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Research Article

Assessing Water Quality of a Rural Stream Southeast Nigeria for Irrigation Purpose

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Abstract: Aspects of the physicochemical parameters of a rural stream, in Southeast Nigeria, were evaluated for 12 months, between November 2021 and October 2022 in 3 stations in relation to suitability for irrigation purposes. Ten (10) physicochemical parameters were evaluated using standard methods and compared with the Food and Agriculture Organization (FAO) Irrigation Water Quality standard. Irrigation indices like Sodium Absorption Ratio (SAR), Percentage Sodium (%Na), Kelly's Index (KI), Magnesium Hazard (MH), Soluble Sodium Percentage (SSP), Cation Ratio of Soil Structural Stability (CROSS), Permeability Index (PI), Potential Salinity (PS), Total Hardness (TH), and Residual Sodium Bicarbonate (RSBC) were also used for the irrigation suitability assessment. The physicochemical parameters were: pH (5.00–8.60), total dissolved solids (9.00–75.00 mg l^{-1}), electrical conductivity (18.00–150.00µS cm^{-1}), bicarbonate (22.70–91.50 mg l^{-1}), chloride (17.00–195.00 mg l^{-1}), sulphate (0.01–0.76 mg l^{-1}), magnesium (0.26–3.71 mg l^{-1}), sodium (0.11–1.18 mg l^{-1}), potassium (0.05–0.98 mg l^{-1}) and calcium (0.31–5.11 mg l^{-1}). Spatially and seasonally, the mean values conformed to irrigation water standards except pH (dry season). All the parameters recorded higher values in station 1 and wet season (except Chloride). The irrigation indices were: SAR (0.10 – 0.14), %Na (15.0 – 25.0), KI (0.12 – 0.25), MH (50.00 – 55.60), SSP (10.53 – 18.20), CROSS (0.10 – 0.20), PI (68.2 – 185.7), PS (1.92 – 2.71), TH (0.20 - 0.64), and RSBC (0.89 – 1.10). All indicated suitability except MH (all stations and wet season) and PI (wet season). Anthropogenic activities and seasons influenced the water quality of the stream and the indices. It can be concluded that the Azueke stream is suitable for irrigation.

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1. Introduction

The main surface water resources that are most easily accessible for industrial, agricultural, and human consumption are rivers and lakes (Shil et al., 2019; Ustaoğlu et al., 2021). Freshwater resources are being misused due to a rapid increase in human population, urbanization, and industrialization

(Menberu et al., 2021) and water shortages have become a global issue due to water pollution and climate change over the last decade (Ustaoğlu et al., 2020; Batarseh et al., 2021). Water pollution poses a threat to the long-term sustainability of water resources, aquatic biota, human life, and socioeconomic growth (Ustaoğlu and Tepe, 2019; Anyanwu et al., 2023). It also results in water scarcity, a decline in agricultural production, contaminated food chains, illnesses, and a decline in aquatic life (Egbueri et al., 2023).

Agriculture has been identified as the most water-demanding sector, contributing to about 70% of the volume withdrawn (Ingrao et al., 2023). Irrigation is the regulated (quantity, quality, and timing) use of water from different sources to boost agricultural production (Malakar et al., 2019). Malakar et al. (2019) further opined that the increasing demand for water to boost productivity will lead to depending on water sources of doubtful quality. Water quantity is the general condition of a water body or source (Er and Sevik, 2023) and has always been a major concern in irrigated agriculture.

Certain quality criteria are required for irrigation water to prevent any negative effect on the soil, irrigated crops, and consumers (Alsubih et al., 2022). Water quality is one of the most important environmental determinants that affect a country's ecosystem, agricultural production, and socioeconomic development (Kundu and Ara, 2019). Water quality encompasses all physical, chemical, and biological factors that influence the most effective use of water. Therefore, when determining water quality, it is essential to identify the physical, chemical, and biological parameters that affect it (Anonna et al., 2022). The quality of the soil and the quality of the water intended for irrigation determine the productivity of crops. Groundwater, surface water, and wastewater are the known sources of water for irrigation (Yerli and Sahin, 2022). Most surface water sources are extremely vulnerable to pollution due to anthropogenic activities, rendering them unsuitable for a number of uses (Akhtar et al., 2021; Anyanwu et al., 2023).

The parameters present as well as their concentrations are the determining factors for the suitability of water for irrigation or other purposes (Tekile, 2023) and the primary contaminants of concern in irrigation are salts (Ukoha-Onuoha et al., 2022). Indices have been applied to determine the suitability of water for various uses. The following indices - Sodium Absorption Ratio (SAR), Percentage Sodium, Kelly’s Index (KI), Magnesium Hazard (MH), Soluble Sodium Percentage (SSP), Cation Ratio of Soil Structural Stability (CROSS), Permeability Index (PI), Potential Salinity (PS), Total Hardness (TH), and Residual Sodium Bicarbonate (RSBC) were applied to determine the suitability of Azueke Stream for irrigation purpose.

Azueke Stream is a rural freshwater body providing for the needs of its immediate community. It is used for different domestic purposes (including drinking), recreation, and irrigation especially during the dry season. It discharges into the Anya River reservoir used by the National Root and Crop Research Institute, Umudike for dry season research activities. The stream and reservoir have been used for years for irrigation and to the best of our knowledge, there is no previous study in the watershed for irrigation purposes. Therefore, this study aims to assess the suitability of Azueke Stream for irrigation purposes.

