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Water Quality Assessment for Irrigation Purpose in Ikot Ekpene, Akwa Ibom State

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Abstract
This study assessed Water Quality for Irrigation Purpose in Ikot Ekpene, Akwa Ibom State, Nigeria. Water samples were collected from upstream (Uwa), midstream (Nto Nsek Afaha), and downstream (Afaha Ikot Ebak) during both dry and rainy seasons. Important water quality indicators such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Permeability Index (PI), and the Magnesium to Calcium ratio (Mg/Ca) were analyzed. During the dry season, SAR was 0.10, SSP was 3.66%, PI was 69.33%, and Mg/Ca was 0.73. In the rainy season, SAR was 0.14, SSP was 4.99%, PI was 66.89%, and Mg/Ca was 1.05. These values fall within safe ranges for irrigation. However, RSC was 1.41 meq/L in the dry season and 1.47 meq/L in the rainy season, both classified as "doubtful," indicating the need for caution with long-term use. Other results showed that pH ranged from 6.80 to 7.90 (dry) and 6.70 to 7.10 (rainy), TDS ranged from 38.33 to 44.67 mg/L (dry) and 39.68 to 40.20 mg/L (rainy), while EC ranged from 26.50 to 29.50 µS/cm (dry) and 25.11 to 26.32 µS/cm (rainy). The dominant ions were bicarbonate (HCO_3^-), calcium (Ca^{2+}), and sulfate (SO_4^{2-}) with hydrogeochemical trend of $HCO_3^- > Ca^{2+} > SO_4^{2-} > Mg^{2+} > Cl^- > K^+ > Na^+$ (dry season), and $HCO_3^- > SO_4^{2-} > Ca^{2+} > Mg^{2+} > Cl^- > K^+ > Na^+$ (rainy season). Based on the forgoing, surface water from the Qua Iboe River in Ikot Ekpene, Akwa Ibom State can be used for irrigation to drive the agricultural productivity in the area. However, routine monitoring of both irrigation water quality and soil chemical properties is essential to prevent cumulative degradation and to ensure long-term agricultural sustainability. This study provides information into localized water quality, offering practical guidance for policymakers/farmers in smaller agrarian communities, contributing to the broader goal of food security. Future research should assess the long-term effects of using Qua Iboe River water with doubtful RSC on soil health and crop yield, and explore low-cost mitigation strategies.

Keywords: Irrigation, Surface water, Water quality, Season, hydrogeochemical, River testing

1. Introduction

Water is fundamental to human survival, public health, and sustainable development. In agriculture, particularly in regions with seasonal rainfall patterns, water availability and quality are critical for crop productivity. Irrigation, the artificial application of water to soil, has emerged as a reliable solution for improving agricultural output during dry periods or in areas facing water scarcity. According to Tiri et al. (2018), irrigated lands, although comprising only 20 percent of global farmland, contribute up to 40 percent of total food production, underscoring their strategic importance in addressing food security. In many developing regions, surface water remains the principal source for irrigation. However, rapid population growth, urban expansion, and the intensifying effects of climate change have exerted significant pressure on available water resources. These challenges often lead to water quality deterioration, especially in rural areas where agricultural activities coexist with unregulated anthropogenic inputs such as fertilizer use, bush burning, and improper waste disposal (Kerr et al., 2022; Wederni et al., 2024). In such settings, the quality of irrigation water directly influences soil structure, nutrient dynamics, crop health, and overall agricultural sustainability (Ibe, 2023; Gad, 2023). The evaluation of irrigation water quality is essential because water with poor physicochemical properties can lead to salinization, soil alkalinity, reduced permeability, and long-term decline in crop yield. Several parameters are used to assess irrigation water quality, including pH, electrical conductivity (EC), total dissolved solids (TDS), and specific ion concentrations such as sodium, magnesium, calcium, chloride, sulphate, nitrate, and bicarbonate (Barua et al., 2021; Samtio, 2023). Additionally, indices such as Sodium Adsorption Ratio (SAR), Sodium percentage, Kelly's Index, Residual Sodium Carbonate (RSC), Permeability Index, and Magnesium Absorption Ratio (MAR) are widely applied in the evaluation of irrigation suitability (Yang et al., 2019; Asadi et al., 2019; Tadesse and Dinka, 2024). The Water Quality Index (WQI) approach, commonly used to simplify water quality assessment, aggregates multiple variables into a single value that reflects the overall suitability of water for specific uses, including irrigation (Godwin et al., 2019; Mezlini et al., 2024). While this method has proven effective in various settings, its application remains limited in localized studies across small agricultural communities in Nigeria.

