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Original Research Article

Assessment of Soil Physicochemical Properties and Agricultural Suitability of Lake Ruma Wetland for Sustainable Irrigation Development in North-eastern Nigeria

Thomas.[1], C.Y Oche.[1], N.L Binbol[1]

[1]University of Jos, Department of Geography and Planning, Plateau State, Nigeria.

Abstract: Wetland soils play a critical role in supporting irrigated agriculture by providing favourable physical conditions, nutrient reserves, and moisture for crop production. However, comprehensive assessments of their physicochemical properties remain limited in north-eastern Nigeria. This study evaluated the physicochemical characteristics of soils in the Lake Ruma Wetland and assessed their suitability for sustainable irrigation agriculture. Composite soil samples were collected during the 2024 field survey and analysed using standard laboratory methods. Physical properties (particle-size distribution, bulk density, particle density, and porosity) and chemical properties (pH, electrical conductivity, organic carbon, organic matter, total nitrogen, available phosphorus, cation exchange capacity, exchangeable bases, and total exchangeable acidity) were determined and interpreted using internationally accepted soil fertility and land evaluation standards. The soils were predominantly loam, silt loam, and clay loam, with a mean bulk density of 1.13 g cm^{-3} and porosity of 68.57%, indicating favourable conditions for root growth and water retention. Soil pH averaged 6.61, while electrical conductivity remained low (0.16 dS m^{-1}), confirming non-saline conditions suitable for irrigation. Organic carbon (1.31 g kg^{-1}) and total nitrogen (0.14 g kg^{-1}) were relatively low, whereas available phosphorus (39.75 mg kg^{-1}) and cation exchange capacity (10.77 cmol(+) kg^{-1}) indicated moderate nutrient retention capacity. The results demonstrate that Lake Ruma Wetland soils exhibit high suitability for irrigated agriculture. However, sustaining long-term productivity will require integrated soil fertility management to enhance organic matter and nitrogen levels. These findings provide a scientific basis for sustainable irrigation planning, land-use management, and wetland conservation in north-eastern Nigeria.

Keywords: *Wetland soils; physicochemical properties; irrigation suitability; soil fertility; sustainable agriculture; Lake Ruma Wetland.*

1. Introduction

Soil is a fundamental natural resource that underpins agricultural production by providing physical support for plant growth, regulating water storage and movement, supplying essential nutrients, and sustaining biological processes that maintain ecosystem productivity. Soil quality directly influences crop productivity, irrigation efficiency, environmental sustainability, and food security. As global demand for agricultural land increases under the combined pressures of population growth, climate change, and land degradation, sustainable soil management has become essential for achieving the Sustainable Development Goals, particularly those related to food security, land restoration, and sustainable agriculture (FAO, 2021; FAO, 2024).

Wetlands are among the world's most productive ecosystems because their soils possess unique hydrological, physical, and chemical characteristics that support agricultural production. Periodic flooding and sediment deposition enrich wetland soils with fine particles and nutrients, while prolonged moisture availability enables crop cultivation during dry periods when upland agriculture is constrained. Consequently, wetlands have become increasingly important for irrigation development, particularly in semi-arid regions where rainfall variability limits reliable rain-fed agriculture (Convention on Wetlands, 2021; FAO, 2024).

In Sub-Saharan Africa, inland wetlands contribute substantially to dry-season crop production, livestock grazing, fisheries, and rural livelihoods. These ecosystems are particularly valuable within the Sudan

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Corresponding Author: Thomas

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and Sahel Savanna zones, where prolonged dry seasons and recurrent droughts restrict agricultural productivity. However, increasing population pressure, agricultural intensification, and environmental degradation threaten the sustainability of wetland ecosystems, emphasizing the need for evidence-based land management strategies that balance agricultural production with ecosystem conservation (Davidson et al., 2023; FAO, 2024).

The suitability of soils for irrigation agriculture depends largely on their physicochemical characteristics. Physical properties such as texture, bulk density, and porosity regulate water infiltration, drainage, aeration, and root development, whereas chemical properties including pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity determine nutrient availability, salinity status, and the capacity of soils to sustain long-term crop production. Therefore, integrated evaluation of these properties provides a robust basis for assessing soil fertility and agricultural suitability using internationally accepted land evaluation frameworks (Brady & Weil, 2017; Hazelton & Murphy, 2016).

