Assessment of Hydro chemical Characteristics and Irrigation-Livestock Suitability of Lake Ruma Wetland Water, North-Eastern Nigeria

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ABSTRACT

Lake Ruma Wetland is an important freshwater resource supporting irrigation agriculture and livestock production in north-eastern Nigeria, yet information on its hydro chemical suitability for agricultural use remains limited. This study evaluated the physicochemical characteristics of wetland water and assessed its suitability for irrigation and livestock production using internationally recognized water quality indices. Water samples were collected from representative locations and analysed following American Public Health Association (APHA) standard procedures. Irrigation suitability was assessed using Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Kelly Ratio (KR), Magnesium Hazard (MH), Permeability Index (PI), Residual Sodium Carbonate (RSC), Potential Salinity (PS), Total Hardness (TH), and the Irrigation Water Quality Index (IWQI/WAWQI), while livestock suitability was evaluated using international drinking-water standards. Results showed that most physicochemical parameters were within recommended limits for agricultural use. Irrigation indices, including SAR, KR, MH, PS, TH, and Na%, indicated low salinity and sodality risks, and the IWQI classified the water as suitable for irrigation. However, the RSC value exceeded the recommended threshold, indicating a potential alkalinity hazard under prolonged irrigation if unmanaged. The water was also suitable for livestock consumption. Overall, Lake Ruma Wetland possesses good hydro chemical quality for sustainable irrigation and livestock production, although periodic water-quality monitoring and appropriate irrigation management are recommended to minimize long-term soil alkalinity risks.

KEYWORDS

Hydrochemistry, Irrigation water quality, Irrigation Water Quality Index, Livestock water quality, Lake Ruma Wetland, Sustainable irrigation, Nigeria

I. INTRODUCTION

Wetlands are among the world's most productive freshwater ecosystems, providing water for irrigation, livestock production, biodiversity conservation, groundwater recharge, and rural livelihoods. In Sub-Saharan Africa, they are particularly important because they sustain agricultural production during prolonged dry seasons when rainfall is insufficient for rain-fed farming. As climate variability and increasing water demand intensify pressure on freshwater resources, the sustainable management of wetlands has become essential for food security and agricultural development. Water quality is a critical factor influencing the sustainability of irrigation agriculture and livestock production. Excessive concentrations of dissolved salts, sodium, bicarbonates, and other chemical constituents can degrade soil

structure, reduce infiltration, increase salinity and sodality, and ultimately lower crop productivity. Similarly, poor-quality water may adversely affect livestock health and performance. Consequently, hydro chemical assessment has become an integral component of water-resource management, particularly in semi-arid regions where limited freshwater resources are intensively.

Comprehensive evaluation of irrigation water extends beyond individual physicochemical parameters to include integrated water quality indices that better represent agricultural suitability. Parameters such as pH, electrical conductivity, total dissolved solids, major captions, and major anions are commonly complemented by indices including Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Kelly Ratio (KR), Magnesium Hazard (MH), Residual Sodium Carbonate (RSC), Permeability Index (PI), Potential Salinity (PS), and the Irrigation Water Quality Index (IWQI). These indices provide a more reliable assessment of irrigation suitability by accounting for interactions among dissolved chemical constituents. Recent studies have similarly emphasized integrated hydro chemical assessment as a more effective approach for irrigation planning than reliance on individual water-quality parameters alone.

Nigeria possesses extensive inland wetlands that support irrigation farming, livestock production, fisheries, and rural livelihoods, particularly within the Sudan and Sahel savanna zones. However, increasing agricultural expansion, climate variability, and land-use change have heightened concerns about the sustainable use of these water resources. Despite their importance, hydro chemical investigations of many Nigerian wetlands remain limited, with most studies focusing on descriptive water chemistry or individual irrigation indices rather than integrated assessments that combine physicochemical characteristics, irrigation water quality indices, and livestock suitability.