Numerous studies have been conducted to assess the suitability of water resources for irrigation. These studies have highlighted the importance of considering various physical, chemical, and biological parameters to determine the water quality (Liday and Agapito, 2022). For instance, comprehensive evaluations often involve analyzing hydrochemical parameters and qualitative indices to ascertain the water's suitability for agricultural application (Hussein et al., 2024). For example, research conducted in Akwa Ibom State, Nigeria involved assessing the physicochemical characteristics and heavy metals in surface water from Idim Idaang stream in Ibiono Ibom, revealing the impact of anthropogenic activities on water quality (Anweting et al., 2024). Similarly, an assessment of the upper segment of Qua Iboe River water, Niger Delta, Nigeria utilized a water quality index tool, classifying it to determine influence of surface runoff and human activities on its physicochemical properties, with most parameters meeting the standard limits except for total dissolved oxygen, nitrate and biochemical oxygen demand (in wet season), and turbidity, phosphates and total suspended solids (in both seasons) exceeded the standard limits (Jonah et al., 2025). Another study focusing on Uyo Municipality investigated the impacts of waste dump on surface water quality, identifying a significant variability in the physico-chemical parameters at different segment of the Ikpa River catchment, with some of the physico-chemical properties such as colour, phosphate, calcium, and magnesium all exceeding the WHO limits (Abraham et al., 2024).

In the Nigerian context, most irrigation water quality assessments have focused on larger agricultural zones such as the Middle Belt, Northern Nigeria, and parts of the Southwest (Adegbola et al., 2019; Adegbola et al., 2021; Gulyi et al., 2023). Further research in Akwa Ibom State, where Ikot Ekpene is located, has also examined the irrigation water quality of Abak River, revealing the surface water was adequate for irrigation use based on the ten investigated irrigation water quality indicators (Udom et al., 2019). Similarly, a study by the authors in South Southern Nigeria examined the suitability of surface water quality obtained from Ikpoba River for agricultural irrigation, and findings revealed that key irrigation water indices such as sodium adsorption ratio, permeability index, Kelly's ratio, sodium percentage, and potential salinity were all within the safe limits for irrigation use (Rawlings and Dauda, 2025). These studies emphasize the need for a comprehensive analysis of water quality parameters to ensure the long-term sustainability of irrigation systems. However, there is a paucity of data from smaller, yet agriculturally active regions such as Ikot Ekpene in Akwa Ibom State, taking into consideration the suitability of surface water sources in Ikot Ekpene for irrigational use. This region is largely rural, with a population that depends heavily on surface water sources such as rivers and streams for domestic and agricultural purposes. The Qua Iboe River, which traverses the Ikot Ekpene stretch, serves as one of the primary water sources for local irrigation. However, the increasing presence of pollutants from domestic, agricultural, and minor industrial activities raises concerns about the suitability of this water for irrigation use.

This study seeks to address the existing knowledge gap by assessing the irrigation water quality of the Qua Iboe River within the Ikot Ekpene stretch. The objective is to determine the suitability of the river water for irrigation based on a comprehensive analysis of key physicochemical parameters. Specifically, the study will analyze pH, electrical conductivity, total dissolved solids, and major ions including sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), and nitrate (NO_3^-). Furthermore, the study will apply established irrigation water quality indices such as SAR, Sodium percentage, Kelly's Index, RSC, Permeability Index, and MAR to evaluate the data. This research will explore the description of the study area, water sample collection and analysis for the various irrigation water quality parameters, statistical analysis of the irrigation indicators, and the suitability analysis based on irrigation water quality indicators. Through the evaluation of current status of surface water used for irrigation in Ikot Ekpene, this research aims to inform local water resource management practices and contribute to efforts toward sustainable agriculture in the region.

2.0 Materials and methods

2.1 Description of the Study Area

The present study was carried out in Ikot Ekpene Local Government Area of Akwa Ibom State, Southern Nigeria. Ikot Ekpene is located on Latitude 5° 11’N and Longitude 7° 43’E. Qua Iboe River which is one of the major rivers has tributaries streams that flows through Akwa Ibom State, with a stretch passing through Ikot Ekpene. This river passes through residential and agricultural areas in a densely populated agrarian community. Human activities include farming, oil palm production, fishing, sand dredging, and construction. Its gradient makes it vulnerable to contamination from runoff, workshops, markets, and waste sites. The Qua Iboe River provides water for domestic, industrial, and agricultural use.

