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Characterization of Soil Quality Parameters in Sector 2 of Watari Irrigation Project, Kano

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Abstract
This study evaluated the physical and chemical properties of soils in Sector 2 of the Watari Irrigation Project, Kano State, Nigeria. The study was conducted to assess the effects of prolonged irrigation on soil quality. A total of 24 composite soil samples were collected from irrigated and non-irrigated fields at two depths (0-30 cm and 30-60 cm). Laboratory analyses assessed bulk density (BD), porosity, pH, electrical conductivity (EC), organic carbon (OC), sodium adsorption ratio (SAR), cation exchange capacity (CEC), and exchangeable cations. Historical (2013) and current (2025) soil data were compared to evaluate temporal changes in soil quality. Independent-samples t-tests and Ordinary Kriging interpolation were used to assess statistical differences and the spatial distribution of selected soil quality indicators. Results showed that irrigated soils had higher EC (2.6 dS/m), SAR (5.2), and pH (7.3-7.5) but lower OC (1.20%) and CEC (6.4 cmol/kg) than non-irrigated soils, indicating progressive salinity, sodicity, and declining soil fertility. Independent-samples t-tests revealed significant differences in SAR ($p = 0.0187$) and Mg ($p = 0.0374$), while CEC ($p = 0.0509$) showed a marginally significant decline. Kriging maps identified degradation hotspots in irrigated zones. The findings demonstrated that prolonged irrigation without appropriate soil and water management has contributed to progressive chemical degradation. Regular soil monitoring, improved drainage, and organic amendments are recommended to enhance soil quality and sustain agricultural productivity.

Keywords: *Soil characterization, Watari irrigation, Salinity, Sodicity, Kriging.*

1.0 Introduction

The sustainable management of soil resources in irrigation schemes is central to enhancing food security, particularly in semi-arid environments like northern Nigeria. However, declining yields in specific zones of irrigated farmland have raised concerns about the long-term impacts of continuous irrigation on soil quality. Sector 2 of the Watari Irrigation Project in Kano State exemplifies this issue, with field reports indicating persistent crop performance decline despite consistent water supply.

Soil degradation under irrigation may be caused by physical and chemical changes such as salinization, sodicity, compaction, and loss of fertility. Numerous studies have reported that inadequate irrigation management leads to the accumulation of soluble salts and exchangeable sodium in the soil profile, which can reduce crop productivity and alter soil structure [4], [6]. In particular, salinity and sodicity are known to interfere with plant water uptake and nutrient availability, leading to long-term soil degradation.

Although previous studies have evaluated soil and irrigation water quality within parts of the Watari irrigation projects, [2], [8], most focused on either current soil conditions or isolated physicochemical properties. Limited studies have integrated temporal comparison, statistical analysis, and geospatial techniques to assess long-term soil degradation within sector 2. Therefore, there is a need to evaluate present soil conditions relative to historical observations in order to identify degradation trends and support sustainable soil management.

This study characterizes the physical and chemical properties of soils in sector 2 of the Watari Irrigation project by integrating historical (2013) and current (2025) datasets. The study combines descriptive statistics, independent-samples t-test, and Kriging interpolation to evaluate temporal changes, determine statistically significant differences, and visualize the spatial distribution of major soil degradation indicators. This integrated approach provides a more comprehensive assessment of soil quality and supports site-specific soil management within irrigated agricultural systems.

2.0 Materials and Methods

2.1 Study Area

The study was carried out at sector 2 of the Watari Irrigation Project, Bagwai Local Government Area of Kano State, Nigeria (12^{o} 05'-12^{o} 12'N, 8^{o} 08'-8^{o} 17'E). The area lies in the Sudan Savanna agro-ecological zone, downstream of the Watari Dam and receives approximately 700-813mm rainfall annually, [13]. Sector 2 was selected due to consistent farmer complaints and observed productivity issues.

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2.2 Sampling Design

A comparative field sampling approach was adopted to evaluate soil quality under irrigated and non-irrigated land uses. Soil samples were collected from two land-use categories at two sampling depths (0-30 cm and 30-60 cm). Twelve sampling locations were selected across the study area. At each location, composite soil samples were collected at each depth, resulting in a total of twenty-four (24) samples. The geographical coordinates of each sampling point were recorded using a Garmin GPS 72H receiver to support spatial interpolation and geostatistical analysis.