Previous studies have demonstrated that favourable physical characteristics alone do not guarantee sustainable agricultural productivity because chemical limitations, including nutrient depletion and declining organic matter, may reduce crop performance. Conversely, chemically fertile soils may possess physical constraints that limit root growth and water movement. Consequently, integrated assessment of both physical and chemical soil properties has become increasingly important for evaluating agricultural suitability and supporting sustainable irrigation planning (FAO, 2024).

Although numerous studies have characterized wetland soils across Africa and elsewhere, many have focused primarily on descriptive soil properties or fertility assessment without explicitly evaluating their suitability for irrigation agriculture. In northeastern Nigeria, available studies have largely emphasized hydrology, land use, or general soil characteristics, while comprehensive assessments integrating soil physicochemical properties with agricultural suitability remain limited. Furthermore, little information exists on the physicochemical quality of soils within Lake Ruma Wetland despite its increasing importance for irrigation farming and livestock production. This knowledge gap limits evidence-based planning for sustainable wetland utilization and long-term soil management.

Lake Ruma Wetland, located in Song Local Government Area of Adamawa State, is an important inland wetland that supports irrigation agriculture, livestock production, fisheries, and rural livelihoods. Increasing agricultural exploitation of the wetland has intensified the need for detailed information on soil quality to guide sustainable land-use planning and prevent long-term soil degradation. Comprehensive evaluation of the physicochemical properties of its soils is therefore essential for determining their suitability for irrigation development and identifying potential fertility constraints.

This study addresses these knowledge gaps by conducting an integrated assessment of the physicochemical properties of Lake Ruma Wetland soils and evaluating their suitability for sustainable irrigation agriculture. Specifically, the study (i) characterizes the physical properties of the soils, including texture, bulk density, particle density, and porosity; (ii) determines their chemical properties, including pH, electrical conductivity, organic carbon, organic matter, total nitrogen, available phosphorus, cation exchange capacity, exchangeable bases, and total exchangeable acidity; (iii) evaluates soil fertility status using internationally recognized classification standards; and (iv) assesses the overall suitability of the soils for irrigated agriculture. The findings provide a scientific basis for sustainable irrigation planning, soil fertility management, and wetland conservation, while contributing to the limited body of knowledge on wetland soil resources in north-eastern Nigeria.

2. Materials and Methods

2.1 Study Area

The study was conducted at Lake Ruma Wetland, located in Song Local Government Area of Adamawa State, north-eastern Nigeria, within the Sudan Savanna ecological zone. The wetland forms part of the Kilange River floodplain and supports irrigation farming, livestock grazing, fishing, and other livelihood activities. The area experiences a tropical continental climate characterized by distinct wet (May–October) and dry (November–April) seasons, with mean annual rainfall ranging from approximately 900 to 1,100 mm and high evapotranspiration during the dry season. These climatic conditions make the wetland an important source of water and fertile soils for dry-season agriculture.

2.2 Research Design

The study adopted a quantitative field and laboratory approach to evaluate the physicochemical properties of wetland soils and determine their suitability for sustainable irrigation agriculture. Soil quality assessment integrated measurements of physical and chemical properties following internationally accepted laboratory procedures and soil evaluation guidelines. Such integrated assessments provide a comprehensive understanding of soil productivity and irrigation suitability because soil physical and chemical properties

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jointly influence crop performance, water movement, nutrient availability, and long-term land sustainability.

2.3 Soil Sampling

Composite soil samples were collected during the 2024 field survey from representative locations across Lake Ruma Wetland to capture spatial variability in land use, topography, hydrology, and vegetation. The wetland was divided into four quadrants, and five sampling points were established within each quadrant, giving a total of 20 sampling locations. At each location, surface soil samples (0–30 cm), representing the principal crop root zone, were collected using a stainless-steel auger. Multiple subsamples within a small radius were composited into a representative sample, while sampling locations were georeferenced using a handheld Global Positioning System (GPS) receiver. The samples were air-dried, gently crushed, sieved through a 2-mm mesh, and prepared for laboratory analysis. Disturbed samples were used for chemical and particle-size analyses, whereas undisturbed core samples were collected separately for bulk-density determination.