2.2 Collection of Water Samples

Water samples used for the study were collected at Uwa 5°.9’ 15”N, 7°.39’ 17”E (Upstream), Nto Nsek Afaha 5°.8’ 4”N, 7°.39’ 27”E (Midstream), and Afaha Ikot Ebak 5°.6’ 30”N, 7°.38’ 36”E (Downstream) of Ikot Ekpene stretch of the Qua Iboe River (see Figure 1). Water samples (a sample at each location) were collected at 7:15 AM in the months of January 2024 (representing dry season) from all three locations, and July 2024 (representing rainy season) from all three locations. Before sampling, one-liter polyethylene bottles were washed and sundried. On each sampling day, bottles were rinsed with the respective water before collection, labeled, and transported in ice-packed coolers for analysis. The selected sampling points, Upstream (Uwa), Midstream (Nto Nsek Afaha), and Downstream (Afaha Ikot Ebak) were chosen to provide a representative spatial coverage of the Ikot Ekpene stretch of the Qua Iboe River. The upstream location was selected to capture baseline water quality before significant anthropogenic influence from settlements and agricultural activities. The midstream point lies within a section of the river that receives direct inputs from domestic discharges, small-scale industries, and runoff from farmlands, making it ideal for assessing the impact of human activities. The downstream site was chosen to evaluate the cumulative effect of upstream and midstream inputs before the river exits the study stretch. This three-point spatial arrangement enables the comparison of water quality variations along the river’s flow path during both dry and rainy seasons, thereby improving the reliability of the findings.

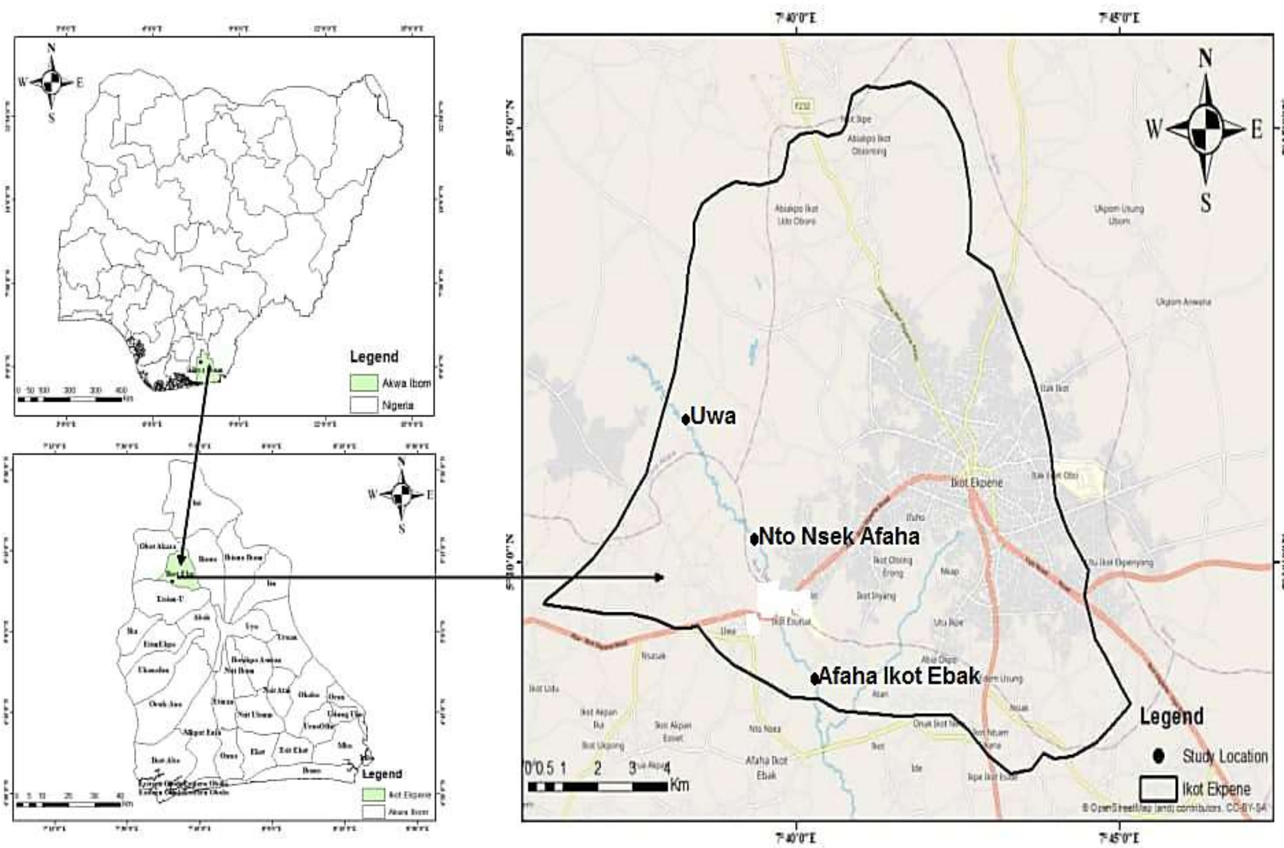

Figure 1: Map showing Study Location and Sampling Points

2.3 Water Samples Examination

The study considered Water Quality Indicators (WQI) such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and key ions (Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, HCO^{3-}, Cl^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}). Analyses followed the standard methods stipulated in Asadi et al., (2019). pH, EC, and TDS were measured in the field using a portable meter (H19810-6). Irrigation Water Quality Indicators (IWQI), including SAR, RSC, SSP, PI, and KR, were calculated using standard equations with all the ions concentration in meq/L.