2. Material and Methods

2.1. Study area and sampling stations

Azueke Stream took its source from a rock within the Azueke community, Abia State, and transverse through Umudike, crossing Umuahia – Ikot Ekpene highway before discharging into Anya River at Amaoba, Ikwuano L.G.A, Abia State. The studied stretch of the Azueke stream is between the Azueke and Umudike communities, flowing through the National Root and Crop Research Institute (NRCRI), Umudike, Abia State (Figure 1). It is between latitude 5°50.406’ and 5°37.100’ N and Longitude 7°25.000’ and 7°27.000’ E. The study area is within the sub-equatorial zone, with a mean annual rainfall of 4000 mm. It is characterized by the wet season (May to October) and dry season (November to April); a double maxima rainfall peaks in July and October. A short period of dryness (August break) usually occurs between the peaks in August. The stream discharges into the National Root Crop Research Institute reservoir used for dry season cropping and research.

Station 1 (N 5º 30’14.628”; E 7º 32’33.9”) is located at Azueke Community. It is upstream and remotely located. The human activities observed were effluent discharges from pig farms. Stormwater from Umuahia – Ikot Ekpene Road also discharges into Station 1 during rainfall, introducing effluents from solid wastes dumped along the road into the stream.

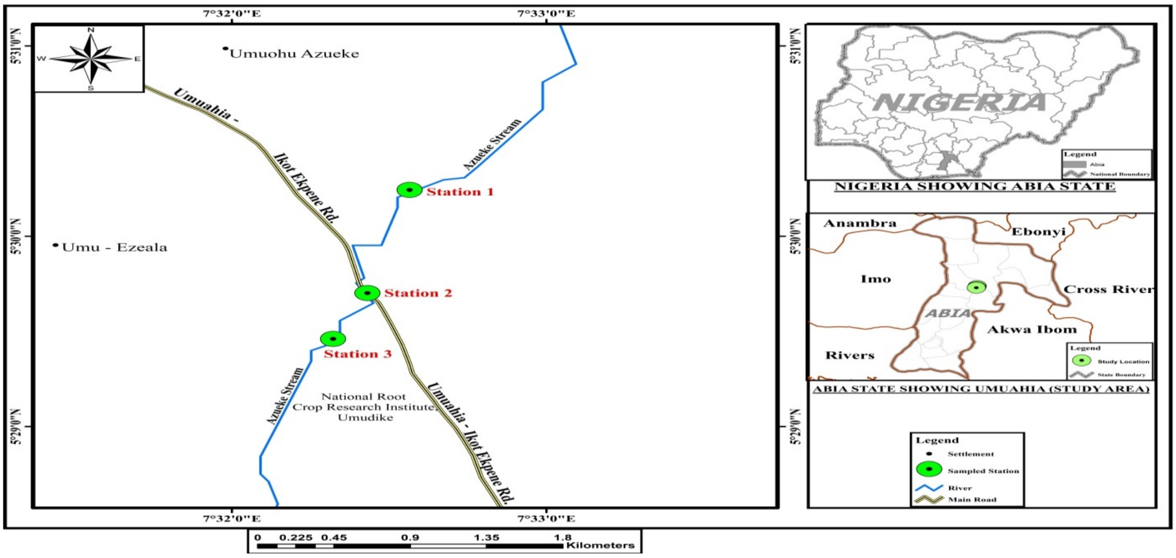

Figure 1. Map of Azueke Stream, Umuahia, Nigeria showing the sampling Stations.

Station 2 (N 5° 29'42.114"; E 7° 32'25.854") is located near Abia State University, Umuahia Campus, about 1.22 km downstream of Station 1. A horticultural garden is located on the right bank and stormwater from the Umudike – Ikot Ekpene road also discharges into the Station. Sand mining activities, and washing of cars, tricycles, and motorcycles were observed on the other side of Station 2 across the road.

Station 3 (N 5° 29'27.672"; E 7° 32'19.296") is about 584.3 m downstream of Station 2; located within the National Root Crop Research Institute (NRCRI), Umudike. The station was surrounded by farmlands that were sometimes irrigated. The residents of the Institute extract water for some of their household activities and stormwater from the residential area and farmlands discharges into this station. After Station 3, the stream empties into a reservoir used by the National Root Crop Research Institute (NRCRI) for irrigation during the dry season cropping and research.

2.2. Samples collection and analyses

Water samples were collected from the Azueke stream monthly from November 2021 to October 2022 with a 1-litre water sampler and stored in clean 250 ml plastic bottles. The physicochemical parameters were analyzed using standards methods –pH (Jenway 550 Portable pH meter) (Tüzüner, 1990), total dissolved solids and conductivity (HACH CO. 150 TDS/Conductivity Meter) (Nollet and De Gelder, 2013), bicarbonate (Titrimetric Method) (Tüzüner, 1990), sulphate (Turbidimetric Method) (Dewis and Freitas 1970), chloride (Argentometric Method) (Tüzüner, 1990), potassium (Flame Photometric Method) (Tüzüner, 1990), calcium, sodium and magnesium (Atomic Emission Spectrophotometry Method) (Tüzüner, 1990).

2.3. Irrigation water quality assessment

The water samples were evaluated for their suitability for irrigation purposes using specific ions and indices. The parameters and indices used to evaluate the suitability of the water for irrigation are pH, total dissolved solids, electrical conductivity, bicarbonate, chloride, sulphate, magnesium, sodium, potassium and calcium, potential salinity (PS), total hardness (TH), percentage sodium (PS), sodium absorption ratio (SAR), magnesium hazards (MH), soluble sodium percentage (SSP), residual sodium bicarbonate (RSBC), cation ratio of soil structural stability (CROSS), permeability index (PI) and Kelly´s index (KI).

2.3.1. Total hardness

Total hardness was determined using an empirical formula as shown in equation (1).

$$\text{Total Hardness} = 2.5\,(Ca^{2+}) + 4.1(Mg^{2+}) \quad (1)$$

Where, Ca^{2+}= concentration of calcium and Mg^{2+} = concentration of magnesium, all in meq l^{-1}.