Lake Ruma Wetland, located in Song Local Government Area of Adamawa State, north-eastern Nigeria, is an important freshwater resource supporting irrigation farming, livestock production, fishing, and domestic water use. Although previous studies have described its environmental and hydrological characteristics, comprehensive evaluation of its hydro chemical suitability for agriculture has not been undertaken. In particular, integrated assessment of irrigation and livestock suitability using internationally recognized water quality indices remains lacking. This study addresses this knowledge gap by evaluating the physicochemical characteristics of Lake Ruma Wetland water and determining its suitability for irrigation and livestock production using internationally accepted water quality indices and guideline standards. The findings provide an evidence-based foundation for sustainable irrigation development, livestock production, and integrated water-resource management in Lake Ruma Wetland and similar inland wetlands of north-eastern Nigeria.

II. MATERIALS AND METHODS

A. Study Area

Lake Ruma Wetland is situated in Song Local Government Area of Adamawa State, north-eastern Nigeria, within the Sudan Savanna ecological zone. The wetland lies approximately between latitudes 09°31’30” N and 09°43’30” N and longitudes 12°40’00” E and 12°44’30”

E, occupying the lower section of the Kilange River floodplain. The wetland receives water primarily from direct rainfall, seasonal runoff, and inflows from the Kilange River, resulting in marked seasonal fluctuations in water level and storage capacity.

The climate is characterized by a distinct wet season (May–October) and dry season (November–April), with annual rainfall ranging between approximately 900 and 1,100 mm. Mean daily temperatures generally exceed 30°C, while potential evapotranspiration is high during the prolonged dry season. The surrounding communities depend extensively on the wetland for irrigation farming, livestock watering, fishing, and domestic activities, making the quality of its water resources critical for sustainable agricultural production.

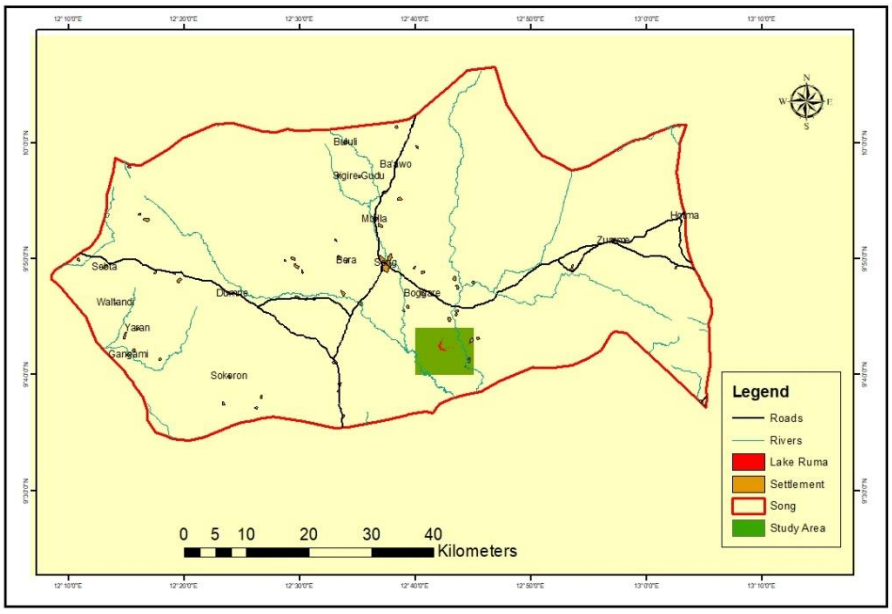

Figure 1: Study Area

B. Research Design

This study adopted a quantitative field-based hydro chemical assessment designed to evaluate the suitability of Lake Ruma Wetland water for irrigation and livestock production. The assessment combined laboratory analysis of physicochemical parameters with internationally recognized irrigation water quality indices and livestock water quality standards. This integrated approach provides a comprehensive evaluation of agricultural water quality and minimizes the limitations associated with interpreting individual chemical parameters independently.

C. Water Sampling

Water samples were collected during the 2024 field survey from four representative sampling locations across Lake Ruma Wetland. The wetland was divided into four quadrats, and one representative sample was collected from each quadrat to capture spatial variations in water quality associated with hydrological conditions and land-use activities. Sampling locations were dereferenced using a handheld Global Positioning System (GPS) receiver.