2.4 Laboratory Analysis

Laboratory analyses were conducted using internationally recognized procedures for soil analysis. Standard analytical methods described by the Food and Agriculture Organization (FAO), the Soil Science Society of America (SSSA), and the United States Department of Agriculture (USDA) were adopted to ensure consistency, reproducibility, and international comparability.

2.4.1 Physical Properties

The following physical properties were determined:

- Particle-size distribution (sand, silt, and clay fractions) using the Bouyoucos hydrometer method.
- Soil textural class using the USDA textural triangle.
- Bulk density using the core sampling method.
- Particle density using the pycnometer method.
- Total porosity calculated from measured bulk and particle densities.

These properties were evaluated because they influence water infiltration, aeration, root penetration, and water-holding capacity, which are fundamental determinants of irrigation suitability.

2.4.2 Chemical Properties

The following chemical properties were analyzed:

- Soil pH (1:2.5 soil-water suspension)
- Electrical conductivity (EC)
- Organic carbon (Walkley–Black method)
- Organic matter (calculated from organic carbon)
- Total nitrogen (Kjeldahl digestion)
- Available phosphorus (Bray I method)
- Exchangeable calcium, magnesium, sodium, and potassium
- Cation exchange capacity (CEC)
- Total exchangeable acidity (TEA)

Analyses were conducted using internationally accepted laboratory procedures for soil fertility investigations.

2.5 Soil Fertility Evaluation

The measured soil properties were interpreted using internationally recognized soil fertility and land evaluation standards. Soil reaction (pH), salinity (EC), organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity were classified according to accepted agronomic thresholds to determine fertility status and identify potential limitations to crop production. Soil texture classes were interpreted using the USDA textural classification system.

2.6 Agricultural Suitability Assessment

Agricultural suitability was evaluated through an integrated interpretation of soil physical and chemical characteristics. Physical indicators such as texture, bulk density, and porosity were used to assess rooting conditions, infiltration, drainage, and water-storage capacity. Chemical indicators including pH, EC, soil organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity were used to evaluate nutrient availability, salinity status, and long-term fertility. The combined interpretation of these indicators formed the basis for determining the suitability of Lake Ruma Wetland soils for sustainable irrigated agriculture.

2.7 Quality Assurance and Quality Control

Quality assurance procedures were implemented throughout field sampling and laboratory analysis. Sampling equipment was cleaned between sampling locations to minimize cross-contamination. Laboratory instruments were calibrated using certified reference standards before analysis, and analytical-grade reagents were used throughout the study. Duplicate analyses and reagent blanks were included where appropriate to verify analytical precision and accuracy. Laboratory procedures followed internationally accepted protocols for soil analysis and quality control.

2.8 Statistical Analysis

Descriptive statistical techniques, including minimum, maximum, mean, standard deviation, and coefficient of variation, were used to summarize soil physicochemical properties. Pearson correlation analysis was employed to examine relationships among selected soil variables and identify interactions influencing soil quality and fertility. Where appropriate, spatial distribution maps of selected soil properties were prepared using Geographic Information System (GIS) techniques to illustrate variability across the wetland. All statistical analyses were undertaken using appropriate statistical software, and results were interpreted at the 95% confidence level ($p < 0.05$).

3. Results

3.1 Physical Properties of Lake Ruma Wetland Soils

The physical characteristics of Lake Ruma Wetland soils are presented in Table 1. Particle-size analysis showed that the soils were predominantly medium-textured, with sand content ranging from 32.0 to 48.0%, silt from 26.8 to 50.8%, and clay from 17.2 to 25.2%. Mean particle-size fractions were 38.50% sand, 40.30% silt, and 21.20% clay, indicating that the dominant textural classes were loam, silt loam, and clay loam. These textures are generally considered favourable for agricultural production because they provide a balance between water retention, drainage, aeration, and root penetration.

Bulk density varied from 1.08 to 1.16 g cm^{-3}, with a mean of 1.13 g cm^{-3}, while particle density ranged from 1.62 to 1.65 g cm^{-3}, averaging 1.63 g cm^{-3}. Total porosity ranged from 65.89 to 70.32%, with a mean value of 68.57%. The relatively low bulk density and high porosity indicate that the wetland soils are not compacted and possess favourable structural conditions for root growth, water infiltration, and soil aeration.