2.3.2. Sodium adsorption ratio (SAR)

SAR was calculated using the equation employed by Wilcox (1955) as presented in equation (2).

$$\text{SAR} = \frac{\text{Na}}{\sqrt{Ca + \text{Mg}/2}} \quad (2)$$

Where the concentrations are in meq l^{-1}

The United States Salinity Laboratory (USSL) salinity diagram based on EC and SAR was used to evaluate the suitability of the irrigation water samples as described by Er and Sevik (2023).

2.3.3. Magnesium hazard (MH)

Magnesium Hazard (MH) is also used for the determination of water suitability for irrigation. It is determined by the level of magnesium ions in the water. It was determined according to Paliwal (1972) with Equation 3. All concentrations are in meq l^{-1}.

$$\text{MH} = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} * 100 \quad (3)$$

2.3.4. Percentage sodium (%Na)

Percentage Sodium (%Na) is used to classify water for irrigation purposes (Al-Aizari et al., 2024). Percentage Sodium compares the proportion of sodium and potassium ions in relation to all cations (Wilcox, 1955). It is determined using Equation 4, where all concentrations are in meq l^{-1}.

$$\%\text{Na} = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} * 100 \quad (4)$$

Wilcox diagram based on Percentage Sodium (%Na) was used to evaluate the suitability of the irrigation water samples as described by Er and Sevik (2023) and Al-Aizari et al. (2024).

2.3.5. Permeability index (PI)

Permeability index (PI) is an important index that is used to assess the movement of water in the soil to determine if the water is suitable for irrigation. The suitability of water for irrigation based on PI was determined by Equation 5 developed by Doneen (1964), where, ions are expressed in meq l^{-1}.

$$\text{PI} = \frac{(Na^{+} + \sqrt{HCO_3^{-}})}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100 \quad (5)$$

2.3.6. Kelly's index

Kelly's index was determined using Equation 6 developed by Kelly (1940). The ions were in meq l^{-1}.

$$\text{KI} = \frac{Na^{+}}{Ca^{+} + Mg^{2+}} \quad (6)$$

2.3.7. Residual sodium bicarbonate (RSBC)

The Residual sodium bicarbonate was calculated with Equation 7 by Kuldeep et al. (2022):

$$\text{RSBC} = HCO_3^{+} + Ca^{2+} \quad (7)$$

2.3.8. Soluble sodium percentage (SSP):

Soluble Sodium Percentage (SSP) for water was determined by using Equation 8.

$$\text{SSP} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100 \quad (8)$$

2.3.9. Potential salinity (PS)

Potential Salinity is an index used to determine the salinity level of a water body with respect to irrigation. It is calculated with Equation 9 as described by Shil et al. (2019) and Berhe (2020)

$$\text{PS} = Cl^{-} + \frac{1}{2} SO_4^{2-} \quad (9)$$

2.3.10. Cation ratio of soil structural stability (CROSS)

Cation ratio of soil structural stability (CROSS) was used to determine the role of sodium and potassium ions in soil structural stability (Rengasamy and Marchuk, 2011). CROSS was determined using Equation 10.

$$\text{CROSS} = \frac{Na^{+} + 0.56K^{+}}{\sqrt{\{(Ca^{2+} + 0.6Mg^{2+}/2\}}} \quad (10)$$

2.4. Statistical analysis

The data obtained within the scope of the study were summarized using Microsoft Excel. Single-factor ANOVA was used to determine significant differences among means while paired t-test was used to determine seasonal variation ($p<0.05$).

3. Results

3.1. Spatio-temporal variations of physicochemical parameters

The summary of the physicochemical parameters recorded in Azueke Stream, Azueke, and Umuahia are presented in Table 1. There was no spatial significant difference ($p>0.05$) in all the parameters, however, relatively higher values were recorded in station 1.

The pH was acidic to slightly alkaline; ranging from 4.90 (station 3)–8.60 (station 2). A greater percentage (52.8%) of the values conformed to the 6.0–8.5 set by the Food and Agriculture Organization (Ayers and Westcot, 1994). The dry season values were acidic (5.45–5.67) and did not conform to the standard while the wet season was neutral to alkaline (7.00–7.08). The mean wet season value was significantly ($p<0.05$) higher than the mean dry season value.

Total Dissolved Solids (TDS) were low; ranging between 9.00 mg l^{-1} (station 2) and 75.00 mg l^{-1} (station 1). The dry season values (16.22–19.52 mg l^{-1}) were lower than the wet season values (21.00–39.00 mg l^{-1}) but not significant ($p>0.05$). All the spatial and temporal values were within 2000 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