Samples were collected at approximately 0.3 m below the water surface using pre-cleaned 1-L high-density polyethylene (HDPE) bottles, following the Standard Methods for the Examination of Water and Wastewater (APHA, 2023). Bottles were rinsed with sample water before collection; samples for caption analysis were preserved with nitric acid (pH < 2), while those for anion analysis were left acidified. All samples were stored at approximately 4°C in insulated ice chests and transported to the laboratory for analysis within 24 hours.

D. Laboratory Analysis

Laboratory analyses were performed following the Standard Methods for the Examination of Water and Wastewater (APHA, 2023). Physicochemical parameters analysed included pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD). Major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and major anions (Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}, and NO_3^-) were also determined using standard APHA analytical procedures. Analytical-grade reagents were used throughout, and all instruments were calibrated with certified standard solutions before analysis.

E. Irrigation Water Quality Assessment

The suitability of Lake Ruma Wetland water for irrigation was evaluated using internationally recognized irrigation water quality indices. These indices integrate the effects of dissolved salts and ionic composition on soil permeability, sodicity, salinity, and crop productivity.

1. Sodium Adsorption Ratio (SAR)

SAR evaluates the sodium hazard associated with irrigation water and is expressed as:

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

Where ionic concentrations are expressed in mill equivalents per litre (meq L^{-1}).

2. Sodium Percentage (Na %)

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + {M_g}^{2+} + Na^+ + K} \times 100$$

This index evaluates the proportion of sodium relative to the total cation concentration.

3. Kelly Ratio (KR)

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

Values less than one indicate irrigation water suitable for agricultural use.

4. Magnesium Hazard (MH)

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

Excess magnesium adversely affects soil quality by increasing alkalinity and reducing crop productivity.

5. Permeability Index (PI)

Following Doneen (1964):

$$PI = \frac{Na^{+} + \sqrt{{HCO_3}^{-}}}{Ca^{2+} + {M_g}^{2+} + Na^{2+}} \times 100$$

The permeability index evaluates the long-term influence of irrigation water on soil permeability.

6. Residual Sodium Carbonate (RSC)

$$RSC = \left({HCO_3}^{-} + {CO_3}^{2-}\right) - \left(Ca^{2+} + {M_g}^{2+}\right)$$

Positive values indicate increasing carbonate hazard and possible soil alkalinity problems.

7. Potential Salinity (PS)

$$PS = Cl^{-} + \frac{1}{2}{SO_4}^{2-}$$

Potential salinity estimates the long-term salinity hazard associated with irrigation water.

8. Total Hardness (TH)

Total hardness was calculated as:

$$TH = 2.497\ (Ca^{2+}) + 4{,}115({M_g}^{2+})$$

Where calcium and magnesium concentrations are expressed in mg L^{-1}.

9. Irrigation Water Quality Index (IWQI)

To provide an integrated evaluation of irrigation suitability, the Irrigation Water Quality Index (IWQI) was computed by combining the standardized ratings of the selected irrigation parameters using weighted aggregation procedures. Each parameter was assigned an appropriate weight according to its relative importance in determining irrigation suitability. The resulting index classified irrigation water into qualitative categories ranging from excellent to unsuitable based on internationally accepted classification thresholds.

F. Livestock Water Quality Assessment

The suitability of Lake Ruma Wetland water for livestock production was evaluated using internationally recognized livestock drinking-water guidelines, including recommendations from the Food and Agriculture Organization (FAO) and the National Research Council (NRC). Assessment considered the concentrations of dissolved salts and major chemical constituents that may affect animal health, water intake, productivity, and reproduction.

The measured physicochemical parameters were compared with recommended threshold values to classify the water as excellent, good, permissible, or unsuitable for livestock consumption.

G. Quality Assurance and Quality Control

Quality assurance procedures were implemented throughout sample collection, preservation, laboratory analysis, and data processing. Sampling bottles were thoroughly cleaned and pre-conditioned before field use. Analytical instruments were calibrated daily using certified reference standards, and reagent blanks were analysed to monitor laboratory contamination. Duplicate analyses were performed for selected samples to evaluate analytical precision, while standard reference materials were included where applicable to verify analytical accuracy.

