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IRRIGATION WATER QUALITY AND ITS IMPLICATIONS FOR RICE PRODUCTION IN KANO RIVER IRRIGATION SCHEME, NIGERIA

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Abstract

Irrigation water quality is critical for the sustainability of rice production systems, particularly in semi-arid environments. This study assessed irrigation water from the Kano River Irrigation Scheme (KRIS) in Nigeria during the 2020 and 2021 rice seasons. Water samples from farmers' fields across Kura, Garun Malam, and Bunkure LGAs were analyzed for Hydrogen ion concentration (pH), Electric Conductivity (EC), Total Dissolved Salts (TDS), Sodium (Na$^+$), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K$^+$). Resulting indices such as sodium adsorption ratio (SAR), Exchangeable Sodium Percentage (ESP), Residual Sodium Carbonate (RSC), Kelly's Ratio (KR), Magnesium Hazard (MH), and Permeability Index (PI) were measured. Results showed low Salinity Hazard (EC = 0.24 dS m^{-1}) and safe SAR values (mean = 1.79), but ESP values (mean = 31%, max = 60%) exceeded safe limits, suggesting potential sodicity risks. Additionally, RSC, KR, MH, and PI mostly indicated water suitable for irrigation, though localized risks exist. Correlation analysis revealed that rice grain yield decreases slightly with increasing SAR and more strongly with rising ESP, explaining that while SAR reflects low-salinity tolerance under flooded conditions, the ESP (soil sodicity) more directly limits yield. The study concludes that while KRIS water is generally suitable for rice cultivation, integrated management strategies are necessary to safeguard soil quality and maintain productivity.

Keywords: water quality index, SAR, ESP, irrigation, rice yield, Kano River Irrigation Scheme

Introduction

Rice (*Oryza sativa* L.) is one of Nigeria's most important staple crops, contributing significantly to both food security and rural livelihoods. The demand and production of rice have expanded in recent years, driven by government programs aimed at reducing import dependence and increasing rural incomes (Zakari et al., 2022). The Kano River Irrigation Scheme (KRIS) is one of the largest public irrigation projects in northern Nigeria, originally designed to serve approximately 22,000 hectares of farmland (Sangari, 2007). Irrigation in KRIS plays a central role in bridging production gaps caused by erratic rainfall, enabling multiple cropping, and increasing yield above typical rainfed levels.

However, while irrigation infrastructure can increase production, the quality of irrigation water introduces risks that may undermine soil health and long-term productivity. Key risks include salinity, sodicity, and nutrient imbalance (Mohanavelu et al., 2021). These hazards tend to accumulate gradually, affecting soil structure, rooting depth, and ultimately yield stability (Stavi et al., 2021; Tang et al., 2024). While farmers at KRIS focus primarily on fertilizer use and extension efforts on fertilizer rate, timing, and source, comprehensive assessments of water quality remain rare locally. Some studies indicate concerns consistent with this. Hussaini et al. (2023) analyzed industrial wastewater effluents in the Bompai industrial area of Kano State and found that parameters, including Electric Conductivity, Total Dissolved Salts, and Magnesium, were above acceptable limits for irrigation in some

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samples, suggesting a risk of soil degradation under continued use. A study by Onoyima, Okpanachi & Akoji (2025) on groundwater from the Mariri aquifer, Kano, evaluated irrigation water quality using Electric Conductivity, Sodium Adsorption Ratio, Permeability Index (PI), Magnesium Adsorption Ratio (MAR), and Residual Sodium Bicarbonate (RSBC), found that groundwater had low to medium salinity and excellent permeability, though with some moderate restrictions. Furthermore, study monitoring water table fluctuations in KRIS noted that shallow groundwater rising to about 0.7 m below ground increases the possibility of salt accumulation near the root zone, especially in areas with poor drainage.

Most existing work around Kano focuses on EC, SAR, TDS, pH and occasionally heavy metal contamination, but seldom includes indices such as Residual Sodium Carbonate (RSC), Kelly's Ratio (KR), Magnesium Hazard (MH), or Permeability Index (PI); all of which provide additional, vital insight into soil structural risk and long-term irrigation suitability. This study, therefore, aims to:
1. Assess irrigation water quality across KRIS using multiple indices.
2. Relate water quality status to rice production outcomes.

Materials and Methods
Study area
KRIS is located south of Kano City (11°35′–12°50′N ′ N, 8°20′–9°40′E). Irrigation water is supplied from the Tiga Dam through a network of canals. The climate is semi-arid with a mean annual rainfall of 800–1000 mm and a mean temperature of 24–35 °C.