Electrical conductivity (EC) exhibited the same trend as TDS; ranging from 18.00 µS cm^{-1} (station 2) and 150.00 µS cm^{-1} (station 1). The dry season values (32.58–39.35 µS cm^{-1}) were also lower than the wet season values (41.67–86.00 µS cm^{-1}) but not significant ($p>0.05$). All the spatial and temporal values were within 3000 µS cm^{-1} (3 d Sm^{-1}) set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The bicarbonate values ranged from 22.70 mg l^{-1} (station 2) to 91.50 mg l^{-1} (station 1). The dry season values (50.83–54.90 mg l^{-1}) were lower than the wet season values (49.90–69.50 mg l^{-1}) but not significant (p>0.05). All the spatial and temporal values were within 620 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The chloride values ranged between 17.00 mg l^{-1} (station 2) and 195.00 mg l^{-1} (station 1). The dry season values (92.13–98.85 mg l^{-1}) were higher than the wet season values (52.52–93.48 mg l^{-1}) but not significant (p>0.05). All the spatial and temporal values were within 1062 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The sulphate values were from 0.01 mg l^{-1} (station 2) to 0.76 mg l^{-1} (station 1). The dry season values (0.05–0.09 mg l^{-1}) were significantly (p<0.05) lower than the wet season values (0.22–0.28 mg l^{-1}). All the spatial and temporal values were within 960 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The magnesium values ranged from 0.26 mg l^{-1} (stations 1 and 3) to 3.71 mg l^{-1} (station 1). The dry season values (0.37–0.40 mg l^{-1}) were significantly (p< 0.05) lower than the wet season values (0.94-1.85 mg l^{-1}). All the spatial and temporal values were within 60.75 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The sodium values ranged from 0.11 mg l^{-1} (station 2) to 1.18 mg l^{-1} (station 1). The dry season values (0.21–0.23 mg l^{-1}) were significantly (p<0.05) lower than the wet season values (0.48–0.82 mg l^{-1}). All the spatial and temporal values were within 920 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The potassium values ranged between 0.05 mg l^{-1} and 0.98 mg l^{-1} (station 1). The dry season values (0.12–0.13 mg l^{-1}) were significantly (p<0.05) lower than the wet season values (0.34–0.62 mg l^{-1}). All the spatial and temporal values were within 2 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

The calcium values varied from 0.31 mg l^{-1} to 5.11 (station 1). The dry season values (0.55–0.59 mg l^{-1}) were significantly (p< 0.05) lower than the wet season values (1.19–2.55 mg l^{-1}). All the spatial and temporal values were within 400 mg l^{-1} set by the Food and Agriculture Organization (Ayers and Westcot, 1994).

Table 1. Summary of physicochemical parameters of Azueke River (with range in parenthesis)

Parameter	Station 1 Mean±SEM	Station 2 Mean±SEM	Station 3 Mean±SEM	Dry Season Mean±SEM	Wet Season Mean±SEM	*	**	***
pH	6.38±0.31 (5.10–8.50)	6.23±0.36 (5.00–8.60)	6.23±0.32 (4.90–8.50)	5.52±0.05 (5.45–5.67)	7.03±0.02 (7.00–7.08)	P>0.05	P<0.05	6.0–8.5
Total Dissolved Solids (mg l^{-1})	29.26±4.99 (14.00–75.00)	19.70±2.86 (9.00–42.00)	18.61±2.42 (10.00–40.00)	17.49±1.02 (16.22–19.52)	27.56±5.74 (21.00–39.00)	P>0.05	P>0.05	2000
Electrical Conductivity (µS cm^{-1})	62.68±9.98 (29.00–150.00)	39.76±5.73 (18.00–84.00)	37.13±4.80 (20.00–80.00)	35.26±2.08 (32.58–39.35)	57.78±14.16 (41.67–86.00)	P>0.05	P>0.05	3000
Bicarbonate (mg l^{-1})	62.20±5.17 (30.50–91.50)	51.20±5.29 (22.70–79.30)	50.37±4.43 (24.40–79.30)	52.19±1.36 (50.83–54.90)	56.99±6.27 (49.90–69.50)	P>0.05	P>0.05	620
Chloride (mg l^{-1})	96.17±14.02 (28.60–195.00)	74.06±11.05 (17.00–141.80)	75.25±8.52 (28.60–142.00)	95.53±1.94 (92.13–98.85)	68.12±12.79 (52.52–93.48)	P>0.05	P>0.05	300
Sulphate (mg l^{-1})	0.17±0.06 (0.02–0.76)	0.17±0.06 (0.01–0.73)	0.14±0.05 (0.03–0.60)	0.07±0.01 (0.05–0.09)	0.25±0.02 (0.22–0.28)	P>0.05	P<0.05	100
Magnesium (mg l^{-1})	1.13±0.30 (0.26–3.71)	0.67±0.12 (0.30–1.76)	0.66±0.11 (0.26–1.60)	0.38±0.01 (0.37–0.40)	1.26±0.30 (0.94–1.85)	P>0.05	P<0.05	40
Sodium (mg l^{-1})	0.53±0.11 (0.12–1.18)	0.35±0.06 (0.11–0.74)	0.35±0.06 (0.18–0.70)	0.22±0.01 (0.21–0.23)	0.59±0.11 (0.48–0.82)	P>0.05	P<0.05	920
Potassium (mg l^{-1})	0.37±0.09 (0.05–0.98)	0.24±0.06 (0.07–0.61)	0.23±0.04 (0.09–0.17)	0.12±0.003 (0.12–0.13)	0.44±0.09 (0.34–0.62)	P>0.05	P<0.05	2
Calcium (mg l^{-1})	1.57±0.40 (0.31–5.11)	1.01±0.19 (0.38–2.40)	0.78±0.15 (0.48–2.33)	0.56±0.01 (0.55–0.59)	1.73±0.40 (1.19–2.55)	P>0.05	P<0.05	400

SEM= Standard Error of Mean; *=Spatial P-value; ** = Seasonal P-value; *** = Ayersand Westcot(1994). Water quality for agriculture. FAO Irrigation and Drainage Paper.

3.2 Irrigation water quality assessment indices

The irrigation water quality indices are presented in Table 2. Sodium Absorption Ratio (SAR) values ranged between 0.10 (station 1) and 0.13 (station 3) while the seasonal values were 0.10 (dry season) and 0.14 (wet season). All the values were within the “excellent” water class (<10). The United States Salinity Laboratory (USSL) salinity diagram showed that Azueke waters fall into the C1-S1 class

- C1: Low salinity water (EC< 0.25 d Sm^{-1}) and S1: Low sodium hazard (SAR<10); indicating suitability for irrigation (Figure 2).