Measured ionic concentrations were examined for internal consistency, and all laboratory results were screened for possible transcription or analytical errors before statistical analysis.

H. Statistical Analysis

Descriptive statistical techniques were used to summarize the hydro chemical characteristics of the wetland water, including minimum, maximum, mean, standard deviation, and coefficient of variation. Relationships among physicochemical variables were examined using Pearson correlation analysis to identify possible geochemical associations influencing water quality. Computed irrigation indices were interpreted according to internationally accepted classification schemes proposed by Richards (1954), Wilcox (1955), Doneen (1964), Ayers and Westcot (1985), and FAO (2024). Where spatial data were available, Geographic Information System (GIS) techniques were employed to visualize the spatial distribution of selected hydro chemical parameters and irrigation suitability classes.

I. Ethical Considerations

The study involved environmental sampling only and did not involve human participants or experimental animals. Permission to access sampling locations was obtained from relevant local authorities and community leaders before fieldwork commenced. Field activities were conducted in accordance with accepted environmental and ethical standards to minimize disturbance to the wetland ecosystem.

III. RESULTS

A. Irrigation Water Quality Assessment

The irrigation suitability of Lake Ruma Wetland water was evaluated using internationally accepted irrigation water quality indices. The results indicate that the wetland water generally possesses favourable hydro chemical characteristics for agricultural use, although one important chemical limitation was identified.

The Sodium Adsorption Ratio (SAR) was 4.56, indicating an acceptable sodium hazard for irrigation. According to established irrigation-water classification systems, this value suggests that sodium accumulation is unlikely to adversely affect soil structure under normal irrigation management. The Total Hardness (TH) was 56.4 mg L^{-1}, classifying the water as soft, while the Kelly's Index (KI) of 0.43 confirmed that sodium concentrations remained within the acceptable range for irrigation use. The Permeability Index (PI) was 40%, indicating moderate suitability for sustaining soil permeability under continued irrigation. However, the Residual Sodium Carbonate (RSC) reached 7.54 meq L^{-1}, exceeding the commonly accepted threshold for irrigation water and indicating a potential carbonate-induced alkalinity hazard.

These findings demonstrate that, although the hydro chemical composition of Lake Ruma Wetland water is generally favourable for irrigation, continued agricultural use should account for the elevated carbonate hazard to minimize long-term deterioration in soil physical properties.

Table 1. Irrigation water quality indices of Lake Ruma Wetland

Parameter	**Value**	**Quality classification**
Sodium Adsorption Ratio (SAR)	4.56	Acceptable
Total Hardness (TH) (mg L^{-1})	56.4	Soft
Permeability Index (PI) (%)	40	Moderate
Kelly's Index (KI)	0.43	Suitable
Residual Sodium Carbonate (RSC) (meq L^{-1})	7.54	Unsuitable

B. Irrigation Water Quality Index (WAWQI)

An integrated evaluation of irrigation suitability was undertaken using the Weighted Arithmetic Water Quality Index (WAWQI). The index incorporated selected physicochemical parameters, including pH, temperature, electrical conductivity, total dissolved solids, nitrate, SAR, RSC, chloride, and boron, to provide an overall assessment of irrigation water quality. The calculated WAWQI was 48.44, placing Lake Ruma Wetland in the Good Water Quality category for irrigation. This classification indicates that the water's combined physicochemical characteristics are generally suitable for irrigated agriculture, despite localized chemical constraints. The relatively favourable composite index demonstrates that the majority of measured parameters remained within internationally accepted irrigation limits. The WAWQI computation further showed that pH, electrical conductivity, chloride, and boron contributed relatively low weighted scores to the overall index, whereas nitrate,

SAR, and particularly RSC contributed proportionally higher quality ratings. These results indicate that carbonate chemistry represents the principal hydro chemical limitation within an otherwise favourable irrigation-water system.