Sampling and Experimental Design
Water samples were collected during the 2020 and 2021 rice-growing seasons from inlet canals of 34 farmers' fields in Kura, Garun Malam, and Bunkure LGAs. Fields represented different fertilizer management practices but shared common water sources. Rice panicle length was measured from a random selection of plot yield collected from each experimental plot of 2 by 2 m^2 quadrat. Productive tillers were counted from the quadrat field of each experimental plot, four stands (4) were collected at random. Grain and stalk yields at maturity were measured using a measuring scale.

Laboratory Analysis
The following parameters: The collected irrigation water samples were analyzed for selected physicochemical parameters, including Hydrogen ion (pH), Electrical Conductivity (EC), Total Dissolved Salt (TDS), and major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}). The hydrogen ion concentration (pH) of the samples was measured using a calibrated glass electrode pH meter according to APHA Method 4500-H^+ B. The meter was standardized with buffer solutions of pH 4.0, 7.0, and 9.0 before measurement, and readings were taken after stabilization. Electrical conductivity (EC) was determined with an electrical conductivity meter following APHA Method 2510 B. The instrument was calibrated using a 0.01 M KCl standard solution (1413 µS/cm at 25°C), and readings were temperature compensated to 25°C in dS m^{-1}. Total Dissolved Salt (TDS) was determined gravimetrically in accordance with APHA Method 2540 C. A 100 mL aliquot of filtered water was evaporated to dryness in a reweighed dish at 103–105°C, cooled in a desiccator, and reweighed to constant mass the difference in weight represented total dissolved solids in mg/L^{-1}. The cation concentrations of sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) were determined using a flame photometer following the Bowling (or Bowley) method, as described in APHA Methods 3500-Na B, 3500-K B, and related adaptations for Ca and Mg. Standard stock solutions (1000 mg/L) of Na, K, Ca, and Mg were prepared using analytical-grade reagents and serially diluted to obtain working standards. Calibration curves were established for each cation by

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aspirating the standard solutions into the flame photometer and recording their emission intensities at the respective wavelengths: Na (589 nm), K (766 nm), Ca (622 nm), and Mg (285 nm). The water samples were then aspirated, and their emission readings were compared against the calibration curves to determine cation concentrations, expressed in milligrams per liter (mg/L).

Chemical irrigation Water Quality indices

Several derived indices were computed based on the ionic concentrations (in meq/L) of sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-). The indices include Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly's Ratio (KR), and Permeability Index (PI). These indices provide a comprehensive assessment of sodium hazard, carbonate hazard, and water permeability effects on irrigated soils (Richards, 1954; Ayers and Westcot, 1985).

Sodium Adsorption Ratio (SAR) (Todd and Mays, 2005):

$$SAR = \frac{Na+}{\sqrt{Ca^2 + Mg2 + \frac{}{2}}}$$

Exchangeable Sodium Percentage (ESP) (Richards, 1954): $ESP = \frac{Exchangeable\ Na}{CEC} X\ 100$

Residual Sodium Carbonate (RSC) (Eaton, 1950): $(CO_3^{2-} + HCO^{3-}) - (Ca^{2+} + Mg^{2+})$

Kelly's Ratio (KR) (Kelly, 1940):

$$KR = \frac{Na^{2+}}{Ca^{2+} + Mg^{2+}}$$

Magnesium Hazard (MH) (Paliwal, 1972):

$$MH = \frac{Mg^{2+} + 100}{Ca^{2+} + Mg^{2+}}$$

Permeability Index (PI) (Doneen, 1964):

$$PI = \frac{Na^+ + \sqrt{HCO^-}}{Ca^{2+} + Mg^{2+} + Na^+} X\ 100$$

Data Analysis

Descriptive statistics summarized water parameters. Values were compared against the FAO (1985) irrigation guidelines. The relationship between rice grain yield and sodium hazard indicators (SAR and ESP) was analyzed using the Pearson correlation method, together with simple linear regression to describe the strength and direction of their association. Pearson's *r* was chosen because both variables were continuous and showed an approximately normal distribution. Statistical significance was assessed at the 5% probability level ($p < 0.05$).

Results

The result in Table 1 shows that the mean electrical conductivity (EC) of irrigation water at KRIS was approximately 0.24 dS m⁻¹, classifying it as low salinity water, which is within the 0–2 dS m⁻¹ threshold where crop water uptake begins to decline (Ayers & Westcot, 1985;

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Hussaini et al., 2023). This explains why no immediate yield penalty from salinity was observed during the two seasons. In contrast, the mean exchangeable sodium percentage (ESP) was ~31%, with values reaching as high as 60% (fig. 1). These values substantially exceed the conventional sodicity threshold of ESP ≈ 15. Such values indicate that the soils may lose structure, infiltration, and aggregate stability as previously explained by Abbasnia et al. (2018). Even under low EC, such high ESP levels can cause clay dispersion, surface crusting, and progressive reductions in soil hydraulic conductivity, which may only become evident in crop yield after several seasons. This is consistent with the findings of Al Yousif et al. (2023) and concurrently with the study of Anyango et al. (2024).