Percentage Sodium (%Na) values ranged between 15.0 (station 1) and 25.0 (station 3) while the seasonal values were 17.8 (dry season) and 17.4 (wet season). Station 1 and the seasonal values were within the "excellent" water class (20) while stations 2 and 3 were within the "good" water class (20 – 40). Wilcox diagram based on Percentage Sodium showed that all water samples were in the "excellent" class for irrigation (Figure 3).

Kelly Index (KI) values ranged between 0.12 (station 1) and 0.25 (station 2) while the seasonal values were 0.17 (dry season) and 0.16 (wet season). All the values were within the "Safe for irrigation" water class (<1).

Table 2. Water quality assessment indices for irrigation purposes

Parameters	Station 1	Station 2	Station 3	Dry Season	Wet Season	Irrigation/Water Quality Categories	Reference
Sodium Absorption Ratio (SAR)	0.10	0.12	0.13	0.10	0.14	Excellent: <10, Good: 10–18, Fair: 18-26, Poor: >26	Richards (1954)
Percentage Sodium (%Na)	15.0	21.4	25.0	17.8	17.4	Excellent: <20, Good: 20–40, Permissible: 40–60, Doubtful: 60-80, Unsuitable: >80	Wilcox (1955)
Kellys Index (KI)	0.12	0.25	0.22	0.17	0.16	≤1 Safe for irrigation, >1 Unsafe for irrigation	Kelly (1940)
Magnesium Hazard (MH)	52.94	54.54	55.60	50.00	52.63	<50 Suitable, >50 Unsuitable	Paliwal (1972)
Soluble Sodium Percentage (SSP)	10.53	15.40	18.20	14.30	13.64	≤ 50 Great water quality, >50 Intolerable water quality	Wilcox (1955)
Cation Ratio of Soil Structural Stability (CROSS)	0.12	0.16	0.17	0.10	0.20	Excellent: <10, Good: 10–18, Permissible: 18–26, Unsuitable: >26	Rengasamy and Marchuk (2011)
Permeability Index (PI)	78.9	107.7	155.6	185.7	68.2	>75 Class I: Excellent, 25-75 Class II: Good, <25 Class III: Unsuitable	Doneen (1964)
Potential Salinity (PS)	2.71	2.10	2.12	2.70	1.92	<3 Suitable, >3 Unsuitable	Rawat et al. (2018)
Total Hardness (TH)	0.60	0.40	0.31	0.20	0.64	Soft (0–60 mg l^{-1} $CaCO_3$), moderate (61–120 mg l^{-1}), hard (121–180 mg l^{-1}) and very hard (>180 mg l^{-1})	USGS (2018).
Residual Sodium Bicarbonate (RSBC)	1.10	0.89	0.90	0.89	1.02	< 5 (safe), 5–10 (marginal), and >10 (unsatisfactory)	Gupta and Gupta (1987)

Magnesium Adsorption Ratio (MAR) values ranged between 52.94 (station 1) and 55.60 (station 3) while the seasonal values were 50.00 (dry season) and 52.63 (wet season). All the values were within the "Unsuitable" water class (>50) except in the dry season.

Soluble Sodium Percentage (SSP) values ranged between 10.53 (station 1) and 18.20 (station 3) while the seasonal values were 14.30 (dry season) and 13.64 (wet season). All the values were within the "great water quality" class (≤ 50).

Cation Ratio of Soil Structural Stability (CROSS) values ranged between 0.12 (station 1) and 0.17 (station 3) while the seasonal values were 0.10 (dry season) and 0.20 (wet season). All the values were within the "excellent" water class (<10).

Permeability Index (PI) values ranged between 78.9 (station 1) and 155.6 (station 3) while the seasonal values were 185.7 (dry season) and 68.2 (wet season). All the values were within the "class I: excellent" water class (>75) except in the wet season.

Potential Salinity (PS) values ranged between 2.10 (station 2) and 2.71 (station 1) while the seasonal values were 2.70 (dry season) and 1.92 (wet season). All the values were within the "suitable" water class (<3).

Total Hardness (TH) values ranged between 0.31 mg l^{-1} $CaCO_3$ (station 3) and 0.60 mg l^{-1} $CaCO_3$ (station 1) while the seasonal values were 0.20 mg l^{-1} $CaCO_3$ (dry season) and 0.64 mg l^{-1} $CaCO_3$ (wet season). All the values were within the "soft" water class (0–60 mg l^{-1} $CaCO_3$).

Residual Sodium Bicarbonate (RSBC) values ranged between 0.90 (stations 2 and 3) and 1.10 (station 1) while the seasonal values were 0.44 (dry season) and 1.01 (wet season). All the values were within the "safe" water class (<5).

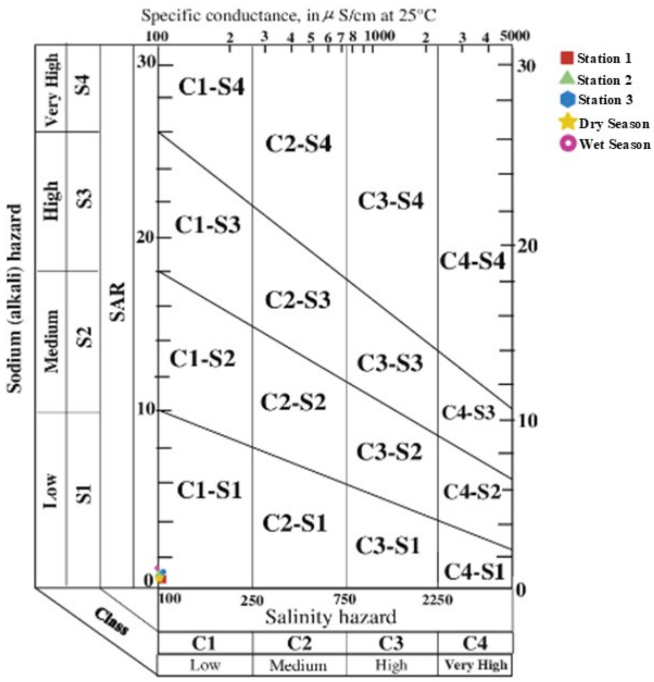

Figure 2. The USSL diagram for classification of Azueke waters for irrigation suitability.

