quad (5).$$

2.4. Data analysis

One-way analysis of variance (ANOVA) followed by Tukey Pairwise test (DMRT) was used to determine the differences between the sampling sites and months using SPSS IBM (Version 20 for Windows) statistical package at $P < 0.05$ level of significance.

Table 1. Physical-chemical characteristics of some selected surface water bodies (rivers).

Parameter	Water body	Range	Reference
T, °C	Aba River, Nigeria	23.5 - 29.3	Amah-Jerry et al. (2017)
	Ossah River, Nigeria	21.0 - 28.0	Anyanwu et al. (2019)
	Obot Okoho Stream, Nassarawa	25.4 - 27.2	Eni et al. (2014)
	Ogba River, Benin City	20.0 - 25.6	Anyanwu (2012)
	Gboko stream	30.2 - 30.8	Ubwa et al. (2013)
	Oshunkaye stream in Ibadan	31.0 - 34.0	Osibanjo and Adie (2007)
pH	South eastern River	4.6 - 6.3	Anyanwu and Ukaegbu (2019)
	Aba river	5.0 - 7.3	Amah-Jerry et al. (2017)
	Water sources in Ife	6.5 - 8.9	Oluyemi et al. (2010)
	Saba River, Osogbo	7.2 -7.6	Yusuf et al. (2017)
EC, μS/CM	Ogba River, Benin City, Nigeria	23.3 - 116.5	Anyanwu (2012)
	Athi River in Machakos, Kenya	12.0 – 1580.0	Ratemo (2018)
	Ole Stream Abeokuta, Ogun state	188.4 - 321.6	Adeosun et al. (2016)
DO, mg/L	River	3.2 - 6.4	Anyanwu et al. (2019)
	Ossah River, Nigeria	2.7 - 8.8	Amah-Jerry et al. (2017)
BOD, mg/L	Ogba River, Benin City, Nigeria	1.7 - 4.8	Anyanwu (2012)
	South eastern River	1.5 - 4.2	Anyanwu and Ukaegbu (2019)
COD, mg /L	Ganga River	6.5 - 8.5	Matta et al. (2018)
	Saba River, Osogbo	14.9 - 31.5	Yusuf et al. (2017)
	Aba River	2.3 - 7.0	Amah-Jerry et al. (2017)
	Illo River, Ota	425.0 - 1675	Omole and Longe (2008)
PO_4^{3-}, mg /L	Saba River, Osogbo	1.9 and 3.8	Yusuf et al. (2017)
	Aba River	2.3 and 79.8	Amah-Jerry et al. (2017)
SO_4^{2-}, mg /L	Ogba River, Benin City	0.60 and 6.39	Anyanwu (2012)
	Ekerekana and Buguma Creeks, Niger Delta	7.10 and 24.64	Makinde et al. (2015)
	Aba river	30.1 - 120	Amah-Jerry et al. (2017)
	Ikwu River Umuahia Abia State	0.3 and 1.3	Anyanwu and Emeka (2019)
Ca^{2+}, mg/L	Ogba River, Benin City	9.6 and 19.2	Anyanwu (2012)
	Ikpoba River	4.8 and 25.0	Ogbeibu and Edutie (2002)
	Utor River	0.4 and 19.2	Ogbeibu and Edutie (2002)

Note. T – temperature; EC - electrical conductivity; DO – dissolved oxygen; BOD – biochemical oxygen demand; COD - chemical oxygen demand.

3. Results

The results of the physical-chemical parameters of the Akor River are summarized in Table 2.

3.1. Physical-chemical parameters

Water temperature

The spatial and temporal variations of surface water temperatures are shown in figure 2. The temperature values recorded ranged between 24.0 and 29.0°C (Table 2). The lowest temperature value (24.0°C) was recorded at Station 3 in July 2019, while the highest temperature (29.0°C) was recorded at Station 2 in February 2019 (Fig. 2). The lowest mean value was recorded at Station 1, while the highest one was recorded at Station 2 (Table 2). There was no significant difference ($P > 0.05$) in temperature values among the stations when ANOVA was applied.

Turbidity

The spatial and temporal variations of turbidity values are shown in figure 3. Turbidity values ranged between 0.2 and 1.5 NTU (Table 2). The lowest values were recorded at Station 1 and Station 2 during the dry season in March 2019, while the highest values were recorded at Station 1 and Station 3 during the onset of rains in May 2019. Turbidity shows a clear trend: the turbidity increased with an increase in rains between March and May 2019 and gradually decreased afterwards from May to August (Fig. 3).

One-way analysis of variance (ANOVA) test employed to ascertain whether there are statistical differences in the values recorded at all stations showed that there were no significant differences in turbidity ($P > 0.05$) at all stations. The highest mean value was recorded at Station 1, while the lowest one was recorded at Station 2. All recorded values were within the acceptable limit of 5 NTU set by FMEnv (2011).

pH

The spatial and temporal variations of pH are shown in figure 4. The values were acidic, with a range of 4.6 to 6.6 mg/L (Table 2). The lowest and highest values were recorded at Station 1 in May and February 2019, respectively. All pH values were outside the acceptable limit of 6.5 to 8.5 set by FMEnv (2011), except for 6.5 and 6.6 recorded in March 2019 (Station 2) and February 2019 (Station 1), respectively. All mean values were also acidic and outside the acceptable limits. The lowest mean value was recorded at Station 2, while the highest ones were recorded at Stations 1 and 3. There was no significant difference ($P > 0.05$) in the pH values across all the stations.

Electrical conductivity (EC)

The electrical conductivity (EC) values ranged between 32.6 and 128.4 µS/CM (Fig. 5). All values were low and within the acceptable limits set by FMEnv (2011), though relatively high values were recorded in May 2019 at all stations. The mean values increased spatially from Station 1 to Station 3 (Table 2). There was no significant difference ($P > 0.05$) in the EC values across all the stations.