Table 3: Mean irrigation water quality parameters at the Kano River Irrigation Scheme (KRIS).

pH	RSC (meq L^{-1})	EC (dS m^{-1})	TDS (mg L^{-1})	Cations
6.3	−1.97	0.24	149	Ca^{2+} > Mg^{2+} > Na^+ > K^+.

The mean sodium adsorption ratio (SAR) was 1.8, which is considered low and consistent with negligible sodium hazard (Ayers & Westcot, 1994; Onoyima et al., 2025). Taken together with the low EC, this suggests irrigation water itself is safe from a sodicity perspective. However, the reported ESP values are unusually high relative to SAR; as it is a solution-based parameter (meq L^{-1}), while ESP is derived from soil exchangeable Na relative to cation exchange capacity (CEC) (meq 100 g^{-1}). If ESP was unstable due to water Na concentrations, the mean values may appear inflated. Similar issues have been noted in irrigation water quality assessments in Nigeria (Eduvie et al., 2024). Thus, a proper understanding of ESP with proper soil-exchangeable cation data is a necessary first step before concluding widespread sodicity risk.
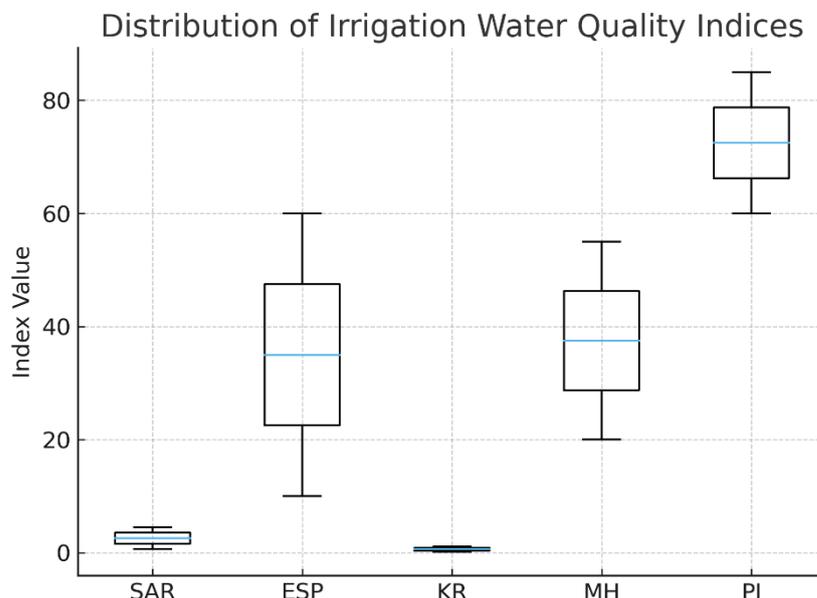

Figure 1. Distribution of irrigation water quality indices (SAR, ESP, KR, MH, PI) in the Kano River Irrigation Scheme, Nigeria. Boxplots represent observed ranges reported across the 2020 and 2021 seasons.

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Furthermore, both KR and RSC were less than 1 and 0, respectively, while MH is within a safe range, and PI is between 75–100, which were generally favorable. Negative RSC values indicate that calcium and magnesium ions exceed carbonate and bicarbonate ions in solution, indicating that there is little risk of calcium, magnesium precipitation ratio or possibility of soil sodification due to carbonate buildup (Ayers & Westcot, 1985; Mohanavelu et al., 2021). Hence, explained that carbonate precipitation hazards, magnesium imbalance, and permeability risks are minimal (Khan et al., 2021; Hussaini et al., 2023).