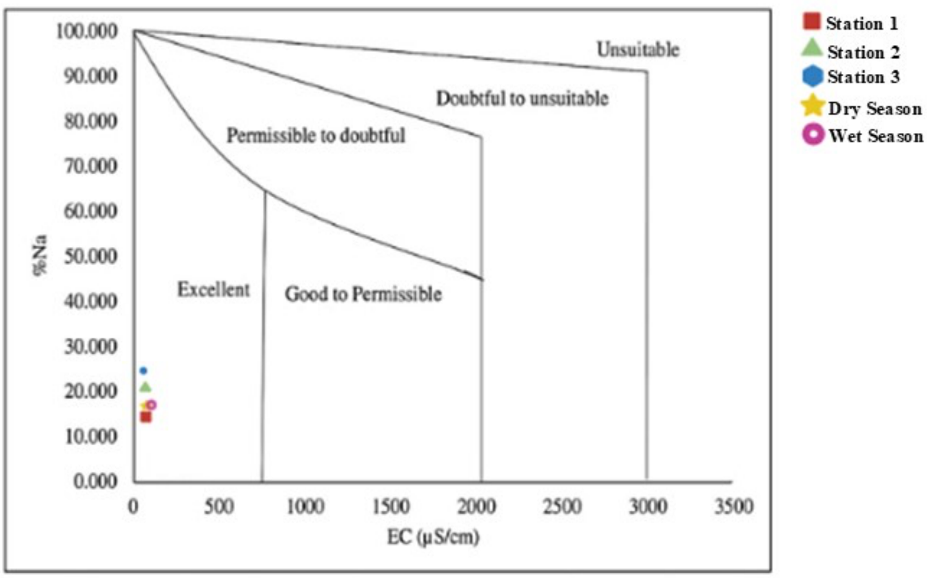

Figure 3. Wilcox diagram based on Percentage Sodium.

4. Discussion

Physico-chemical assessment is very important in the determination of river water suitability for irrigation (Anyanwu et al., 2023; Er and Sevik, 2023). The pH was acidic to slightly alkaline with a greater percentage (52.8%) of the values conforming to the acceptable limit. The optimum pH range for irrigation water is between 6.0 and 8.5 and values outside this range could lead to nutritional imbalance or indicate the presence of toxic ions (Ayers and Westcot, 1994). All the mean values conformed to the optimum pH value for irrigation water except in the dry season while the spatial mean values were acidic though within the limit. The relatively higher mean value recorded in station 1 could be due to the buffering effects of effluent discharges from solid waste dumps and pig farms into the stream (Anigbo et al., 2021). On the other hand, the higher wet season mean value could be due to dilution. Dilution reduces concentrations of solutes and the acidity of a river as the volume of water discharging into the river through runoff increases during the wet season (Huang et al., 2020). The dry season values were acidic and could be detrimental to crop production since irrigation is the major source of water for dry season cropping (Mba and Ugosor, 2024). Related studies also recorded higher mean values in the wet season and lower values in the dry season in Oba River (Adeyemi et al., 2019) and Ikose River (Adeyemi et al., 2021) both in Ogbomoso, Nigeria. Acidic irrigation water can affect nutrient availability and soil structure, lead to a reduction in plant growth and yield as a result of nutrient unavailability as well as alter the microbial activity necessary for decomposition and nutrient cycling (Li et al., 2018).

The Total Dissolved Solids (TDS) and electrical conductivity were low and exhibited the same spatial and temporal trends. The higher values in station 1 could be due to effluent discharges while the higher values during the wet season could be due to allochthonous input from increased surface runoffs laden with inorganic and organic matters discharged into the stream. Similar seasonal variation was also observed by Adeyemi et al. (2019, 2021). The total dissolved solids (TDS) and electrical conductivity (EC) values can be used to determine the salinity of water and may have an adverse effect on the soil when the maximum permissible values are exceeded (Abualhaija et al., 2020). Irrigation water with high salinity creates a high osmotic potential, where there is a competition between salts in the solution and the soil with the crops for the available water (Mohanavelu et al., 2021). Therefore, the salts will accumulate in the soil; resulting in a drought condition (Ayers and Westcot, 1994; Porter and Marek, 2006). However, the EC and TDS levels recorded in this study were within the permissible limit for irrigation and considered suitable for irrigation use.

All the spatial and temporal values of bicarbonate were within acceptable limits. Relatively higher mean values were also recorded in station 1 and wet season; attributable respectively to anthropogenic impact as observed by Abualhaija et al. (2020) in site 5 which receives effluent and allochthonous input due to rainfall (Adeyemi et al., 2019, 2021). Bicarbonate is an important anion needed in moderate concentrations, which influences soluble sodium percentage and regulates sodium hazard (Adeyemi et al., 2019). High concentrations may affect mineral nutrient uptake and metabolism in the plant. Bicarbonate increases the pH of the soil, which makes many of the micro-nutrients like iron, manganese, and zinc unavailable, consequently leading to the deficiency of these elements in irrigated plants (Grow Abundant Gardens, 2024). Elevated bicarbonate levels can also have adverse effects on irrigation equipment, the structure of the soil, and crop foliage (ANZG, 2023). Accumulation of bicarbonate in the soil water will occur due to evapotranspiration when such water is used over a long time. There is also an increasing tendency to reduce calcium and magnesium through precipitation as insoluble carbonates, which will increase the sodium adsorption ratio and negatively affect soil structure and permeability (ANZG, 2023).