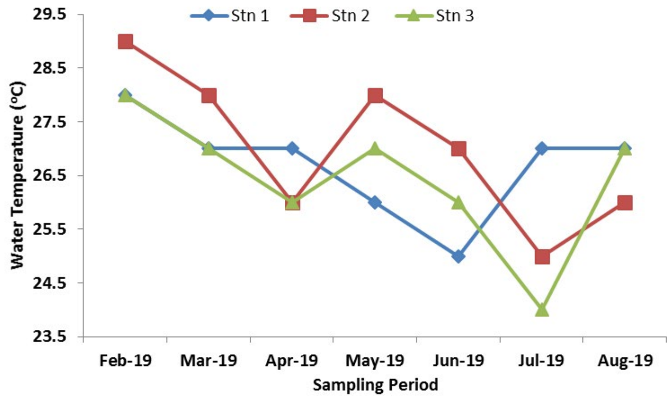

Fig.2. Spatial and temporal variations of temperature at the study stations of the Akor River.

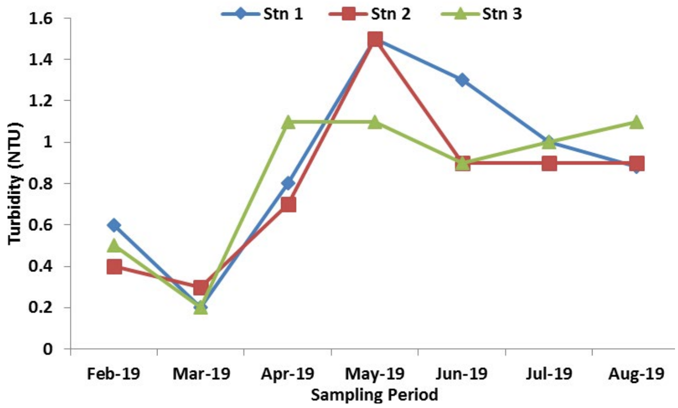

Fig.3. Spatial and temporal variations of turbidity at the study stations of the Akor River.

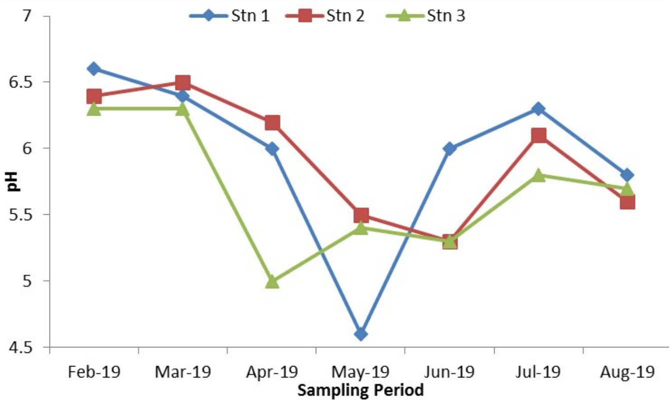

Fig.4. Spatial and temporal variations of pH at the study stations of the Akor River.

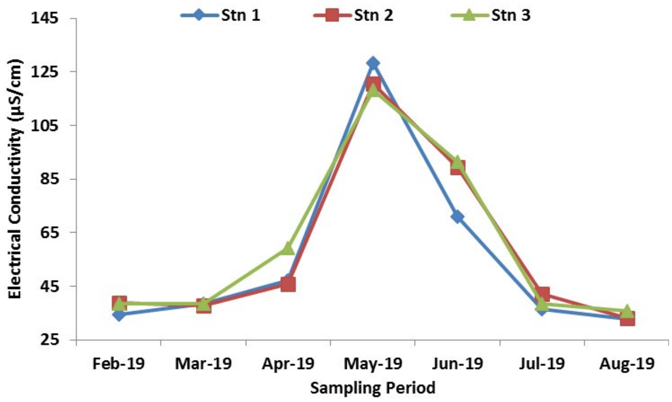

Fig.5. Spatial and temporal variations of EC at the study stations of the Akor River.

Table 2. Summary of physical-chemical parameters of the Akor River (with range given in parentheses).

Parameter	Station 1	Station 2	Station 3	P-value	FMEnv., 2011
T, °C	26±0.36 (25-28)	27±0.53 (25- 29)	26.42±0.48 (24 -28)	P>0.05	30
Turbidity, NTU	0.90±0.16 (0.2 -1.5)	0.80±0.15 (0.3 -1.5)	0.85±0.14 (0.2 -1.1)	P>0.05	5
pH	5.96±0.25 (4.6 - 6.6)	5.94±0.18 (5.3 - 6.5)	5.96±0.18 (5.0 - 6.3)	P>0.05	8.5
EC, μS/cm	55.56±13.3 (32.6-128.4)	58.29±12.62 (33.2 -120.5)	60.00±12.3 (35.0 - 118.3)	P>0.05	1000
TDS, mg/L	26.14±7.04 (13.3 -64.4)	28.83±6.52 (13.3 -60.4)	29.37±6.41 (13.6 -59.2)	P>0.05	500
TSS, mg/L	2.10±0.41 (0.6-4.2)	2.14±0.38 (0.9-4.0)	2.31±0.41 (0.7 -3.7)	P>0.05	0.25
DO, mg/L	4.91±0.82 (4.3 -6.8)	4.34±0.80 (3.4 -6.4)	4.37±0.70 (4.0 -6.3)	P>0.05	6
BOD, mg/L	1.50±0.18 (1.0 -2.4)	1.61±0.25 (1.2 - 2.1)	1.69±0.14 (1.2 - 2.3)	P>0.05	3
COD, mg/L	191.93±58.1 (41.2-480.1)	175.03±63.5 (28.8-416.00)	180.86±68.8 (31.2-491.00)	P>0.05	30
SO_4^{2-}, mg /L	0.30±0.10 (0.09-0.85)	0.34±0.10 (0.09 -0.75)	0.35±0.10 (0.10-0.73)	P>0.05	100
NO_3^-, mg/L	0.82±0.23 (0.30-2.15)	0.84±0.20 (0.24-1.88)	0.84±0.18 (0.27-1.75)	P>0.05	9.1
PO_4^{3-}, mg /L	1.29±0.35 (0.50-3.12)	1.32±0.32 (0.36-2.85)	1.29±0.31 (0.50-2.71)	P>0.05	3.5
Na^+, mg/L	0.81±0.23 (0.22-2.1)	0.87±0.22 (0.37-1.57)	0.98±0.24 (0.27-1.88)	P>0.05	120
K^+, mg/L	0.36±0.10 (0.08-0.91)	0.30±0.08 (0.13-0.73)	0.38±0.08 (0.11-0.64)	P>0.05	50
Ca^{2+}, mg/L	2.56±0.70 (0.88-6.44)	2.59±0.63 (0.72-5.12)	2.71±0.58 (0.98-4.83)	P>0.05	180
Mg^{2+}, mg/L	1.49±0.48 (0.66-4.32)	1.73±0.48 (0.51-4.11)	1.91±0.46 (0.66-3.75)	P>0.05	40
% Na	15.59	15.85	16.39		
NPI	0.63	0.59	0.61		
WQI	53.42	52.70	54.50		