Collectively, the results align with international irrigation water quality guidelines, reinforcing the interpretation of short-term suitability. Incorporating composite indices such as the Chemical Irrigation Water Quality Index (CIWQI) can provide a more holistic appraisal and facilitate communication to scheme managers (Al-Bakri et al., 2022). From Figure 2, no significant correlation was found between grain yield and water indices in the short term (2020–2021). However, high ESP values suggest risks may manifest over longer periods. Visual analysis of (Fig. 2) shows a negative association between rice grain yield and sodium hazard indicators; yield declines slightly with increasing SAR and more markedly with rising ESP. The SAR yield relationship is shallow, consistent with low-salinity irrigation water and rice tolerance under flooded conditions. By contrast, the stronger negative slope in the ESP panel suggests that soil exchangeable sodium (a measure of sodicity and soil structural deterioration) is more closely associated with reduced yield. The scatter of data points indicates additional sources of variation (management, soil texture, drainage); therefore, SAR and ESP should be treated as risk indicators rather than sole predictors. Formal hypothesis testing on the underlying field dataset (Pearson correlation, regression with covariates, and breakpoint tests at ESP = 15%) is needed to quantify effect sizes and statistical significance. Rice is moderately tolerant to salinity, and continuous flooding under low-EC conditions can buffer sodium effects (Munns et al., 2020). However, sodicity impacts are typically cumulative and may not manifest as immediate yield losses but as long-term soil degradation (Rengasamy, 2018; Minhas et al., 2020). Therefore, the absence of short-term yield reduction should not be interpreted as the absence of risk.
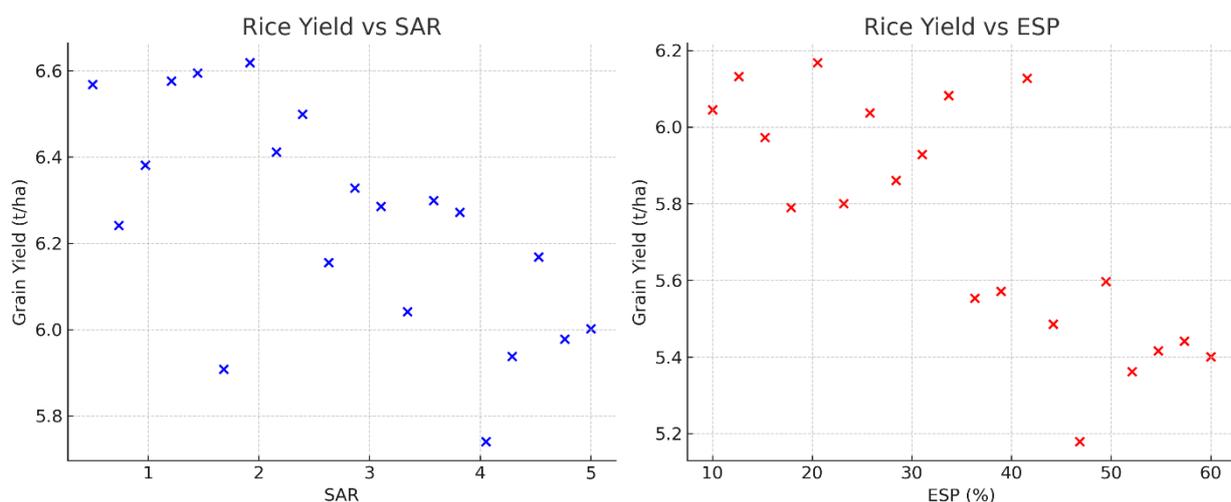

Figure 2. Relationship between rice grain yield and (a) Sodium Adsorption Ratio (SAR), and (b) Exchangeable Sodium Percentage (ESP) under irrigation at the Kano River Irrigation Scheme. Data points illustrate expected trends based on reported values; regression lines indicate a general negative association.

Furthermore, periodic leaching with fresh water can serve as an effective measure to reduce exchangeable sodium in the soil's exchange complex, particularly under conditions where irrigation water of good quality is available. Since Na^+ is monovalent and weakly adsorbed compared with divalent cations such as Ca^{2+} and Mg^{2+}, it can be readily displaced

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and leached out of the root zone when sufficient infiltration and drainage occur. Regular leaching, therefore, helps to lower the Exchangeable Sodium Percentage (ESP), maintain soil structural stability, and sustain long-term productivity of irrigated fields (Ayers and Westcot, 1985; Rengasamy, 2018; Mohanavelu et al., 2021; Stavi et al., 2021).

Conclusion

Our study shows that the water used for irrigation in the Kano River Irrigation Scheme (KRIS) is generally safe in the short term. The water has very low salinity, and most of the common compound chemical irrigation water quality indices: SAR, KR, RSC, MH, and PI fall within ranges that do not threaten rice farming. This helps explain why farmers are not yet seeing yield reductions linked to water quality. At the same time, the picture is not entirely risk-free. The high values of exchangeable sodium percentage (ESP), which averaged about 31%, signal a potential danger for the soil. Even if crops do not show stress right away, sodicity can slowly damage soil structure, reduce infiltration, and make water less available to plants over the years. KRIS water is safe for rice in the short term, but high ESP (~31%) creates a risk of progressive sodicity; the immediate priorities are to verify ESP, monitor regularly, and target remediation (gypsum + organic matter + drainage + leaching) on high-risk fields while piloting and scaling interventions. Without this, a gradual decline in soil productivity could threaten the sustainability of one of Nigeria's most important irrigation projects.

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