2.3.1 Sodium adsorption ratio (SAR)

The SAR which expresses the processes of ion interactions on soil quality and its sodium uptake was evaluated using Eq. (1) as provided in Ishola, 2024.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

2.3.2 Residual sodium carbonate (RSC)

This was determined for each sample using Eq. (2) as given in Ishola, 2024.

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

2.3.3 Soluble sodium percentage (SSP)

The SSP was evaluated using Eq. (3) as stipulated in Omeka, 2024.

$$SSP = \frac{Na^{+}\ x\ 100}{Ca^{2+} + Mg^{2+} + Na^{+}} \quad (3)$$

2.3.4 Permeability Index (PI)

The PI was evaluated using Eq. (4), following Ashie et al., 2024.

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} x100 \quad (4)$$

2.3.5 Kelly's ratio (KR)

The KR of each of the sample was calculated using Eq. (5) according to Ugbor et al., 2024.

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (5)$$

2.4 Statistical Analysis

Laboratory results and computed irrigation indicators were analyzed using descriptive statistics (mean, min, max, and standard deviation). The Coefficient of Variation (Cv) separated the means. Statistical analyses were done in Excel (v.16) at a 5% significance level, and results were compared with existing standards (Agidi et al., 2024).

3.0 Result and discussion

3.1 Statistical Summary of Qua Iboe River Water Parameters in Ikot Ekpene Stretch

The results of the basic descriptive statistics of the studied water quality indicators are given for the dry season and rainy season as in Table 1 and Table 2, respectively. From the results, TDS concentrations were consistently low across all locations in both seasons, remaining far below the maximum permissible limit of 2000 mg/L (Kudamnya et al., 2025) and well within the < 450 mg/L guideline for unrestricted irrigation use (Agidi et al., 2024). Mean values were slightly higher in the dry season, reflecting mineral concentration from reduced river flow, while rainy-season values were more stable due to dilution by fresh inflow. This seasonal trend aligns with the findings of Adegbola (2021) and Anyanwu and Emeka (2020) for similar river systems. The higher coefficient of variation during the dry season further supports the influence of fluctuating water volume on mineral content. However, variations in TDS levels as observed in the samples can be linked to shifts in water volume caused by rainfall; during the dry season, with less water available, the concentration of dissolved minerals increases as water evaporates, leading to higher TDS levels, while the rainy season dilutes these minerals with fresh rainwater, resulting in lower TDS levels.

pH values in both seasons fell within the recommended range of 6.0–8.5 for irrigation water, indicating a slightly basic nature of the river. Seasonal differences were marginal, suggesting that factors such as buffering capacity and mineral composition maintain a relatively stable pH throughout the year, thus, the water is fit for application, with mean pH values falling within the preferred range. The range of pH values recorded in this study agrees with the findings of Ibuot et al., (2022) who reported a pH range of 6.7 – 8.5 in borehole water samples in Ikot Ekpene, and disagrees with the findings of Anweting et al., (2024) who reported a pH value of 5.66 in Idaang stream in Ibiono, Akwa Ibom State. Lower values of pH have also been reported by Ekwere et al., (2025) for groundwater samples obtained in Onna, Akwa Ibom State. These variations could be linked to differences in the degree and nature of anthropogenic influence, geological settings, and buffering capacity of the respective water sources.

Table 1: Dry season Statistical data on analyzed sample characteristics

Variables	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation	Irrigation Standards
TDS (mg/L)	38.33	44.67	42.04	3.31	7.86%	2000
pH	6.80	7.90	7.47	0.59	7.85%	6.0-8.5
EC (µs/cm)	26.50	29.50	28.35	1.62	5.71%	3000
Ca^{2+} (mg/L)	35.20	37.20	36.17	1.00	2.77%	400
Mg^{2+} (mg/L)	15.60	16.60	16.03	0.51	3.20%	61
Na^{+} (mg/L)	2.10	3.50	2.73	0.71	25.96%	400
K^{+} (mg/L)	4.20	5.90	4.97	0.86	17.36%	2
PO_4 (mg/L)	0.36	0.96	0.67	0.30	44.85%	2
NO_3 (mg/L)	0.08	1.10	0.58	0.51	87.98%	10
HCO_3 (mg/L)	263.00	295.00	276.33	16.65	6.03%	620
SO_4^{2-} (mg/L)	29.70	35.90	32.60	3.12	9.57%	960
Cl^{-} (mg/L)	8.70	11.80	9.90	1.66	16.81%	1065