C. Livestock Water Suitability

The suitability of Lake Ruma Wetland water for livestock production was also assessed using the Weighted Arithmetic Water Quality Index. The analysis produced a livestock WAWQI of 22.40, which falls within the Excellent Water Quality category for livestock consumption. This result indicates that the measured physicochemical characteristics present little apparent limitation for livestock watering and support the continued use of the wetland as a dependable water source for pastoral production. The excellent livestock-water classification suggests that dissolved salts and the evaluated chemical constituents remain below levels expected to impair animal health or productivity. Consequently, Lake Ruma Wetland provides a valuable water resource capable of supporting mixed crop–livestock production systems within the study area.

D. Overall Agricultural Water Suitability

The combined irrigation and livestock assessments indicate that Lake Ruma Wetland possesses a generally favourable hydro chemical environment for agricultural use. Most irrigation indices classified the water as acceptable, suitable, or moderate, while the integrated irrigation WAWQI classified the water as Good. Similarly, the livestock assessment classified the water as Excellent, confirming its suitability for animal consumption. Nevertheless, the elevated Residual Sodium Carbonate (7.54 meq L^{-1}) represents an important hydro chemical constraint. Unlike the other indices, RSC exceeded recommended irrigation thresholds, suggesting that prolonged irrigation without appropriate management may increase soil alkalinity and reduce infiltration capacity. Therefore, although Lake Ruma Wetland water is suitable for irrigation and livestock production, routine monitoring of carbonate chemistry and appropriate soil and water management practices will be necessary to ensure long-term agricultural sustainability.

IV. DISCUSSION

A. Hydro chemical Characteristics and Irrigation Suitability

The hydro chemical evaluation demonstrated that Lake Ruma Wetland water is generally suitable for irrigation, as evidenced by the favourable performance of most irrigation water quality indices. The Sodium Adsorption Ratio (SAR) of 4.56 indicates a low sodium hazard, suggesting that prolonged use of the water is unlikely to cause significant deterioration of soil structure through sodium-induced clay dispersion. According to the United States Salinity Laboratory (USSL) classification, SAR values below 10 are considered suitable for irrigation of most agricultural soils, provided salinity remains within acceptable limits. The relatively low SAR observed in this study reflects a favourable balance between sodium and the divalent cations calcium and magnesium, both of which help maintain soil aggregate stability and infiltration capacity.

The Kelly's Index (0.43) further confirms the suitability of Lake Ruma Wetland water for irrigation. Kelly's Index evaluates the dominance of sodium relative to calcium and magnesium, and values below one generally indicates irrigation water that poses little sodicity risk. The consistency between the SAR and Kelly's Index strengthens confidence in the overall assessment, demonstrating that sodium is not the principal factor limiting irrigation development within the wetland. Similar findings have been reported in recent hydro chemical studies of tropical wetlands, where relatively low sodium concentrations were associated with favourable soil permeability and sustainable irrigation potential.

The Total Hardness value of 56.4 mg L^{-1} classified the water as soft. Soft water is generally desirable for irrigation because it minimizes mineral precipitation within irrigation infrastructure and reduces the risk of emitter blockage in sprinkler and drip irrigation systems. The relatively low hardness also reflects limited concentrations of calcium and magnesium salts, suggesting that the wetland water has undergone minimal mineralization. Comparable hardness values have been reported for freshwater wetlands within tropical environments where seasonal rainfall provides substantial dilution of dissolved minerals.

The Permeability Index of 40% indicates moderate suitability for irrigation. Soil permeability is controlled by the combined influence of sodium, calcium, magnesium, and bicarbonate concentrations. Moderate PI values suggest that continuous irrigation is unlikely to produce rapid deterioration of soil permeability, although long-term monitoring remains necessary because seasonal variations in hydrochemistry may influence infiltration characteristics. Similar moderate permeability conditions have been documented in semi-arid wetlands where seasonal hydrological fluctuations alter the ionic composition of irrigation water.