Table 1. Physical properties of Lake Ruma Wetland soils

Property	Minimum	Maximum	Mean
Sand (%)	32.00	48.00	38.50
Silt (%)	26.80	50.80	40.30
Clay (%)	17.20	25.20	21.20
Bulk density (g cm^{-3})	1.08	1.16	1.13
Particle density (g cm^{-3})	1.62	1.65	1.63
Porosity (%)	65.89	70.32	68.57
Dominant texture	–	–	Loam, Silt loam, Clay loam

3.2 Chemical Properties of Lake Ruma Wetland Soils

The chemical properties of the wetland soils revealed generally favourable conditions for irrigated agriculture. Soil pH ranged from 6.03 to 7.86, with a mean value of 6.61, indicating slightly acidic to near-neutral conditions suitable for the cultivation of a wide range of crops. Electrical conductivity (EC) varied from 0.13 to 0.18 dS m^{-1}, with a mean of 0.16 dS m^{-1}, confirming that the soils are non-saline and unlikely to impose salinity constraints on crop growth.

Organic carbon ranged from 1.01 to 1.53 g kg^{-1}, with a mean of 1.31 g kg^{-1}, while organic matter ranged from 1.74 to 2.64 g kg^{-1}, averaging 2.26 g kg^{-1}. Total nitrogen varied between 0.10 and 0.16 g kg^{-1}, with a mean value of 0.14 g kg^{-1}. Available phosphorus ranged from 23.0 to 67.0 mg kg^{-1}, averaging 39.75 mg kg^{-1}. These results indicate that, although phosphorus availability is relatively favourable, organic carbon and nitrogen contents are comparatively low and may limit sustained crop productivity without nutrient replenishment.

Total exchangeable acidity (TEA) ranged from 8.42 to 15.12 cmol(+) kg^{-1}, with a mean value of 11.35 cmol(+) kg^{-1}. Mean exchangeable cation concentrations were 1.48 cmol(+) kg^{-1} for calcium, 0.18 cmol(+) kg^{-1} for magnesium, 0.24 cmol(+) kg^{-1} for potassium, and 0.45 cmol(+) kg^{-1} for sodium. Cation exchange capacity (CEC) ranged from 7.32 to 15.92 cmol(+) kg^{-1}, with an average of 10.77 cmol(+) kg^{-1}, indicating a moderate capacity for nutrient retention and exchange.

Table 2. Chemical properties of Lake Ruma Wetland soils

Property	Minimum	Maximum	Mean
pH	6.03	7.86	6.61
EC (dS m^{-1})	0.13	0.18	0.16
Organic carbon (g kg^{-1})	1.01	1.53	1.31
Organic matter (g kg^{-1})	1.74	2.64	2.26
Total nitrogen (g kg^{-1})	0.10	0.16	0.14
Available phosphorus (mg kg^{-1})	23.0	67.0	39.75
TEA (cmol(+) kg^{-1})	8.42	15.12	11.35
CEC (cmol(+) kg^{-1})	7.32	15.92	10.77

3.3 Soil Fertility Status

The combined physical and chemical characteristics indicate that Lake Ruma Wetland soils possess favourable conditions for agricultural production. The predominance of loam, silt loam, and clay loam textures, together with low bulk density and high porosity, provides an appropriate physical environment for crop establishment and root development. Similarly, the slightly acidic to near-neutral pH and very low electrical conductivity indicate chemically suitable conditions with little risk of salinity-related crop stress. However, the relatively low concentrations of organic carbon, organic matter, and total nitrogen suggest that soil fertility may gradually decline under continuous cultivation if nutrients are not replenished. In contrast, the moderate cation exchange capacity and comparatively high available phosphorus indicate that the soils retain an appreciable capacity to supply and retain essential nutrients for crop growth.

3.4 Agricultural Suitability of Lake Ruma Wetland Soils

The integrated assessment indicates that Lake Ruma Wetland has favourable soil physical and chemical properties for irrigated agriculture. The soils exhibit good water-holding capacity, adequate drainage, favourable rooting conditions, are non-saline, and have a suitable pH for most crops. However, relatively low organic carbon and total nitrogen levels indicate that soil fertility management is necessary for sustained productivity. Therefore, while the soils are highly suitable for irrigation, long-term agricultural performance will depend on practices such as organic amendments, balanced fertilizer application, legume-based crop rotation, and conservation agriculture.