Electrical conductivity (EC) remained well below the 3000 µS/cm limit for irrigation water in all samples, with slightly higher dry season values. However, the observed variation in the mean values with the dry season showing the highest EC concentration, may be as a result of an increase in the dissolved salts in the studied river, resulting from either natural (increase in the rate of dissolution of minerals) or man-made (agricultural and domestic) processes (John and Das, 2020; Yan et al., 2024). The results of this present study in terms of EC values, gives credence to the findings of Akpan et al. (2024) who reported similar trend, and disagrees with the reports of Adegbola et al. (2021) who observed higher values of EC in their respective river water samples. These discrepancies may be attributed to both geogenic and anthropogenic influences (Akankali et al., 2017).

For major cations, Ca^{2+} levels were higher in the dry season, likely reflecting evaporation effects and rock mineralization, while Mg^{2+} showed the reverse trend, with elevated values in the rainy season possibly from enhanced weathering and runoff inputs. In all cases, concentrations were far below the irrigation water thresholds of 400 mg/L for Ca^{2+} and 61 mg/L for Mg^{2+}, confirming suitability for agricultural use. The result from this study gives credence to the submission of Ukwani et al., (2024) who observed lower concentrations of Ca^{2+} and Mg^{2+} in twelve different borehole samples in Uyo, Itu, Ibesikpo, and Ibiono Ibom local government areas of Akwa Ibom State.

Another important indicator used in the evaluation of irrigation water quality which was considered in this study was Sodium (Na^{+}). Sodium (Na^{+}) levels were low in both seasons and far below the 400 mg/L threshold for irrigation water, indicating negligible sodium hazard. A slight increase in the rainy season suggests inputs from agricultural runoff, possibly linked to sodium-rich fertilizers, yet the concentrations remain within safe limits. The reason behind the slight increase in Na^+ concentration in the rainy season would have been possible through changes in water availability and runoff from farmlands where sodium rich fertilizers have been used for improved agricultural productivity, resulting in higher concentrations. The results however revealed that the mean and range values in both dry and rainy season were far lower compared to the maximum permissible limits of 400mg/L, thereby implying no restrictions for irrigation purpose. The low concentration of Na^+ recorded in this study means good for agricultural productivity due to its characteristic low sodium hazards, since irrigation water with high Na^+ content has the potential to cause soil clay minerals to lose its exchangeable cations (such as Ca^{2+} and Mg^{2+}), whose spaces may be taken up by Na^+, resulting in reduced soil fertility (Al saleh and Nehaba, 2024). Similar low range and mean values of Na^+ have been reported by Adegbola et al. (2021) in Ikose River, and Anyanwu and Emeka (2020) in Ossah River, all in Nigeria.

Table 2: Rainy season Statistical data on analyzed sample characteristics

Variables	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation	Irrigation Standards
TDS (mg/L)	39.68	40.20	39.95	0.26	0.65%	2000
pH	6.70	7.10	6.90	0.20	2.90%	6.0-8.5
EC (μs/cm)	25.11	26.32	25.77	0.61	2.37%	3000
Ca^{2+} (mg/L)	31.80	34.60	32.93	1.47	4.48%	400
Mg^{2+} (mg/L)	19.65	22.60	21.16	1.48	6.98%	61
Na^+ (mg/L)	3.20	4.94	4.08	0.87	21.33%	400
K^+ (mg/L)	4.80	6.80	5.60	1.06	18.90%	2
PO_4 (mg/L)	0.51	0.86	0.66	0.18	27.68%	2
NO_3 (mg/L)	0.11	0.72	0.44	0.31	70.01%	10
HCO_3 (mg/L)	288.00	305.00	296.00	8.54	2.89%	620
SO_4^{2-} (mg/L)	36.30	40.60	38.30	2.17	5.65%	960
Cl^- (mg/L)	12.30	15.20	13.53	1.50	11.07%	1065