B. Carbonate Hazard as the Principal Limitation

Despite the generally favourable irrigation characteristics, Residual Sodium Carbonate (RSC) emerged as the principal hydro chemical limitation. The measured RSC value of 7.54 meq L^{-1} substantially exceeds the internationally recommended threshold of 2.5 meq L^{-1}, indicating a potential alkalinity hazard during prolonged irrigation. Elevated RSC occurs when bicarbonate and carbonate ions exceed the combined concentrations of calcium and magnesium. Under irrigation conditions, excess bicarbonate promotes the precipitation of calcium and magnesium carbonates, thereby increasing the relative proportion of sodium in the soil solution. This process gradually elevates soil alkalinity, reduces aggregate stability, decreases infiltration capacity, and may ultimately impair crop productivity.

The elevated RSC observed in Lake Ruma Wetland is likely associated with seasonal hydro climatic processes characteristic of the Sudan Savanna. Previous investigations of the wetland demonstrated that water availability declines substantially during the prolonged dry season as evapotranspiration exceeds rainfall. Under these conditions, evaporation concentrates dissolved bicarbonates and carbonates within the remaining water, thereby increasing carbonate alkalinity even when overall salinity remains relatively low. This interpretation highlights the importance of considering seasonal hydrological processes when evaluating irrigation water quality in temporary and seasonal wetlands.

The coexistence of favourable SAR and elevated RSC illustrates the importance of integrated hydro chemical assessment. If irrigation suitability had been evaluated solely using SAR,

the potential long-term carbonate hazard would have remained undetected. The combined application of multiple irrigation indices therefore provides a more realistic assessment of agricultural water quality than reliance on a single parameter.

C. Integrated Water Quality Assessment

The Weighted Arithmetic Water Quality Index (WAWQI) classified Lake Ruma Wetland water as Good for irrigation, indicating that the combined influence of the evaluated physicochemical parameters remains within acceptable limits for agricultural use. Unlike individual irrigation indices, the WAWQI integrates multiple hydro chemical variables into a single quantitative measure that reflects the overall suitability of the water resource. This integrated approach minimizes the limitations associated with interpreting individual parameters independently and provides a more comprehensive basis for water resource management.

The relatively favourable WAWQI suggests that most measured parameters contribute positively to irrigation suitability, while the elevated RSC represents a localized chemical constraint rather than evidence of widespread hydro chemical deterioration. Similar observations have been reported in several recent studies where irrigation water exhibited acceptable composite quality despite isolated exceedances of individual chemical indicators. Consequently, management decisions should consider the combined interpretation of hydro chemical parameters rather than focusing exclusively on single indices.

D. Livestock Water Suitability

The livestock WAWQI classified Lake Ruma Wetland water as Excellent, demonstrating that the physicochemical characteristics of the water satisfy internationally accepted requirements for livestock consumption. This finding is particularly important because mixed farming systems dominate the study area, where irrigation farming and livestock production depend on the same water resource throughout much of the year. The excellent livestock classification indicates that dissolved mineral concentrations are unlikely to impair animal health, water intake, or productivity.

The dual suitability of the wetland for both irrigation and livestock production substantially enhances its strategic importance for rural livelihoods. In semi-arid environments where perennial freshwater resources are limited, wetlands capable of simultaneously supporting crop production and livestock watering provide critical ecosystem services that contribute to food security, household income, and climate resilience.

E. Implications for Sustainable Wetland Management

The findings have important implications for sustainable agricultural development within Lake Ruma Wetland and comparable inland wetlands across north-eastern Nigeria. First, the generally favourable irrigation quality confirms that the wetland possesses considerable potential for supporting expanded dry-season irrigation. Second, the identification of elevated carbonate hazard emphasizes the need for proactive management strategies to prevent long-term soil degradation.

Appropriate management measures may include periodic monitoring of irrigation water quality, application of gypsum where necessary to offset sodium and carbonate effects, incorporation of organic matter to improve soil structure, adoption of efficient irrigation scheduling, and periodic leaching to prevent the accumulation of soluble salts and carbonates within the root zone. Integrating these practices into local irrigation management programmes would help sustain agricultural productivity while preserving the ecological integrity of the wetland.

F. Scientific Contribution

This study contributes to the growing body of knowledge on agricultural water quality assessment by providing one of the first integrated evaluations of irrigation and livestock suitability for Lake Ruma Wetland. Unlike many previous investigations that considered only individual physicochemical parameters or isolated irrigation indices, the present study combined multiple hydro chemical indicators with composite water quality indices to provide a comprehensive evaluation of agricultural suitability. The results demonstrate that integrated hydro chemical assessment offers a more robust framework for irrigation planning and wetland management than conventional single-parameter approaches.