2.3 Laboratory Analysis

Soil samples were air-dried, gently crushed, and sieved through a 2 mm sieve before laboratory analysis. Physical and chemical analyses were conducted using standard analytical procedures recommended by FAO and ISO.

2.3.1 Physical properties

- **Bulk Density (BD):** Measured using the core method following current FAO protocols [5].

$$Bulk\ Density\ (BD) = {Oven\ dry\ weight\ of\ soil\ (g)} \Big/ {Volume\ of\ core\ (cm^3)} \quad (1)$$

- **Porosity:** Calculated from bulk density and particle density of 2.65 g/cm^3 using:

$$porosity = \left[1 - \frac{BD}{PD}\right] \times 100 \quad (2)$$

2.3.2 Chemical properties

- Soil pH: Measured in both distilled water and 0.01 M $CaCl_2$ at a 1:2:5 soil-to-solution ratio using a digital pH meter [9].
- Electrical conductivity (EC): Assessed using a conductivity meter in soil-water extract at 1:2 ratios [9].
- Organic carbon (OC): Determined using Walkley-Black dichromate oxidation method [9].
- Cation Exchange Capacity (CEC): Determined using ammonium acetate saturation at pH 7.0 [9].
- Exchangeable Cations (Ca^{2+}, Mg^{2+}, K^+, Na^+): Extracted with 1M ammonium acetate and analyzed by ICP-OES [9].
- Sodium Adsorption Ratio (SAR) was calculated from the concentrations of sodium, calcium and magnesium ions as:

$$Sodium\ Adsorption\ Ratio\ (SAR) = [Na^+] / (\sqrt{([Ca^{2+}]+[Mg^{2+}])/2}) \quad (3)$$

where BD is the bulk density, PD is the particle density, SAR is sodium adsorption ratio, Na^+ is sodium ion, Ca^{2+} is the calcium ion, and Mg^{2+} is the magnesium ion.

2.4 Historical and Present Data Presentation

Historical soil data obtained from previous studies conducted in 2013 [1], within the study area were used as baseline information for comparison with the present (2025) observations. The comparison was intended to evaluate changes in selected soil quality indicators over time and to assess the extent of soil degradation associated with prolonged irrigation practices.

2.5 Statistical and Spatial Analysis

Descriptive statistics were conducted for all measured soil properties. Independent-samples t-tests were performed using IBM SPSS Statistics version 25 to determine significant differences between irrigated and non-irrigated soils at a 95% confidence level ($p < 0.05$). Spatial variability of bulk density, pH, electrical conductivity, sodium adsorption ratio, organic carbon and cation exchange capacity was evaluated using Ordinary Kriging interpolation in ArcGIS. The interpolation maps were used to identify spatial patterns and potential soil degradation hotspots within the study area.

3.0 Results and Discussion

3.1 Physical Properties

Table 1 shows the mean physical properties of irrigated and non-irrigated fields. Irrigated soils exhibited slightly higher bulk density and lower porosity than non-irrigated soils, indicating gradual soil compaction associated with continuous irrigation and field operations. Increased bulk density reduces pore space, restricts root penetration, limits aeration, and decreases water infiltration. Similar observations have been reported in irrigated soils of northern Nigeria where prolonged irrigation accelerated structural deterioration. Lower moisture retention and field capacity further suggest deterioration of soil physical quality due to reduced organic matter and repeated cultivation [6], [14].

Table 1: Physical Soil Properties

Property	Irrigated (Mean ± SD)	Non-irrigated (Mean ± SD)
Porosity (%)	44.2 ± 1.5	46.8 ± 1.2
Moisture Content (%)	11.20 ± 0.20	13.13 ± 0.15
Field Capacity (%)	24.50 ± 0.36	26.13 ± 0.15
Wilting Point (%)	9.27 ± 0.15	10.53 ± 0.15

3.2 Chemical Properties

Table 2 shows the chemical properties for both irrigated and non-irrigated fields. Irrigated soils recorded higher EC, SAR and soil pH than non-irrigated soils, indicating progressive salt accumulation and increasing sodicity. Continuous irrigation under inadequate drainage promotes the accumulation of soluble salts within the root zone, particularly in semi-arid environments where evapotranspiration exceeds rainfall. Elevated SAR suggests increasing sodium dominance, which adversely affects soil aggregation, infiltration and hydraulic conductivity. Conversely, lower organic matter and cation exchange capacity indicate declining soil fertility and reduced nutrient-holding capacity. These findings agree with previous studies that reported deterioration of irrigated soils due to prolonged cultivation without adequate soil management practices [2], [4].