Note. Column 6 (FMEnv., 2011) – upper permissible limits of physical-chemical parameters given by Federal ministry of environment (2011); T – water temperature; EC - electrical conductivity; TDS - total dissolved solids; TSS - total suspended solids; DO – dissolved oxygen; BOD – biochemical oxygen demand; COD - chemical oxygen demand; % Na – sodium percentage; NPI - Nemerow pollution index; WQI - water quality index.

Dissolved oxygen (DO)

The spatiotemporal variations of dissolved oxygen are presented in figure 6. The values ranged between 3.4 and 6.8 mg/L (Table 2). The lowest value was recorded at Station 2 (July 2019), while the highest one was recorded at Station 1 (May 2019). Most of the values recorded were below the acceptable limit (6 mg/L) set by FMEnv (2011) though values recorded at Station 1 (May and June 2019), Station 2 (April 2019) and Station 3 (February 2019) were above the limit (Fig. 6). The mean values decreased spatially with no significant difference ($P > 0.05$) between the stations.

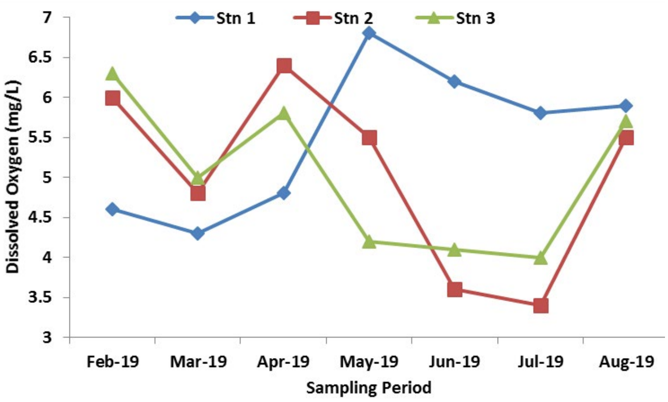

Fig.6. Spatial and temporal variations of DO at the study stations of the Akor River.

Biochemical oxygen demand (BOD)

The spatiotemporal variations of BOD are presented in figure 7. The values of BOD ranged from 1.0 to 2.4 mg/L (Table 2), the spatial and temporal variations of which are shown in figure 7. The lowest and highest values were recorded at Station 1 in February and May 2019, respectively. All BOD values recorded were below 3.0 mg/L set by FMEnv (2011). The mean values increased spatially, though there was no significant difference ($P > 0.05$) across the stations.

Total dissolved solids (TDS)

The spatial and temporal variations of total dissolved solids (TDS) are shown in figure 8. The TDS values ranged from13.3 to 64.4 mg/L (Table 2). All values were within the acceptable limit set by FMEnv (2011). The lowest values were recorded at Station 1 (July 2019) and Station 2 (February 2019), while the highest one was recorded in May 2019 at Station 1. TDS followed the same trend as electrical conductivity (EC). The mean values also increased spatially, though there was no significant difference ($P > 0.05$) across the stations.

Total suspended solids (TSS)

The spatial and temporal variations of total suspended solid (TSS) are shown in figure 9. The TSS values ranged between 0.6 and 4.2 mg/L (Table 2). The lowest and highest values were recorded at Station 1 in March 2019 and May 2019, respectively. All values exceeded the acceptable limit (0.25 mg/L) set by FMEnv (2011). TSS followed the same trend as turbidity. The mean values also increased spatially, though there was no significant difference ($P > 0.05$) across the stations.

Chemical oxygen demand (COD)

The spatial and temporal variations of chemical oxygen demand (COD) are shown in figure 10. The values ranged between 28.8 and 491.0 mg/L (Table 2). The lowest values were recorded at Station 2 (March and June 2019), while the highest one was recorded at Station 3 (April 2019). All values exceeded the acceptable limit (30 mg/L) set by FMEnv (2011), except for 28.8 mg/L recorded at station 2 in March and June 2019 (Fig. 10). The highest mean value was recorded at Station 1, while the lowest one was recorded at Station 2. There was no significant difference ($P > 0.05$) in COD across the stations.

SO_4^{2-}

The spatial and temporal variations of SO_4^{2-} are shown in figure 11. The values ranged between 0.09 and 0.85 mg/L (Table 2). The lowest values were recorded at Station 1 and Station 2 (February and March 2019, respectively), while the highest value was recorded at Station 1 (May 2019). All values were lower than acceptable limit (100 mg/L) set by FMEnv (2011) at all stations in 2019 (Fig. 11). The highest mean value was recorded at Station 2, while the lowest one was recorded at Station 3. There was no significant difference ($P > 0.05$) in SO_4^{2-} across the stations.