4. Discussion

4.1 Physical Properties and Their Implications for Irrigation Agriculture

The physical characteristics of Lake Ruma Wetland soils indicate favourable conditions for sustainable irrigated agriculture. The predominance of loam, silt loam, and clay loam textures reflects a balanced distribution of sand, silt, and clay fractions, providing an optimum combination of water retention, drainage, aeration, and root penetration. Such medium-textured soils are widely regarded as the most productive agricultural soils because they retain sufficient moisture for crop growth while permitting adequate infiltration and gaseous exchange (Brady & Weil, 2022; USDA-NRCS, 2022). Similar textural characteristics have been reported for the Hadejia–Nguru Wetlands in northern Nigeria, the Kilombero Wetland in Tanzania, and the Kafue Flats in Zambia, where seasonal flooding deposits fine alluvial sediments that improve soil structure and agricultural productivity. These similarities suggest that the geomorphological processes governing floodplain wetlands across sub-Saharan Africa produce soils with comparable physical characteristics favourable for irrigated agriculture.

The mean bulk density of 1.13 g cm^{-3} is considerably lower than the critical threshold (approximately 1.40–1.60 g cm^{-3}) that commonly restricts root development in mineral soils. Low bulk density indicates minimal soil compaction, allowing unrestricted root proliferation, improved infiltration, and efficient movement of air and water within the soil profile. The corresponding mean porosity of 68.57% further confirms the favourable structural condition of the wetland soils. High porosity enhances soil-water storage, facilitates gaseous exchange, and supports microbial activity responsible for nutrient cycling. Comparable bulk density values have been reported for freshwater wetlands in Ghana and Ethiopia, where values between 1.10 and 1.25 g cm^{-3} were associated with high infiltration rates and favourable rooting conditions. Conversely, higher bulk densities exceeding 1.35 g cm^{-3} have been reported for intensively cultivated floodplain soils in northern Nigeria, where continuous cultivation and machinery traffic have increased soil compaction and reduced infiltration.

The observed physical properties are also consistent with the geomorphological setting of Lake Ruma Wetland. Seasonal flooding associated with the Kilange River contributes to the deposition of fine sediments and alluvial materials that improve soil structure and moisture-holding capacity. Similar depositional processes have been documented in the Inner Niger Delta of Mali and the Lower Volta floodplain of Ghana, where periodic sediment deposition replenishes soil particles and maintains favourable physical conditions for agricultural production. These findings demonstrate that the physical characteristics of Lake Ruma Wetland are comparable with those of productive floodplain wetlands elsewhere in Africa.

4.2 Soil Reaction and Salinity Status

Soil reaction is one of the principal determinants of nutrient availability and crop productivity. The mean soil pH of 6.61 indicates slightly acidic to near-neutral conditions, which are generally considered optimal for the availability of most essential plant nutrients. Within this pH range, phosphorus remains relatively available, while micronutrient toxicity and aluminium toxicity are minimized. Consequently, the measured pH suggests that the soils provide a chemically favourable environment for cultivating a broad range of food and cash crops. Similar pH values have been reported in the Hadejia–Nguru Wetlands, the Upper Benue floodplains, and several Ethiopian floodplain wetlands, where slightly acidic to neutral soils supported high agricultural productivity. In contrast, wetlands located within more arid environments of Sudan and northern Egypt commonly exhibit alkaline soil conditions due to

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prolonged evaporation and accumulation of exchangeable bases.

Electrical conductivity averaged 0.16 dS m^{-1}, confirming that the soils are non-saline. This value is substantially below internationally accepted salinity thresholds for irrigated agriculture, indicating that soluble salt concentrations are unlikely to restrict germination, plant growth, or crop yield. Comparable non-saline conditions have been reported for freshwater wetlands in Ghana, Uganda, and Tanzania, where seasonal rainfall and floodwaters continually flush soluble salts from the soil profile. Conversely, considerably higher electrical conductivity values have been reported from irrigated wetlands in Pakistan, India, and Egypt, where prolonged irrigation combined with high evapotranspiration has promoted progressive salt accumulation. The very low salinity observed in Lake Ruma Wetland therefore demonstrates that the wetland currently faces little risk of salinity-induced land degradation.