The chloride values were also moderate and all the spatial and temporal values were within the acceptable limit for irrigation. The highest spatial mean value was also recorded in station 1; attributed to anthropogenic effects. On the other hand, the highest mean temporal value recorded in the dry season could be attributed to little or no rainfall, reduced flow velocity, higher air temperatures, and evaporation. These conditions have been reported to result in the concentration of water and higher values in some parameters (Houssou et al., 2017; Anyanwu et al., 2023). Chloride is essential for plant growth but can hinder plant growth as well as become toxic to some sensitive plants at elevated concentrations (Zaman et al., 2018). With proper irrigation application, water with a chloride concentration of <150 mg l^{-1} is safe and necessary for healthy crops (Aliyu et al., 2017). Elevated chloride concentrations in irrigation waters pose three major concerns linked to the risk of crop foliar damage (Niu et al., 2008), salty taste in the crops and fruits (Coli et al., 2015), and higher uptake of cadmium from the soil by plants (Ishikawa et al., 2015).

The sulphate values were low and all the spatial and temporal values were well within acceptable limit for irrigation; suggesting no threat. Higher mean values were also recorded in station 1 and wet season as observed in bicarbonate and could be attributed to the same factors. Moderate levels of sulphate in irrigation water can favor plant growth but soil salinity, alkalinity, and toxicity will arise from elevated sulphate concentrations (Ashie et al., 2024). The study further reported that plants grown with elevated sulphate irrigation water may exhibit a reduction in growth and yield and a higher susceptibility to drought and pests.

The magnesium values were also low with all the spatial and temporal values within the limit for irrigation purposes. It is an indication that the water is suitable for irrigation use. Relatively higher mean values were also recorded in station 1 and wet season as observed in bicarbonate and sulphate; attributable to the same factors. Magnesium concentration is a very important criterion in assessing irrigation water suitability (Adeyemi et al., 2021). However, higher magnesium values will adversely affect crop yields because of an increase in soil salinity (Joshi et al., 2009).

Sodium concentration is another major indicator used in assessing irrigation water quality; however, the sodium values were low with all the spatial and temporal values within the acceptable limit for irrigation. It is an indication that the water is suitable for irrigation use. Relatively higher mean values were also recorded in station 1 and wet season as observed in bicarbonate, sulphate, and magnesium; attributable to the same factors. Sodicity is the level of sodium (Na^+) ions in relation to other cations in the irrigation water or on the soil exchange complex (ANZG, 2023). High sodium concentration is mainly important because of its destructive effect on the soil structure (Awedat et al., 2021). Plant growth can be affected by soil dispersion caused by high sodium content, which limits water movement and the soil infiltration rate (Fipps, 2003).

The potassium values were also low with all the spatial and temporal values within the acceptable limit for irrigation; indicating that the water is suitable for irrigation use. Relatively higher mean values were also recorded in station 1 and wet season as observed in bicarbonate, sulphate, magnesium, and sodium; attributable to the same factors. High potassium concentrations in irrigation water are a serious concern because of their adverse effects on the hydraulic properties of soil, which in turn negatively affect infiltration, water availability, and growth of plants (Oster et al., 2016; Yan et al., 2023). Increasing potassium can affect soil aggregate stability and a regular application of potassium should make for uptake by the crop (Hu et al., 2015; Aramrak et al., 2021). However, the addition of potassium results in a significant increase in CROSS (Emami et al., 2014).

The calcium values were also low and all the spatial and temporal values were within acceptable limits for irrigation; indicating that the water is suitable for irrigation use. Relatively higher mean values were also recorded in station 1 and wet season as observed in bicarbonate, sulphate, magnesium, sodium, and potassium; attributable to the same factors. Though the recorded calcium values were within the levels required for irrigation, calcium concentrations lower than 40 mg l^{-1} will require calcium addition in the form of fertilizer to avoid deficiency while elevated levels (>100 mg l^{-1}) may lead to deficiency in phosphorus and magnesium (PennState Extension, 2022). Furthermore, the addition of calcium will increase soil salinity because of the addition of calcium salts which will further displace Na^+ from the exchange complex into the soil solution (ANZG, 2023).

Irrigation indices integrate the most important physicochemical parameters required to determine the suitability of a water body for irrigation. The Sodium Adsorption Ratio indicates the tendency of Na ions to adsorb onto soil beyond acceptable limits (Zaidi et al., 2016). It is used to assess the likelihood of cation exchange in irrigation water to occupy the cation exchange sites in the soil (González-Acevedo et al., 2016). All the Sodium Absorption Ratio (SAR) values indicated that the river water was suitable for irrigation. However, Water with high SAR (>9) could result in serious permeability issues. Apart from reduced infiltration and water availability, it could also result in temporal oversaturation of surface soil, increased pH, soil erosion, poor nutrient availability, and a higher risk of plant diseases (Wisialowski, 2023). Anyanwu et al. (2023) recorded a lower SAR value (0.040 - 0.048) in Ikwu River, Umuahia, Nigeria, higher values - 0.18-0.69 were recorded by Er and Sevik (2023) in irrigation canals in Bingol, Türkiye and 0.30- 0.89 by Ashie et al. (2024) in Wiwi River, Kumasi, Ghana. The USSL salinity diagram classified the water as C1-S1 as reported by Er and Sevik (2023); indicating little to no risk of sodium accumulation in the soil. Therefore, the water is considered safe for the irrigation of different types of soil (Richards, 1954).