Potassium (K^+) concentrations in both seasons exceeded the desirable limit of 2 mg/L, with slightly higher values during the rainy season. Similarly, high values of potassium have been reported by Morphy et al., (2024) for groundwater samples within Uyo and Itu, and George and Thomas (2023) for groundwater samples obtained in Ikot Abasi, all in Akwa Ibom State. These high values of potassium ion found in the studied water samples could have been as a result of leachates from agricultural lands in the study location where fertilizers were applied to improve soil nutrients as reported by Falowo et al. (2017). According to Elemile et al. (2022), one-third to half of these inorganic fertilizers are used up by the crops for their nourishments, while the remaining half or two-third resides in the soil and may eventually join nearby water bodies. Elevated potassium concentrations (>2 mg/L) in irrigation water warrant careful consideration due to their potential agronomic and soil management implications. While potassium is an essential macronutrient for plant growth, excessive levels in irrigation water can disrupt soil–plant nutrient balance by competing with calcium and magnesium for uptake sites, leading to deficiencies of these cations in sensitive crops (Abugu et al., 2024). In fine-textured or poorly drained soils, sustained application of potassium-rich water may lead to cation imbalance, increased soil salinity, and altered soil structure through displacement of divalent cations from exchange sites (FAO, 2020). Such imbalances can impair osmotic regulation in plants, reduce yield quality, and in extreme cases, contribute to soil sodicity where sodium levels are also elevated. Consequently, irrigation water with potassium above the typical guideline of 2 mg/L should be managed within an integrated irrigation and nutrient monitoring program to avoid negative agronomic and soil structural effects.

Phosphate (PO_4^{3-}) concentration in the sampled water were low in both seasons, remaining well below the 2.0 mg/L permissible limit. This result is in line with the findings of Jonah and Archibong (2022) who recorded similar values when assessing the water quality of North-West District of Akwa Ibom State. However, the low concentration of phosphate observed in the study is not a deviation from the normal since phosphorus is less prominent in surface water, due to its tightly bound nature to the soil and aquifer sediments (Anonna et al., 2022).

Table 3. Guidelines for interpretations of water quality for irrigation

Potential Irrigation Problem	**Degree of Restrictions**		
	Use	**Slight to moderate**	**Severe**
Salinity (affects crop water availability)			
Ecw (µs/cm)	< 700	700 - 3000	> 3000
TDS (mg/L)	< 450	450 - 2000	> 2000
Permeability (affects infiltration rate into soil)			
SAR = 0 - 3 and Ecw =	> 700	700 - 200	> 200
SAR = 3 - 6 and Ecw =	> 1200	1200 - 300	< 300
SAR = 6 - 12 and Ecw =	> 1900	1900 - 500	< 500
SAR 12 - 20 and Ecw =	> 2900	2900 - 1300	< 1300
SAR 20 - 40 and Ecw =	> 5000	5000 - 2900	< 2900
Specific ion Toxicity (affects sensitive crops) (Surface Irrigation)			
Sodium (Na) as in SAR	< 3	3 - 9	> 9
Chloride (Cl^-) (meq/L)	< 4	4 - 10	> 10
Miscellaneous Effects			
Nitrogen ($NO3^-$) (mg/L)	< 5	5 - 30	> 30
Bicarbonate (HCO_3) (meq/L)	< 1.5	1.5 - 8.5	> 8.5
pH	**Normal range 6.5 - 8.4**		

The mean and maximum Nitrate (NO_3^-) concentration in the studied water Nitrate (NO_3^-) levels were also well within safe irrigation limits of 10 mg/L, with slightly lower mean values in the rainy season. The low values of nitrate concentration resulting from the study could be as a result of the use of lower nitrogen rich fertilizers in the area (Adegbola et al., 2021). Similar trend has been previously reported outside the study area, with the obtained concentrations well within the range recorded in the present study (Mbinkong et al., 2024; Folarin et al., 2023).

Bicarbonate (HCO_3^-), which regulates sodium hazards, was the dominant carbonate species across seasons, with concentrations below the 620 mg/L threshold. The concentration of bicarbonates in the present study is in consonance with the study of Morphy et al., (2024) who reported low values in all ten water samples analysed in Uyo and Itu, in Akwa Ibom State. The near-neutral pH indicates the absence of carbonate, making bicarbonate the dominant ion, consistent with Hoque et al. (2024), who noted carbonate dominance in waters with pH above 9.

Sulphates (SO_4^{2-}) which are present in surface water by default could greatly be affected by atmospheric precipitation and industrial effluents, with the ability to increase its concentration levels. In this study, the concentrations of Sulphates (SO_4^{2-}) were moderate in both seasons, remaining well under the permissible 960 mg/L limit. Similar results have been reported by Rawlings and Dauda (2025) for three different water samples studied in Benin city, Nigeria. The result also agrees with the postulations of Morphy et al., (2024) in a similar study carried out in Akwa Ibom State using groundwater samples. Slightly higher rainy-season values may be linked to increased atmospheric deposition and surface runoff, although levels indicate no restriction for irrigation use of the water sample regarding the sulphate parameter.

The concentration of Chloride (Cl^-) were low overall but showed an increase during the rainy season. This variation in concentration level could be attributed to surface runoff increase following heavy rainfall, with the potential to carry chloride-rich substances such as fertilizers, road salts, or wastewater from urban, agricultural, or industrial areas into the river, leading to a spike in chloride levels. Similar report of low chloride concentration has been made by Ubong et al., (2021) who assessed the water quality index of borehole water in Mkpat Enin local government area, Akwa Ibom State**,** and Nde (2021) who investigated the physicochemical parameters and some heavy metals levels of surface and groundwater of Ibiaku Osuk Community, Akwa Ibom State.