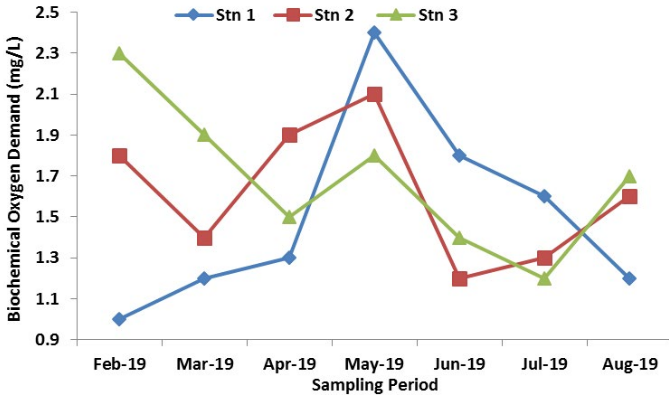

Fig.7. Spatial and temporal variations of BOD at the study stations of the Akor River.

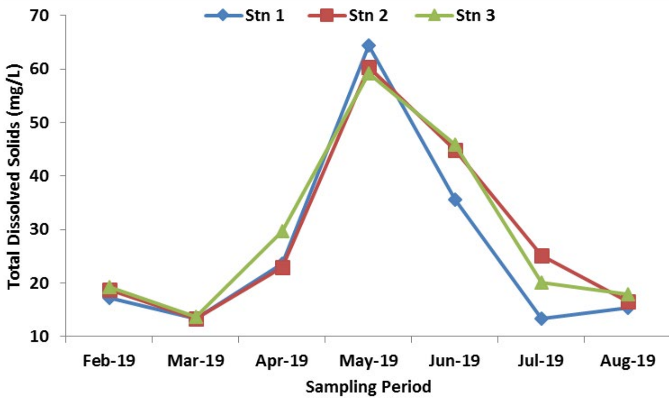

Fig.8. Spatial and temporal variations of TDS at the study stations of the Akor River.

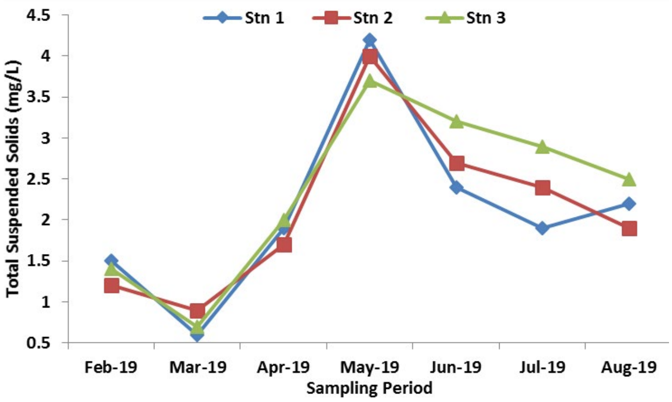

Fig.9. Spatial and temporal variations of TSS at the study stations of the Akor River.

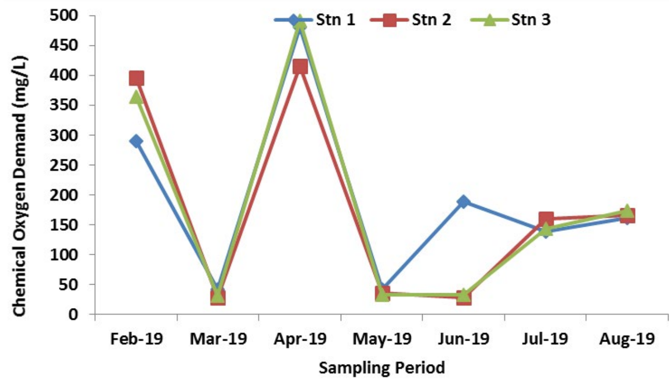

Fig.10. Spatial and temporal variations of COD at the study stations of the Akor River.

PO_4^{3-}

The spatial and temporal variations of PO_4^{3-} are shown in figure 12. The values ranged between 0.36 and 1.12 mg/L (Table 2). The lowest values were recorded at Station 2 (March 2019), while the highest value was recorded at Station 1 (May 2019). All values were lower than acceptable limit (3.5 mg/L) set by FMEnv (2011) at all stations in 2019 (Fig. 12). There was no significant difference ($P > 0.05$) in PO_4^{3-} across the stations.

NO_3^-

The spatial and temporal variations of NO_3^- are shown in figure 13. The NO_3^- values ranged between 0.24 mg/L and 2.15 mg/L. (Table 2). All values were lower than acceptable limit (9.1 mg/L) set by FMEnv (2011). The lowest values were recorded at Station 1 (March 2019), while the highest value was recorded at Station 1 in May 2019. The mean values also increased spatially, though there was no significant difference ($P > 0.05$) across the stations.

Na^+

Spatial and temporal variation of Na^+ values was shown in figure 14. The values ranged between 0.22 and 2.1 mg/L (Table 2). All the values were much lower than acceptable limit (120 mg/L) set by FMEnv. (2011). Both lowest and highest values were recorded at Station 1 in March 2019 and May 2019, respectively. The mean values had no significant difference ($P > 0.05$) across the stations.

K^+

The spatial and temporal variations of K^+ are shown in figure 15. The values ranged from 0.08 to 0.91 mg/L (Table 2). The lowest and highest values were recorded at Station 1 in February and May 2019, respectively. All K^+ values were lower than the acceptable limit of 50 set by FMEnv (2011). There was no significant difference ($P > 0.05$) in the K values across all stations.

Ca^{2+}

The concentration of Ca^{2+} measured at the three stations during this study period ranged from 0.72 to 6.44 mg/L. The lowest and highest Ca^{2+} concentrations were recorded at Station 1 in February and at Station 2 in May, respectively. Results of Ca^{2+} contents indicated no significant difference across the three stations. The spatial variation of Ca^{2+} at Station 1 revealed gradual increments between February and April, then sharp increments in May, and afterward, it gradually decreased until the end of this study period. Spatial variation at Station 3 followed the same trend with no variations between February and March (Fig. 16). At Station 2, the trend decreased from February to March but increased between March and May and then decreased.