Percentage Sodium (%Na) is one of the indicators of sodium hazard; used to determine the suitability of any water for irrigation (Abualhaija et al., 2020; Al-Aizari et al., 2024). The %Na values has to be lower than 60% for water to be considered suitable for irrigation. All the Na% values recorded were less than 40% (excellent to good) as observed by Khatri et al. (2022). However, high percentage sodium increases the soil salinity, which decreases the productivity of most crops as well as affects the physicochemical properties of the soil, and ecological balance (Hailu and Mehari, 2021).

Percentage Sodium is often represented with a Wilcox diagram (Khatri et al., 2022; Er and Sevik, 2023). The diagram is an illustration of the relationship between salinity hazards (EC value) and water sodium content (%Na). The Wilcoxian diagram indicated that all the spatial and seasonal values fall under the excellent to good category. Misaghi et al. (2017) reported that the higher the value of %Na, the higher the risk of alkali damage, which could affect soil structure, reduce permeability in soil, and result in soil compaction, thereby blocking soil and atmospheric gas exchange.

Kelly's Index (KI) is based on the concept that as sodium (Na^+) levels increase, sodium tends to replace calcium (Ca^{2+}) in the soil (Ewaid, 2018). Over time, irrigation and rainfall leach away the displaced calcium, causing soil dispersion (Amer and Mohamed, 2022). Calcium is crucial for plant mineral nutrition and stimulates potassium (K^+) uptake while suppressing sodium (Na^+) absorption, even at low calcium concentrations (Dhembare, 2012). Kelly's Index (>1) is an indication of a high level of sodium in water, which will displace more calcium and result in calcium deficiency in the soil and plants (Ewaid, 2018). The water is considered suitable for irrigation because all the KI values were < 1.

Magnesium hazard (MH) or magnesium ratio (MR) values were unsuitable, except during the dry season. The implication is that the water is suitable for dry-season cropping. Irrigation water with MH values below 50% is considered suitable, while values above 50% are unsuitable (Abualhaija et al., 2020). Irrigation waters with elevated magnesium levels (>50%) will negatively affect the soil quality; changing it to alkali soil and reducing crop production (Ayers and Westcot, 1994).

Irrigation water quality can be classified based on soluble sodium percentage (SSP) (Wilcox, 1955). Exchange of clay particles Mg^{2+} and Ca^{2+} ions can be initiated by sodium ions in irrigation water (Soomro et al., 2024). Waters with values less than 50 are good for irrigation while higher values (> 50) are not safe for irrigation (Richards, 1954). All the spatial and seasonal SSP values indicated that the water quality was good and safe for irrigation purposes.

All the Cation Ratio of Soil Structural Stability (CROSS) values were within the "excellent" water class (<10); indicating good water quality for irrigation. CROSS is the irrigation water quality index that considers the effects of all four major cations on the physical properties of soil (Oster et al., 2016). High CROSS value will result in potential soil degradation (Aramrak et al., 2021; Awedat et al., 2021).

Permeability Index (PI) has been used to check soil permeability. The crop production process will be affected by the reduction in water supply to crops as a result of the low permeability of the soil (Sarkar et al., 2022). Reduction in water availability will result in problems like waterlogging of the surface soil, seedbed crusting, and the initiation of other related concerns like infections, salinity, growth of weeds, oxygen deficiency, and nutritional issues (Barik and Pattanayak, 2019). All the values were within the "class I: excellent" water class (>75) except in the wet season; indicating that the water is suitable for irrigation purposes.

All the Potential Salinity (PS) values were <3; within the "suitable" water class and the water is considered suitable for irrigation (Rawat et al., 2018). Salts play an important role in soil fertility and low-solubility salts in irrigation water will increase the level of salt in soil and are therefore considered unsafe (Hwang et al., 2017).

Water hardness is one of the criteria for assessing water suitability for intended use including agriculture (Sappa et al., 2014). All the total hardness (TH) values were within the "soft" water class (0 – 60 mg l^{-1} $CaCO_3$) based on the USGS (2018) classification. Hard water can result in soil compaction, thereby reducing soil and limiting oxygen and water availability to plant roots (Ashie et al., 2024).

Residual Sodium Bicarbonate (RSBC) is used to assess alkalinity hazard in irrigation water. The values were all within the "safe" water class (<5). Gupta and Gupta (1987) classified RSBC as < 5 (safe), 5–10 (marginal) and >10 (unsatisfactory). Water with high RSBC is associated with high sodium hazard and high pH leading to soil infertility due to sodium carbonate deposition (Ewaid, 2018).

Conclusion

Aspects of the physicochemical parameters of the Azueke stream were evaluated in relation to suitability for irrigation purposes. Spatially and seasonally, the mean values of the physicochemical parameters conformed to irrigation water standards except pH (dry season). All the irrigation indices indicated suitability except MH (all stations and wet season) and PI (wet season). Anthropogenic activities and seasons influenced the water quality of the stream and the indices. Therefore, this comprehensive evaluation demonstrates that, with few exceptions, the Azueke Stream's water can be considered a reliable source for irrigation, promoting sustainable agricultural practices in the area. However, continuous and periodic monitoring is recommended to ensure water quality remains within acceptable limits to prevent potential adverse impacts on soil and crop health. Regulated, efficient, and timely use of the water for irrigation is also recommended to prevent the discharge of used irrigation water laden with fertilizer and pesticides from discharging back into the stream. This can be achieved by building a bund wall or planting riparian vegetation around the reservoir.

Ethical Statement

Ethical approval is not required for this study because no animal or human models were used.

Conflict of Interests

The authors declare that there are no conflicts of interest.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: EDA, OGA; field studies: EDA, OGA, AGS, PNO; data analysis and validation, EDA, HE; draft manuscript preparation: EDA, HE, OGA, AGS, PNO. All authors reviewed the results and approved the final version of the manuscript.

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