Table 2: Chemical Soil Properties

Property	Irrigated (Mean)	Non-irrigated (Mean)
pH (H_2O)	7.34	6.82
pH ($CaCl_2$)	6.88	6.55
Electrical Conductivity (EC) (dS/m)	2.60	0.90
Sodium Adsorption Ratio (SAR)	5.20	2.10
Organic Matter (OM) (%)	1.20	1.58
Cation Exchange Capacity (CEC) (cmol/kg)	6.40	7.10
Calcium (Ca^{2+}) (cmol/kg)	3.44	3.66
Magnesium (Mg^{2+}) (cmol/kg)	1.55	1.39
Potassium (K^{+}) (cmol/kg)	1.64	1.69
Sodium (Na^{+}) (cmol/kg)	0.55	0.38

3.3 Present and Past Soil Characteristics Data

Comparison of the 2013 and 2025 datasets revealed substantial changes in several soil quality indicators. The marked increases in electrical conductivity and sodium adsorption ratio indicate progressive salinity and sodicity development over the twelve-year period. The increase in soil pH also reflects gradual alkalization associated with continuous irrigation. Conversely, the decline in cation exchange capacity suggests depletion of soil organic matter and deterioration of clay mineral exchange sites. These changes collectively indicate gradual soil degradation and emphasize the need for improved irrigation scheduling, drainage management and organic matter restoration. [1], [8].

Table 3 shows the past and present soil characteristics, EC and SAR increased drastically (1.75 dS/m and 3.65), indicating advanced salinity and sodicity development, often linked to prolonged irrigation without drainage [15]; [12]. Rise in pH (7.0) confirmed a trend toward alkalinity, affecting nutrient availability [21]. Decrease in CEC (6.75cmol/kg) was recorded, reflecting organic matter decline and possible clay dispersion, impairing nutrient retention, which is consistent with the findings by [17]. Increase in Na^{+} (0.64 cmol/kg) is alarming, and aligns with SAR rise and reduced CEC, suggesting early sodic soil conditions. K^{+}, Ca^{2+}, and Mg^{2+} levels show moderate changes, which could likely be residual from fertilizers or water sources.

Table 3: Past and Present Soil Properties

Parameter	Data (2013)	Present (2025)
pH (H_2O)	6.130	7.00
pH ($CaCl_2$)	5.500	5.84
EC (dS/m)	0.532	1.75
SAR	0.328	3.65
OM (%)	1.242	1.39
CEC (cmol/kg)	10.555	6.75
Ca^{2+} (cmol/kg)	3.560	3.66

Parameter	Data (2013)	Present (2025)
Mg^{2+} (cmol/kg)	1.380	1.55
K^{+} (cmol/kg)	1.660	1.75
Na^{+} (cmol/kg)	0.360	0.64

Source: Adamu, (2013)

3.4 Kriging Spatial Analysis

Kriging, a geostatistical interpolation method, was used to assess and visualize the spatial distribution of key soil chemical properties across the sampled area. The analysis was conducted using ArcGIS. The six variables interpolated were bulk density (BD), pH, electrical conductivity (EC), sodium adsorption ratio (SAR), organic matter (OM), and cation exchange capacity (CEC). As the critical indicators of soil degradation under irrigation.