Mg^{2+}

The concentrations of Mg^{2+} ranged between 0.51 and 4.32 mg/L. The highest concentration of Mg^{2+} was recorded in May 2019 across the three stations, whereas the lowest concentration was recorded at Station 1 in February 2019, though Stations 2 and 3 recorded their lowest concentrations

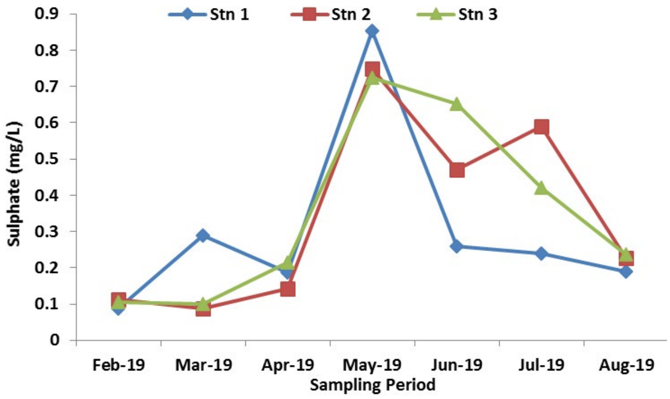

Fig.11. Spatial and temporal variations of SO_4^{2-} at the study stations of the Akor River.

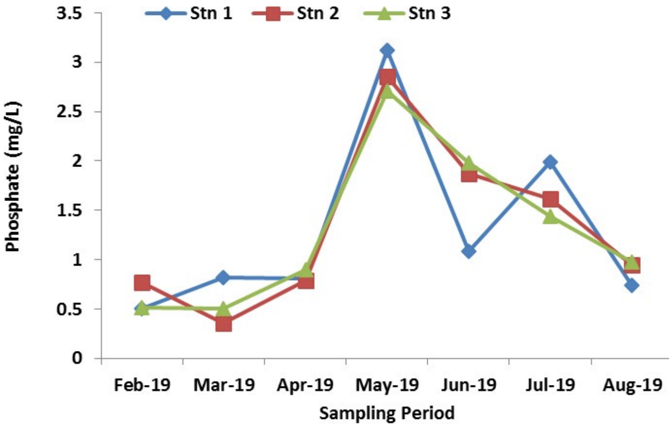

Fig.12. Spatial and temporal variations of PO_4^{3-} at the study stations of the Akor River.

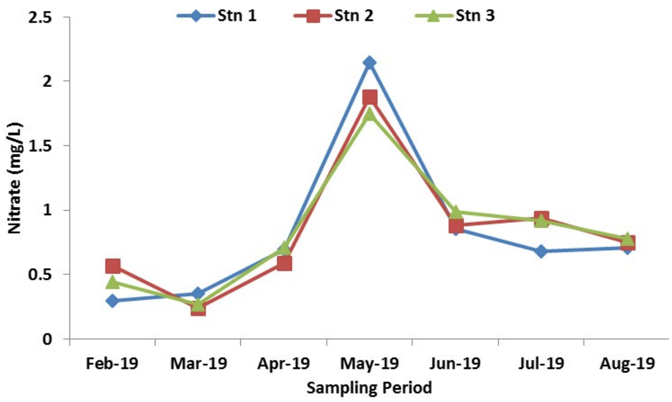

Fig.13. Spatial and temporal variations of NO_3^- at the study stations of the Akor River.

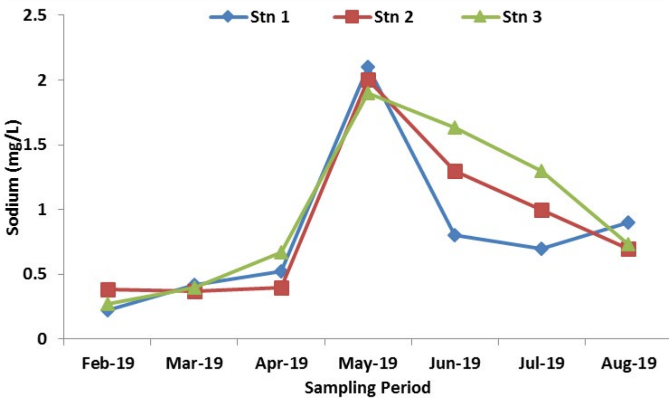

Fig.14. Spatial and temporal variations of Na^+ at the study stations of the Akor River.

in March 2019. No significant difference ($P > 0.05$) was recorded among the stations. The spatial variation of Mg^{2+} concentration followed the same trend as Ca^{2+}. At Station 1, there were gradual increments between February and May, then there was a monthly decreased throughout the study period. At the same time, at Station 2 and Station 3, the trend revealed a decrease between February and March followed by a gradual increase between March and April, then there was a drastic increase in May (onset of rain) and afterwards a monthly decrease throughout the study period (Fig. 17).

3.2. Water pollution index

The percentage of Na^{+} ranged from 15.85 to 16.39%, indicating that Akor River has excellent irrigation water quality. The highest value was recorded at Station 3 (July), whereas the lowest value was observed at Station1 (February). The Nemerow pollution index varied from 0.59 to 0.63, which also indicated that the water in the river is of good quality. The water quality index results varied from 52.70 to 54.50%, indicating that the Akor River has good water quality status. The result of water pollution index revealed that the Akor River status is excellent and capable of sustaining biodiversity as well as crop irrigation.

4. Discussion

4.1. Physical-chemical parameters

This study compared the impact of anthropogenic activities on water quality of the Akor River, Ikwuano, Abia state, Nigeria. There are some marked variations in the physical-chemical parameters observed from the sampling stations and the seasons on the river. The range of surface water temperature for the river correlated well with the ranges recorded for other southeast surface river waters (Amah-Jerry et al., 2017; Anyanwu et al., 2019; Anyanwu and Ukaegbu, 2019). Both micro- and macro-aquatic organisms depend on certain temperature range for optimal growth and survival. The higher surface water temperature of the river during the dry season could be attributed to climate variability such as air temperatures and associated sunshine. Many studies recorded surface water temperatures within or slightly lower than the range obtained in this study.