The combination of favourable pH and very low salinity demonstrates that Lake Ruma Wetland soils possess a chemically suitable environment for irrigation development. Unlike many irrigated soils in semi-arid regions where salinity progressively increases through evapotranspiration, the hydrochemical environment of Lake Ruma Wetland currently shows little evidence of salt accumulation.

4.3 Soil Fertility Status

Although the physical properties of the wetland soils were highly favourable, the chemical fertility indicators reveal opportunities for improved nutrient management. Mean soil organic carbon (1.31 g kg^{-1}) and total nitrogen (0.14 g kg^{-1}) were comparatively low, suggesting limited organic matter accumulation and nitrogen reserves. Organic carbon is fundamental to soil quality because it enhances aggregate stability, increases water-holding capacity, improves nutrient retention, and supports soil microbial activity. Likewise, nitrogen is the nutrient most frequently limiting crop production in tropical agricultural systems.

The relatively low organic carbon and nitrogen concentrations observed in this study are consistent with reports from the Sudan Savanna of Nigeria, northern Ghana, and Ethiopian floodplain wetlands, where continuous cultivation, residue removal, grazing pressure, and rapid decomposition under high temperatures have contributed to declining soil organic matter. Similar observations have been reported in the Hadejia floodplain and other inland wetlands of northern Nigeria, where nitrogen depletion rather than soil physical quality was identified as the principal limitation to sustainable agricultural production. In contrast, wetlands under permanent vegetation or limited agricultural disturbance generally contain substantially higher organic carbon concentrations because of continuous organic matter accumulation.

The comparatively favourable available phosphorus concentration (39.75 mg kg^{-1}) differs from many tropical wetland soils where phosphorus deficiency is common due to fixation by iron and aluminium oxides. The relatively high phosphorus availability observed at Lake Ruma Wetland may be attributed to seasonal sediment deposition and nutrient replenishment during annual flooding. Similarly, the moderate cation exchange capacity (10.77 cmol(+) kg^{-1}) agrees with findings from alluvial wetlands in Ghana and Tanzania, indicating a reasonable capacity to retain nutrient cations while remaining responsive to fertilizer application. Consequently, future soil management should prioritize replenishment of organic matter and nitrogen rather than extensive phosphorus supplementation.

4.4 Agricultural Suitability of Lake Ruma Wetland Soils

The integrated evaluation of soil physical and chemical properties demonstrates that Lake Ruma Wetland possesses high agricultural suitability for irrigated crop production. The favourable soil texture, low bulk density, high porosity, suitable pH, and non-saline conditions collectively provide an excellent physical and chemical environment for sustainable agriculture. These characteristics are expected to promote efficient water infiltration, favourable root development, adequate nutrient availability, and sustained crop productivity.

The overall agricultural suitability identified in this study is consistent with irrigation suitability assessments conducted in the Kilombero Valley of Tanzania, the Inner Niger Delta of Mali, the Lower Volta floodplain of Ghana, and the Hadejia–Nguru Wetlands of Nigeria, where medium-textured, non-saline soils with favourable structural characteristics were identified as suitable for sustainable irrigation agriculture. Similar to those studies, however, long-term productivity depends less on inherent soil physical properties than on maintaining soil fertility through appropriate nutrient management.

The assessment further demonstrates that long-term agricultural sustainability will depend upon maintaining soil fertility through appropriate management interventions. The relatively low organic carbon and nitrogen concentrations indicate that continuous cultivation without nutrient replacement may gradually reduce soil productivity. Consequently, integrated soil fertility management—including the application of farmyard manure, compost, green manure, crop residue incorporation, legume-based crop rotations, and balanced mineral fertilization—will be essential for sustaining agricultural production. The findings therefore indicate that the principal constraint to agricultural development within Lake Ruma Wetland is not inherent soil quality but nutrient management. This distinction is important because management-related limitations can be corrected through appropriate agronomic practices, whereas inherent physical limitations are considerably more difficult and expensive to overcome.

4.5 Relationship with the Hydrochemical Assessment

The soil-quality findings complement the hydrochemical assessment presented in the companion water-quality study. Whereas the irrigation-water assessment demonstrated that Lake Ruma Wetland water is generally suitable for irrigation, with elevated Residual Sodium Carbonate representing the principal chemical limitation, the present investigation shows that the soils themselves possess favourable physical properties and acceptable chemical conditions for crop production.