3.2 Suitability Analysis based on Irrigation Water Quality Indicators (IWQI)

3.2.1 Sodium Adsorption Ratio (SAR)

The concentrations of sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) in water are evaluated using the Sodium Adsorption Ratio (SAR). SAR is useful because it accounts for how calcium and magnesium ions interact with sodium in water and soil. Veena and Satheeshkumar (2018) highlighted the importance of SAR in irrigation studies, as it helps understand how cation exchange reactions occur in soil. When SAR values exceed 12–15, it can lead to serious problems in the soil's physical structure, as noted by Onwe et al. (2023). High SAR levels make it harder for plants to absorb water, which can negatively affect crop growth. Adegbayo et al. (2021) also pointed out that elevated SAR levels can cause soil to become compact and less permeable, further hindering water movement and plant development. According to Unigwe et al. (2022), water with SAR below 10 meq/L is considered excellent for irrigation, 10 –18 meq/L is good, 18 –26 meq/L is fair, and above 26 meq/L is unsuitable (see Table 5). In this study, all water samples from both the dry and rainy seasons (Table 4) had SAR values below 10 meq/L, making them excellent for irrigation.

Table 4: Irrigation Water Quality Assessment in Dry and Rainy season

Indicator Variables	Assessment Level (meq/L)	
	Dry Season	Rainy Season
Sodium Adsorption Ratio (SAR)	0.10	0.14
Residual Sodium Carbonate (RSC)	1.41	1.47
Sodium Soluble Percentage (SSP)	3.66	4.99
Permeability Index (PI)	69.33	66.89
Kelly's Ratio (KR)	0.04	0.05
Magnesium Calcium ratio (Mg/Ca)	0.73	1.05

Table 5: Summary of guidelines for interpretation of Irrigation Water Quality Indicators (Unigwe et al., 2022).

SAR	Class	Mg/Ca	Class
<10	Excellent	<1.5	Excellent
10 – 18	Good	1.5 – 3	Excellent
18 – 26	Fair	>3	Unsuitable
>26	Unsuitable		
KR	**Class**	**SSP**	**Class**
< 1	Good	< 50	Safe
>1	Unsuitable	> 50	Unsuitable
RSC	**Class**	**PI**	**Class**
< 1.25	Suitable	< 25	Unsuitable
1.25 -2.50	Doubtful	25- 75	Good
>2.50	Unsuitable	> 75	Excellent

3.2.2 Kelly's Ratio (KR)

Kelly's Ratio determines the potential for water to cause alkali-related issues in soil. According to Singh et al. (2020), water is considered good for irrigation if Kelly's Ratio is 1 or less. However, if the ratio exceeds 1, it indicates the presence of alkali hazards, making the water unsuitable for agricultural use. The result in Table 4 shows that KR values for dry and rainy seasons were consistently below 1, meaning the water is free from alkali hazards and safe for agricultural use.

3.2.3 Residual Sodium Carbonate (RSC)

RSC measures the balance between carbonates and bicarbonates in water, which can affect soil quality. Water with RSC below 1.25 meq/L is safe for irrigation, values between 1.25 and 2.5 meq/L are doubtful, and above 2.5 meq/L is unsuitable (see Table 5). In the present study, the water samples had RSC values of 1.41 meq/L in the dry season and 1.47 meq/L in the rainy season (see Table 4) falling under the doubtful category. This level of RSC implies a gradual tendency for bicarbonate and carbonate ions to precipitate calcium and magnesium as insoluble carbonates, reducing the concentration of these divalent cations in the soil solution. Over time, this process can lead to sodium enrichment on the soil exchange complex, which in turn increases sodicity hazard, reduces soil aggregate stability, and impairs infiltration and aeration. These changes can progressively degrade soil physical quality, especially in fine-textured soils, ultimately impacting crop productivity. To mitigate such risks, management strategies may include blending with low-RSC water sources, applying gypsum ($CaSO_4 \cdot 2H_2O$) or other soluble calcium amendments to replenish exchangeable calcium, adopting leaching practices to remove excess sodium carbonates, and selecting crops with higher tolerance to sodicity. Routine monitoring of both irrigation water quality and soil chemical properties is also essential to prevent cumulative degradation and to ensure long-term agricultural sustainability in the area.