Figure 1 shows low EC levels (≤ 1.2 dS/m) in red, in the Western part of the area (non-irrigated area), suggesting non-saline conditions. Central region ranges between 1.6 – 2.3 dS/m, indicating moderate salinity, while eastern part (irrigated area), has higher EC values (> 2.3 dS/m) in blue, which indicated salinity buildup. Higher EC levels in the east suggest accumulation of salts, possibly due to poor drainage or excessive irrigation without leaching. Spatial variability indicates potential soil salinization risks, especially in intensively irrigated fields. This study is consistent with the findings by [16], who observed similar salinity patches in irrigated zones of Watari, attributed to waterlogging and high evapotranspiration. [20] confirmed salt accumulation in subsurface layers due to long-term irrigation without adequate drainage.

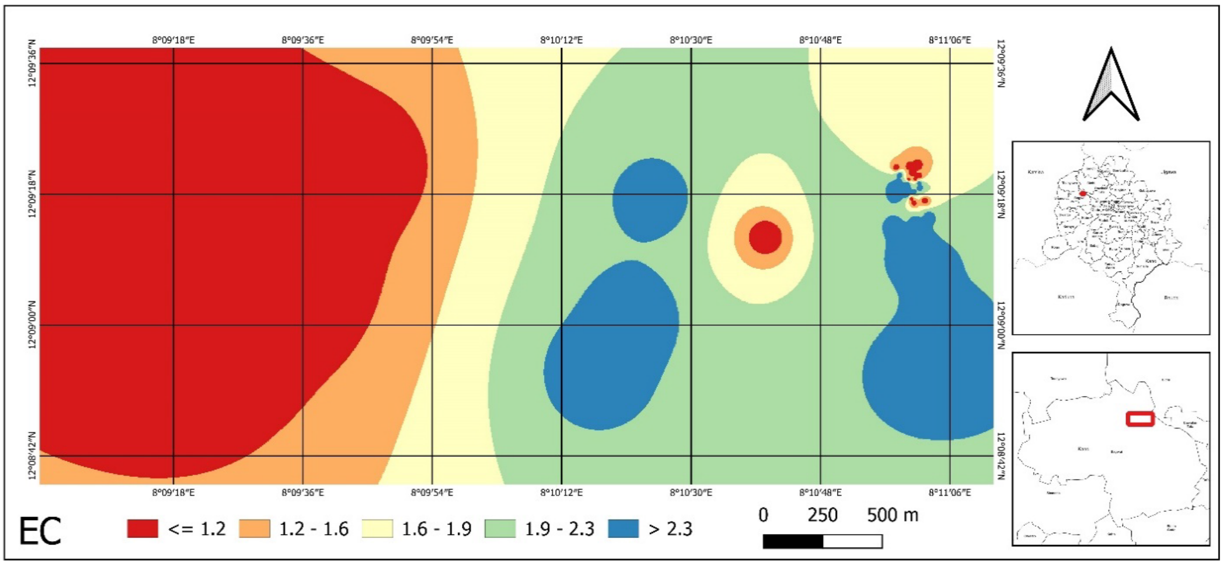

Figure 1: Kriged Map of Electrical Conductivity EC (dS/m)

Figure 2 shows the Kriged map of bulk density of the sector 2 of Watari Irrigation Project. Low bulk density values (≤ 1.4 g/cm³) dominated the western side of the field shown in red, suggesting loose and porous soils. It increases gradually eastwards, with values > 1.4 g/cm³ in blue zone. The higher bulk density implies compaction, which reduces infiltration, aeration, and root growth. [3] found bulk density increases under irrigation, particularly in fine-textured soils subjected to intensive traffic and tillage. Similar results were reported by [8], showing a correlation between irrigation age and soil compaction.