Turbidity is a resultant accumulation of materials such as organic and inorganic materials, plankton and other microscopic organisms, including mud (Effendi et al., 2015). The mean values of turbidity during this study period were higher than the mean values (1.98 ± 0.91 NTU) obtained by Anyanwu and Ukaegbu (2019) for the Ossah River, southeastern Nigerian river. In the same line, Anyanwu (2012) reported higher values of turbidity for the Ogba River, Benin City, Nigeria, than the results obtained in this study. The results revealed relatively higher turbidity values during the rainy season. This may be attributed

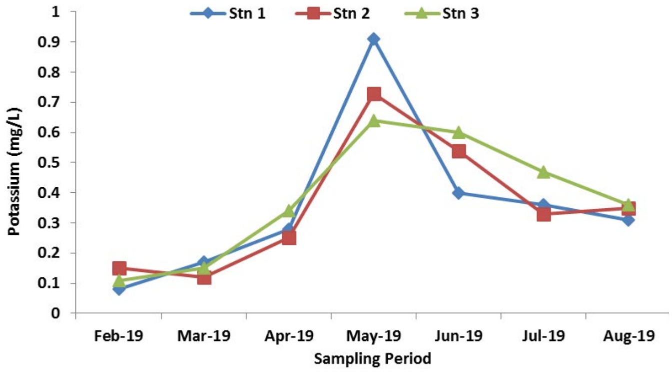

Fig.15. Spatial and temporal variations of K^{+} at the study stations of the Akor River.

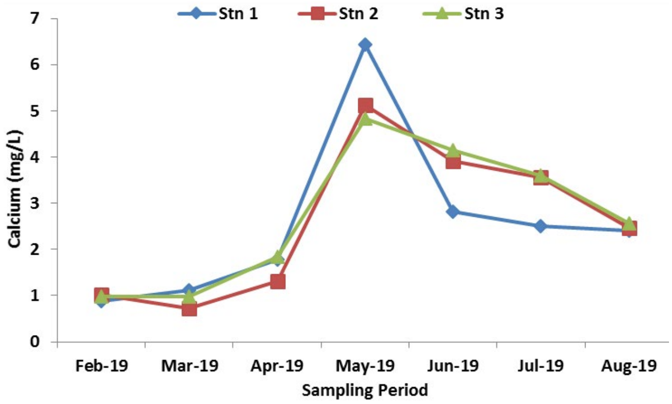

Fig.16. Spatial and temporal variations of Ca^{2+} at the study stations of the Akor River.

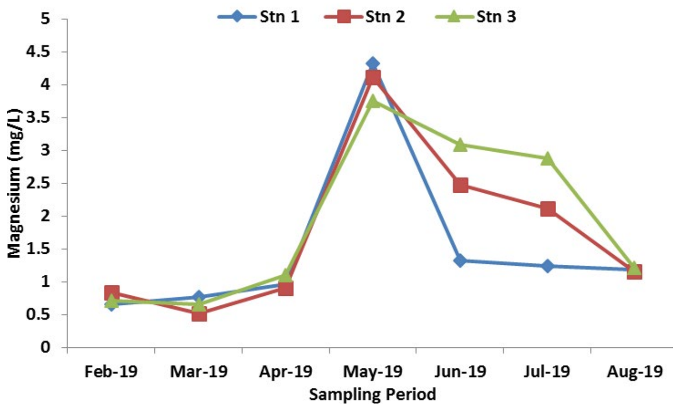

Fig.17. Spatial and temporal variations of Mg^{2+} at the study stations of the Akor River.

to emptying of suspended solids loads into the river via runoffs. The variation patterns obtained across all the sampling stations on both rivers could be attributable to the degree of anthropogenic activities in and around the river.

The pH values obtained during this study were within acidic range and this is in line with results obtained by Anyanwu and Ukaegbu (2019) and Amah-Jerry et al. (2017) in Ossah River, Umuahia and Aba River, Aba, Southeast Nigeria. The pH values in this study were lower than the values obtained by Oluyemi et al. (2010) from the water sources in Ife North Local Government Area of Osun State and Yusuf et al. (2017) that recorded pH values ranging from nearly neutral to weakly alkaline in the Saba River, Osogbo, both in

Southwest Nigeria. Water pH determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals in surface water. All pH values recorded were acidic and below the acceptable limit set by SON (2015). This could be attributed to geogenic influence. Studies have shown that rivers in the region are acidic (Okereke, 2014; Bobor and Umeh, 2019; Anyanwu and Umeham, 2020; Anyanwu et al., 2022). Geogenic low pH is usually a result of acid-generating rocks/soils and oxidation or reduction processes within the river (USEPA, 2022).

The results of conductivity indicate that anthropogenic activities had no noticeable impact on the river and equally showed that the river is a freshwater body. The EC values obtained during this study period were within or slightly higher than the values recorded for the Ogba River, Benin City, Nigeria by Anyanwu (2012). EC values were rather lower than the values recorded in the Ikwu River, Umuahia, Nigeria by Anyanwu et al. (2022). The low EC values obtained in this study corresponded to the low total dissolved solids, thus attributing the low EC to low TDS.

Dissolved oxygen is the quantity of oxygen dissolved in water, and it is essential to determine whether the water under study can support aquatic life (Joshua and Nazrul, 2015). The mean DO values recorded indicated that the Akor River can support aquatic life and is good for drinking. There is no public health implication of DO in drinking water but higher concentrations are associated with better water quality and taste (Omer, 2019). DO values were lower during the rainy season than the dry season and this could result from decomposition of eroded materials discharged into the river. The results of this study correlate with the findings of lower DO in rainy season (Amah-Jerry et al., 2017). The range of DO values recorded in this study is in line with the results obtained by Amah-Jerry et al. (2017) and Anyanwu et al. (2019). Similarly, the findings of this study corroborate the result of Adeosun et al. (2016) and Olalekan et al. (2012) that reported that DO values were higher in the rainy season than in the dry season in the Ole Stream of the Federal University of Agriculture, Abeokuta, and the Ogun River, respectively, both in Ogun state, Southwest Nigeria.