This integrated assessment supports the FAO recommendation that irrigation planning should simultaneously evaluate both irrigation-water quality and soil suitability because deficiencies in either resource can limit agricultural productivity. Similar integrated approaches have been recommended for irrigation development in floodplain wetlands across Africa, where sustainable agricultural production depends on the combined suitability of water resources and soil characteristics.

The integration of both studies therefore provides a comprehensive evaluation of the agricultural resource base of Lake Ruma Wetland. The combined evidence demonstrates that the wetland possesses complementary water and soil resources capable of supporting sustainable irrigation development, provided that irrigation-water chemistry and soil fertility are periodically monitored and appropriately managed.

4.6 Scientific Contribution and Management Implications

This study represents one of the first comprehensive evaluations of the physicochemical properties of Lake Ruma Wetland soils within the context of irrigation suitability. Unlike previous studies in north-eastern Nigeria that primarily emphasized descriptive soil characterization, hydrology, or land-use dynamics, the present study integrates soil physical properties, chemical fertility indicators, and irrigation suitability within a single evaluation framework. This integrated approach provides a more comprehensive and evidence-based basis for irrigation planning, sustainable land management, and policy formulation for inland wetlands within the Sudan Savanna.

The findings contribute to wetland management by demonstrating that Lake Ruma Wetland possesses a favourable soil resource capable of supporting agricultural intensification under appropriate management. Similar conclusions have been reported for floodplain wetlands in Ghana, Tanzania, and Mali, where sustainable agricultural development depended not only on favourable soil characteristics but also on effective nutrient management and environmental conservation. The present study therefore reinforces the importance of integrating soil quality assessment into irrigation planning because sustainable agricultural development depends not only on water availability but also on maintaining soil fertility and structural integrity.

From a policy perspective, the findings support strategic investment in irrigation infrastructure within Lake Ruma Wetland while emphasizing the need for complementary soil conservation programmes. Strengthening agricultural extension services, promoting integrated soil fertility management, encouraging conservation agriculture, and implementing routine soil monitoring will enhance long-term productivity while safeguarding the ecological integrity of the wetland ecosystem.

5. Conclusions

This study evaluated the physicochemical properties of soils within Lake Ruma Wetland to determine their suitability for sustainable irrigation agriculture in northeastern Nigeria. The results indicate that the wetland possesses favourable edaphic conditions for irrigation development. The soils are predominantly loam, silt loam, and clay loam, with low bulk density and high porosity, providing suitable conditions for root growth, water infiltration, moisture retention, and aeration. Chemically, the soils are slightly acidic to near neutral (mean pH 6.61), non-saline, and exhibit moderate cation exchange capacity, indicating favourable conditions for crop production and nutrient retention.

The principal limitation is low organic carbon and total nitrogen, suggesting that long-term productivity will depend on effective soil fertility management. Practices such as organic amendments, balanced fertilizer application, conservation agriculture, residue retention, and legume-based crop rotation are therefore recommended to sustain soil fertility.

Overall, the findings demonstrate that Lake Ruma Wetland has high potential for sustainable irrigation agriculture and provide an evidence-based foundation for irrigation planning, sustainable land management, and agricultural policy development in the Sudan Savanna region of northeastern Nigeria.

Practical Recommendations

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Based on the findings, the following recommendations are proposed:

1. The soils of Lake Ruma Wetland should be prioritized for sustainable irrigation development because of their favourable physical characteristics and non-saline chemical conditions.
2. Organic matter management should be strengthened through the incorporation of compost, farmyard manure, green manure, and crop residues to improve soil organic carbon and nitrogen status.
3. Balanced fertilizer application based on periodic soil testing should be encouraged to maintain nutrient availability and optimize crop productivity.
4. Conservation agriculture practices, including minimum tillage, mulching, and crop rotation with legumes, should be promoted to reduce soil degradation and improve long-term soil health.
5. Routine monitoring of soil physicochemical properties should be undertaken to detect temporal changes associated with continuous irrigation and changing climatic conditions.
6. Future investigations should evaluate seasonal variations in soil fertility, micronutrient availability, biological soil quality, and carbon sequestration potential to support long-term wetland management.

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