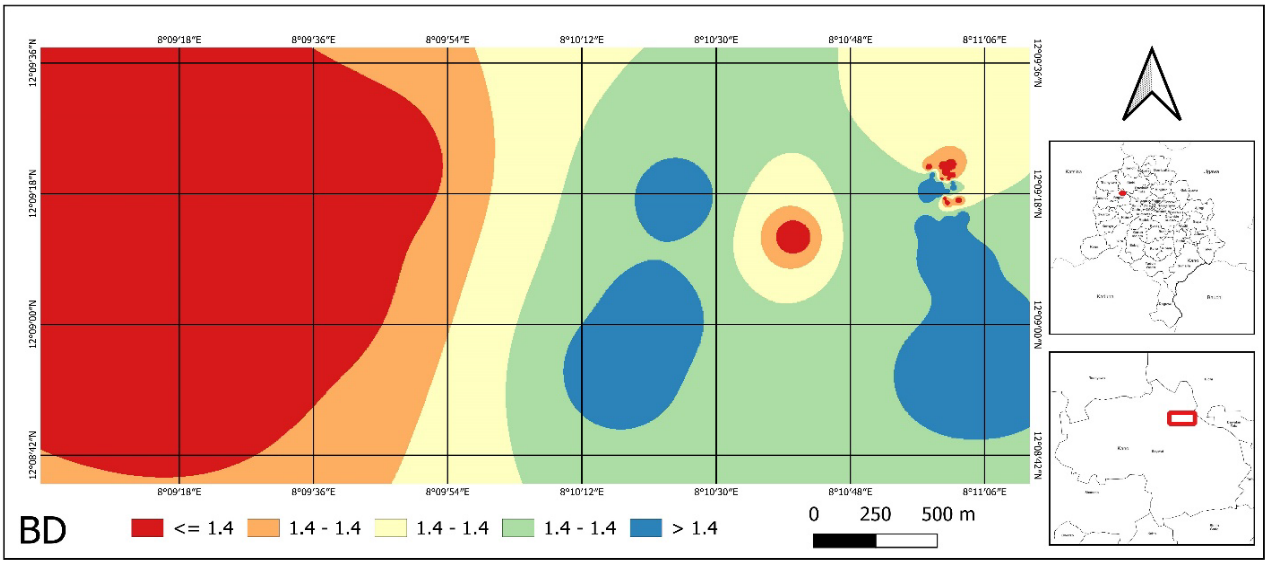

Figure 2: Kriged Map of Bulk Density BD (g/cm³)

Figure 3 shows the Kriged map of the sector for pH, it shows that acidic zones (non-irrigated), (pH ≤ 6.8) are located in the west (red). The center is dominated by neutral to slightly alkaline soils (6.8 – 7.2). The eastern portion was noted to be an alkaline area (irrigated area), (> 7.2) shown in blue. Shift from acidic to alkaline conditions reflects irrigation effects, possibly from alkaline irrigation water or accumulated basic cations (Na^+, Ca^{2+}, Mg^{2+}). pH values above 7.2 may affect nutrient availability, especially micronutrients like Fe, Zn, and Mn.