However, the result is not in line with Oribhabor et al. (2013) that reported that DO level was lower than in the rainy season in the Lower Cross River, Nigeria. The higher DO values recorded in the Akor River between March and June may be attributed to early rainfall that has led to the increase in water volume, turbulence and increased dissolution of oxygen at air-water interface.

Biochemical oxygen demand is one of the important parameters of water employed in determining the pollution load of freshwater bodies (Anyanwu et al., 2019). The results recorded indicate that the level of oxygen required by microorganisms for respiration in the water is lower than the required maximum standard of 3 mg/L. The BOD values obtained were in line with the study of Anyanwu (2012) on the Ogba River, Benin City, and of Anyanwu and Ukaegbu (2019) on the Ossah River, Umuahia, both in Southeast Nigeria. Anyanwu et al. (2019) recorded similar results for the Ossah River, Umuahia, Southeast Nigeria. However, the results of BOD recorded for most surface waters in Southwest Nigeria (Oluyemi et al., 2010) were higher than the values observed during this study period.

The BOD values recorded indicated that anthropogenic activities in and around the river had no significant impact on the quality of water and revealed that Akor River is a clean surface water body. The higher BOD recorded in the southwestern river than southeastern rivers, including the Akor, may be attributed to climate variables, anthropogenic activities and abundance of aquatic microflora and fauna within the region.

Total dissolved solids influence the aesthetic value of the water through altering the turbidity and limit water body from performing its ecosystem functions as a drinking water source and irrigation supply (Amanial, 2015; Titilawo et al., 2019). The TDS values obtained in the present study were the same or higher than those recorded by Amah-Jerry et al. (2017) on the Aba River, and Anyanwu et al. (2019) on the Ossah River, Umuahia, both in Southeast Nigeria. However, the results obtained in the present study were rather lower than in the study of Flura et al. (2016) in the Meghna River, Bangladesh, and Yusuf et al. (2017) on the Saba River, Osogbo, Nigeria. Similarly, higher values of TDS were recorded by Ewa et al. (2011) in the Omoku Creek and Makinde et al. (2015) in the Ekerekana and Buguma Creeks, both in the Niger delta, Nigeria.

Higher values of TDS recorded for the Akor River between April and June 2019 could probably be due to active various farming activities such as clearing, ploughing and ridge making in the farmlands around the river (Petlušová et al., 2019). Additionally, heavy runoffs as a result of early rainfall during these months may also have contributed immensely to these higher values.

Total suspended solids value is normally used as a potential index for drinking water contamination. The higher the TSS values, the higher likelihood of introduction of different diseases in the water body, which affect all living organisms, especially humans. Results of TSS obtained in the present study were lower than in the study of Amah-Jerry et al. (2017) on the Aba River, Southeast Nigeria. Similarly, the study of Danha et al. (2014) at discharging point and downstream of charging point recorded higher values than the present study. The higher TSS values obtained in the river between April and August could be attributed to high runoff as result of early rains that emptied debris and other suspended materials into the river.

Chemical oxygen demand values recorded were higher compared to 2.0-7.0 mg/L recorded in Aba River, Aba by Amah-Jerry et al. (2017) and 14.95-31.47 mg/L recorded in Saba River, Osogbo, Nigeria by Yusuf et al. (2017) but lower than 425.0-1675 mg/L recorded in Illo River, Ota, Nigeria by Omole and Longe (2008) and 444.0-1508 mg/L recorded in a stream in Gboko, Nigeria by Ubwa et al. (2013). The highest COD values were recorded in April 2019 and declined afterwards; a trend observed by Yusuf et al. (2017). The COD values indicated that the Akor River was mildly polluted. The values of COD recorded in surface waters usually range from 20 mg/L or less in unpolluted waters to greater than 200 mg/L in effluent-receiving waterbodies (Chapman and Kimstach, 1996).

PO_4^{3-} value gives an indication of the degree of both nutrients and eutrophication of any aquatic system. Disposal of detergents, contaminated sewage and direct washing of clothes in water, as well as application of fertilizer, pesticides and other agrochemicals to crop plants, cause PO_4^{3-} contamination of water body (Anyanwu and Ukaegbu, 2019). PO_4^{3-} values recorded in this study were generally poorly compared to the data of Yusuf et al. (2017), Amah-Jerry et al. (2017), Osibanjo and Adie (2007), who studied the Nigerian rivers. However, the PO_4^{3-} values were within the range obtained by Anyanwu and Emeka (2019) for the Ikwu River and by Anyanwu and Ukaegbu (2019) in Umuahia Abia state, Southeast Nigeria. Similarly, the spatial variations and higher values during the rainy season in the Akor River may be attributed to early rains that empty both animal and human faeces into the river coupled with active farming activities such as the application of fertilizers, pesticides and other agrochemicals. The higher values of PO_4^{3-} in the Akor River could also be probably due to indiscriminating using of fertilizer and agrochemicals by rural cocoa and rice farmers.

NO_3^- values in natural surface waters are often less than 1 mg/L, but a water body under the influence of anthropogenic activities could have NO_3^- values up to 5 mg/L (Anyanwu and Ukaegbu, 2019). NO_3^- values above of 5 mg/L usually indicate anthropogenic activities or animal waste, or fertilizer pollution. The NO_3^- values in this study were within the values of natural river (< 1 mg/L), except for May when the values exceeded 1mg/L. The spatial and temporal variations recorded may be attributed to the application of nitrogen containing fertilizers and run-off. The NO_3^- values observed in the present study were low compared to results of some studies in Nigerian rivers (Igbinosa et al., 2012; Yusuf et al., 2017; Amah-Jerry et al., 2017; Anyanwu and Emeka, 2019). However, NO_3^- values recorded during this study were within or little below the results of Anyanwu and Ukaegbu (2019) and Kindele and Olutona (2014), both obtained in Nigeria.