Furthermore, by linking hydro chemical quality with the seasonal hydrological characteristics previously established for Lake Ruma Wetland, the study advances understanding of how hydro climatic variability influences agricultural water resources within the Sudan Savanna region. These findings provide an important scientific basis for sustainable irrigation planning, livestock production, and evidence-based wetland management in north-eastern Nigeria and other seasonally variable tropical wetlands.

V. CONCLUSIONS

This study evaluated the hydro chemical characteristics of Lake Ruma Wetland and assessed its suitability for irrigation and livestock production using internationally recognized physicochemical parameters, irrigation water quality indices, and the Weighted Arithmetic Water Quality Index (WAWQI). The integrated assessment provides a comprehensive understanding of the agricultural potential of this strategically important wetland in north-eastern Nigeria.

The results showed that Lake Ruma Wetland water is generally suitable for irrigation. Most irrigation water quality indices, including the Sodium Adsorption Ratio (SAR), Kelly's Index (KI), Total Hardness (TH), and Permeability Index (PI), fell within internationally accepted limits, indicating low sodium hazard, acceptable hardness, and favourable soil permeability. The computed irrigation WAWQI further classified the water as Good, confirming that its overall hydro chemical quality supports sustainable irrigated agriculture.

Despite these favourable characteristics, Residual Sodium Carbonate (RSC) exceeded the recommended threshold, identifying carbonate alkalinity as the principal hydro chemical constraint. Elevated RSC may gradually increase soil alkalinity, reduce infiltration, and impair soil structure if irrigation is practised continuously without appropriate management interventions. This finding demonstrates the importance of evaluating irrigation water using

multiple complementary indices rather than relying on a single parameter, as individual indices may not adequately identify all potential agricultural risks.

The livestock water quality assessment classified the wetland water as Excellent, indicating that the measured physicochemical characteristics are suitable for livestock consumption and are unlikely to adversely affect animal health or productivity. Consequently, Lake Ruma Wetland represents a valuable freshwater resource capable of simultaneously supporting irrigated crop production and livestock development within the Sudan Savanna region.

The principal scientific contribution of this study lies in its integrated hydro chemical evaluation of irrigation and livestock suitability using multiple irrigation water quality indices and a composite water quality index. Unlike previous investigations that focused primarily on descriptive hydrochemistry or isolated water quality indicators, this study demonstrates the value of combining hydro chemical analyses with internationally accepted agricultural suitability indices to provide a more comprehensive basis for water-resource management and irrigation planning.

A. Practical Recommendations

Based on the findings, the following recommendations are proposed:

- Lake Ruma Wetland water can be utilized for irrigation, provided that appropriate soil and water management practices are implemented to mitigate the effects of elevated Residual Sodium Carbonate.
- Periodic monitoring of irrigation water quality should be undertaken throughout both the wet and dry seasons to identify temporal variations in hydrochemical composition and detect potential deterioration before it affects agricultural productivity.
- Soil chemical properties should be monitored regularly in irrigated fields to evaluate changes in alkalinity, exchangeable sodium, and infiltration characteristics associated with long-term irrigation.
- Where carbonate accumulation becomes significant, appropriate soil amendments such as gypsum should be considered to improve calcium availability, reduce sodium-related hazards, and maintain favourable soil structure.
- Efficient irrigation methods, including sprinkler and drip irrigation systems where feasible, should be promoted to improve water-use efficiency and reduce unnecessary accumulation of soluble salts within the root zone.
- Integrated watershed conservation measures should be strengthened to minimize sediment transport, agricultural runoff, and other anthropogenic activities capable of altering the hydro chemical characteristics of the wetland.
- Future studies should investigate seasonal hydro chemical dynamics, trace elements, heavy metals, microbial water quality, and climate-change impacts to provide a more comprehensive understanding of long-term water-resource sustainability in Lake Ruma Wetland.

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