3.2.4 Soluble Sodium Percentage (SSP)

SSP indicates the amount of sodium in water relative to other dissolved salts. The standards show that water is suitable for irrigation if the Soluble Sodium Percentage (SSP) is less than 50 (Unigwe et al., 2022). However, if the SSP value is greater than 50, the water is considered unsuitable for irrigation. The values of SSP from this study (see Table 4) were 3.66meq/L and 4.99meq/L for dry and rainy season, respectively. These were below the desirable threshold; hence, the studied water samples are suitable for crop production (Table 5).

3.2.5 Permeability Index (PI)

The Permeability Index (PI) is a key factor in assessing irrigation water quality because it influences soil permeability. Soil permeability affects how water moves through the soil and how well plants can absorb nutrients. Adebayo et al. (2021) emphasized that PI plays a critical role in determining the long-term suitability of water for irrigation purposes. PI is classified under Class I (> 75% permeability) as excellent, Class II (25–75% permeability) as good, and Class III (< 25% permeability) as unsuitable. The result of the analysis in Table 4 reveal that the value of PI in this study was 69.33meq/L during the dry season and 66.89meq/L during the rainy season, thus classifying the sample water as good quality and suitable for irrigation (see Tables 4 and 5).

3.2.6 Magnesium to Calcium Ratio (Mg/Ca)

The Mg/Ca ratio is another indicator of irrigation water quality. A ratio below 1.5 is excellent, while values between 1.5 and 3 are good. Ratios above 3 may indicate magnesium-related issues (Unigwe et al., 2022). In this study (Table 4), all the water samples had Mg/Ca ratios below 1.5 during the dry and reason season, showing excellent quality and no magnesium-related hazards.

From the foregoing discussions, the concurrent presence of multiple marginal water quality indicators can exert a compounded influence on soil health and crop performance that exceeds the impact of each parameter in isolation. In the present case, the combination "doubtful" RSC levels and elevated potassium in irrigation water can accelerate calcium and magnesium depletion, leading to soil structural decline, nutrient imbalance, and increased sodicity risk. To mitigate these effects, simple measures such as blending with better-quality water, applying calcium-based amendments, and monitoring soil chemistry should be adopted.

4.0 Conclusion

This study evaluated the irrigation water quality of the Qua Iboe River in Ikot Ekpene, Akwa Ibom State, using key irrigation water quality indicators such as SAR, RSC, SSP, PI, and Mg/Ca ratio. Surface water samples were collected from three different locations within the study area and analyzed using standard methods and procedures.

Independent analysis was carried out during dry and rainy season. Results revealed that the water is classified as excellent or good quality, confirming its suitability for irrigation purposes, with SAR, SSP, PI, and Mg/Ca values falling within acceptable limits for both dry and rainy seasons. However, RSC values in both seasons were within the "doubtful" category, necessitating caution when using this water over extended periods to avoid potential soil quality issues. Water quality parameters such as pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) consistently fell within acceptable ranges for irrigation across both dry and rainy seasons giving further credence to the suitability of the water samples for irrigation. However, dominant ionic species of Ca^{2+}, HCO_3^- and SO_4^{2-} with hydrogeochemical trend of $HCO_3^- > Ca^{2+} > SO_4^{2-} > Mg^{2+} > Cl^- > K^+ > Na^+$ were obtained during the dry season, while a hydrogeochemical trend of $HCO_3^- > SO_4^{2-} > Ca^{2+} > Mg^{2+} > Cl^- > K^+ > Na^+$ were obtained during the rainy season. Surface water from the Qua Iboe River in Ikot Ekpene, Akwa Ibom State can be used for irrigation to drive the agricultural productivity in the area. However, routine monitoring of both irrigation water quality and soil chemical properties is also essential to prevent cumulative degradation and to ensure long-term agricultural sustainability in the area. These findings can inform local farmers and policymakers on best practices for water use and irrigation planning. Additionally, this study provides a detailed assessment of water quality in a smaller agrarian community, emphasizing the importance of localized studies for effective agricultural and environmental management, contributing to ongoing food security efforts in Nigeria and other regions with similar hydrogeological and socio-economic contexts. Future research should investigate the long-term effects of utilizing Qua Iboe River water with questionable RSC values on soil physicochemical properties, crop yield, and nutrient balance. Additionally, it should explore cost-effective mitigation strategies, including blending, calcium amendment, and crop rotation with sodicity-tolerant species.

5.0 Recommendation

Based on the findings of this study, the following recommendations were drawn:

1. Qua Iboe River water is suitable for irrigation and can support agricultural productivity in the area.
2. Regular monitoring of water quality and soil conditions is necessary to prevent long-term degradation.
3. Farmers should reduce excessive K-fertilizers and prioritize calcium and magnesium inputs.
4. Grow sodicity-tolerant crops (e.g., maize, cassava, okra) and apply stricter management for sensitive crops like tomato and lettuce.
5. Further studies should assess long-term impacts of the water's RSC on soil and crops, and develop cost-effective mitigation strategies.

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