Similarly, the spatial and temporal variations of NO_3^- in this study is in line with the spatial variation results in the study of Yusuf et al. (2017), who reported higher NO_3^- values between March and May in the Saba River, Osogbo, but they do not fall in line with the study of Makinde et al. (2015), who recorded higher NO_3^- values during dry season months (November to February) than during rainy season months (July to October) in the Ekerekana Creek and the Buguma Creek, River state, and Amah-Jerry et al. (2017), who obtained lower values of NO_3^- between March and May in the southeast of the Aba River, all in Nigeria. The spatial and temporal variations, especially the higher values obtained between March and May, could be attributed to early rains and fertilizers applied to early planted crop that empty NO_3^--containing materials into the river.

The SO_4^{2-} concentration values recorded in this study were rather low compared to related studies on the Nigerian rivers (Anyanwu, 2012; Makinde et al., 2015; Amah-Jerry et al., 2017). On the other hand, the present SO_4^{2-} values were within or slightly lower than the range of values obtained in some studies (Anyanwu and Emeka, 2019; Anyanwu and Ukaegbu, 2019). Similarly, the higher SO_4^{2-} values obtained in this study during the rainy season are comparable with Makinde et al. (2015), who reported higher values during the rainy season in the Ekerekana and Buguma Creeks, the Niger delta, and Amah-Jerry et al. (2017), who recorded higher values during the rainy season in the Aba River, southeast, both in Southeast Nigeria. The high values of SO_4^{2-} during the rainy season may be attributed to the oxidation of SO_3^{2-} to SO_4^{2-} from run-off loaded and decaying organic materials (Makinde et al., 2015).

Na^+ is always present in all-natural surface waters as a result of its salt solubility, and it is relatively abundant on earth. The values of Na^+ in most surface water are well below 5 mg/L (Anyanwu, 2012). The Na^+ values obtained in the present study were similar to the study of Anyanwu and Ukaegbu (2019) on the Ossah River, Umuahia, Southeast Nigeria. However, Na^+ values were low compared to Ikhuoriah and Oronsaye (2016) but slightly higher than Anyanwu and Emeka (2019) and Anyanwu et al. (2022).

K^+ is usually found in low values in natural waters due to relative resistance of rocks containing K^+ to weathering (Skowron et al., 2018). All aquatic organisms require K^+ for several metabolic processes, including growth and development. Furthermore, K^+ not only limits growth at low values but also can be toxic at sufficiently high values (Anyanwu and Ukaegbu, 2019). The values of K^+ recorded in this study were within the results range obtained by Anyanwu (2012). However, some recent studies on fresh waters (Matta et al., 2018; Anyanwu and Ukaegbu, 2019) reported quite lower K^+ values compared to the values recorded in this study.

Ca^{2+} is an essential component of many aquatic organisms, constituting part of plant cell walls, shells and bones (Chapman and Kimstach, 1996). Low Ca^{2+} values may cause osmotic problem and deformities in shell fish such as crayfish, oyster, crab, prawn, periwinkle, and aquatic snails (Hessen et al., 2017; Jeziorski and Smol, 2017). Ca^{2+} values recorded in this study were relatively lower compared to some studies (Ikhuoriah and Oronsaye, 2016; Anyanwu and Emeka, 2019; Anyanwu et al., 2022). However, the values were within the range recorded in the Ossah River, Umuahia, Abia state, Southeast Nigeria (Anyanwu and Ukaegbu, 2019). In this study, Ca^{2+} values were higher in rainy season months than in dry season months, and this could be probably a result of burnt shell via farmland preparation that emptied into the river by wastewater. Higher Ca^{2+} values observed in the Akor River may be attributed to intensive farming activities by numerous farmers in communities along the river.

Mg^{2+} is available in many organic matters such as rock and forms an essential element for living organisms. Naturally, concentration of Mg^{2+} depends on the rock types along the watershed area, and its range in freshwaters is between 1 and > 100 mg/L. Very low ionic Mg^{2+} concentration in Ca^{2+}-deficient aquatic environment pose the greatest risk to aquatic organisms.

In this study, Mg^{2+} values recorded were low and within acceptable limits set by FMEnv (2011). Some recent studies carried out in Southeast Nigerian fresh waters also recorded low Mg^{2+} values. Anyanwu and Ukaegbu (2019) equally recorded values between 0.42 and 1.38 mg/L in the Ossah River, Umuahia. There is a seasonal variation with respect to Mg^{2+} values in the river; higher values were observed during the rainy season than in the dry season. This may be attributed to multiple factors such as physical weathering and farming activities coupled with early and heavy rains that could wash the weathered Mg^{2+}-contained materials into the Akor River.

The cation values obtained in this study were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. The major cations order in this study agrees with the common trend observed in Nigerian inland fresh waters, in which Ca^{2+} and Mg^{2+} are the most important cations (Imevbore, 1970; Egborge, 1971; Anyanwu, 2012; Anyanwu and Ukaegbu, 2019). Despite the higher values of Ca^{2+} and Mg^{2+} recorded, the water of the river is soft.

4.2. Water quality indices

The results of water pollution status reflected the effects of seasons and anthropogenic activities. The seasonal variations may be associated with different human activities in different seasons of the year. Although, generally, the results indicate that the Akor River has a good water quality throughout the sampling periods. The results of quality indices of the Akor River were within the range obtained by Anyanwu and Umeham (2020), making it capable of sustaining biodiversity as well as crop irrigation.

5. Conclusions

Activities such as intensive farming, industrialization and waste discharge into surface water bodies have been a threat to the physical-chemical parameters of water bodies, and surface water bodies in Southeast Nigeria are not an exception. In this study, physical-chemical parameters were investigated. The study indicated that human (anthropogenic) activities, including sand mining, agricultural activities, washing of household utensils, swimming, etc. had not negative impact on the water quality according to the water quality indices. However, some parameters such as turbidity, pH, DO, BOD, and COD did not meet the standards. The pollution status of the Akor River depends on season and anthropogenic activities, but presently the river has a good status and is capable of sustaining biodiversity as well as crop irrigation.

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Conflict of interests

The authors declare no conflict of interests.

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