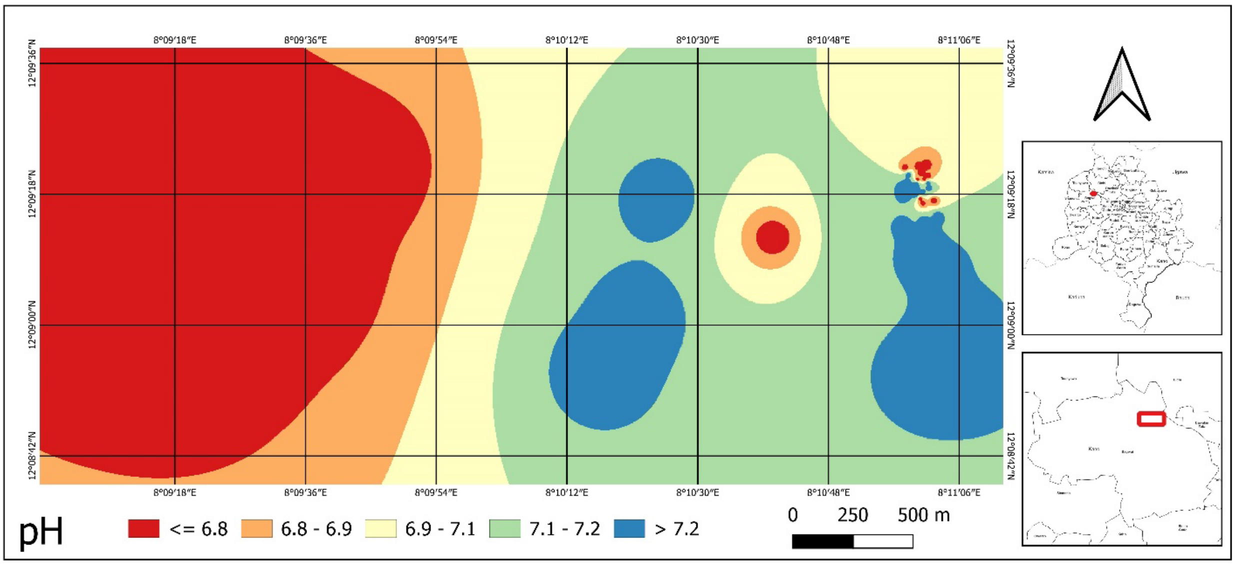

Figure 3: Kriged Map of pH

Figure 4 shows the Kriged map of organic matter of the sector 2. The western part of the study area (non-irrigated area), showed relatively high organic matter content (> 1.5 %) in blue and green zones, likely due to better soil structure or less intensive land use, which is adequate for agricultural soils in the region. This aligns with the findings of [19], who observed higher OM levels in less disturbed fields within the Watari project. The Central and Eastern zones (irrigated zones), recorded very low OM (≤ 1.3%) in red and orange zones, consistent with [11], who reported declining organic matter levels in Kano's irrigated lands due to continuous cropping without organic residue return.

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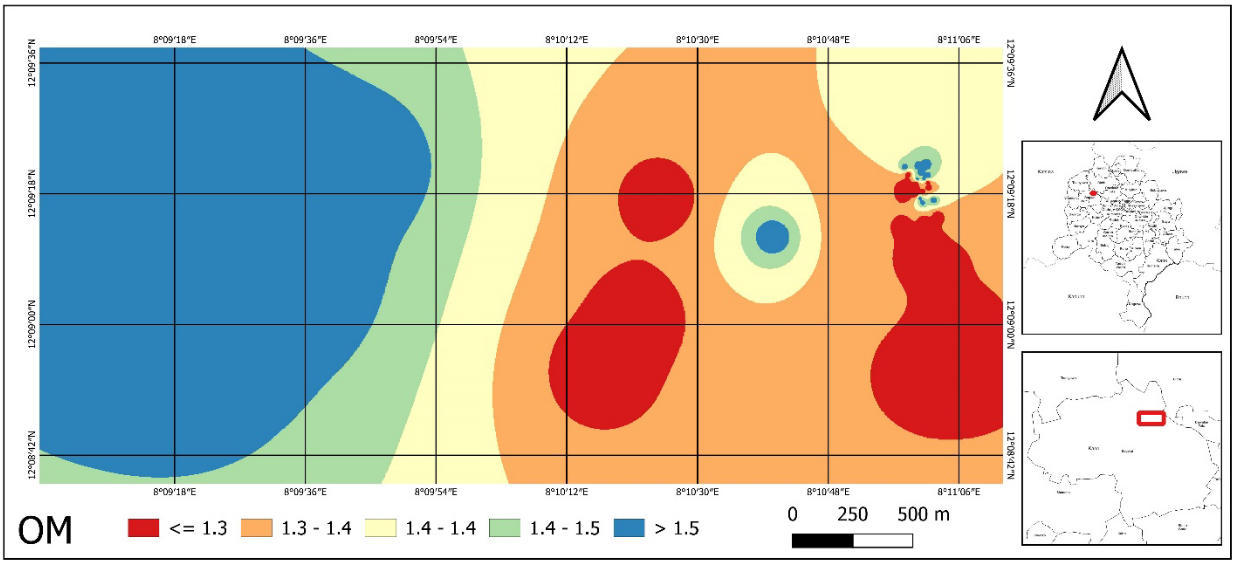

Figure 4: Kriged Map of Organic Matter OM (%)

Figure 5 shows the Kriged map for sodium adsorption ratio of the area. SAR values were lowest in the Western zone (non-irrigated area), (≤ 2.7) in red and orange, indicating minimal sodicity. However, Central and Southeastern zones (irrigated zones), showed elevated SAR (>4.6) blue areas, suggesting serious sodicity risks, potentially caused by poor leaching. Consistent with findings by [20], who observed that irrigation without proper drainage led to SAR buildup in Kano's irrigated zones. [18], reported increasing sodicity levels in similar fields at KRIP and Watari under poor leaching conditions.

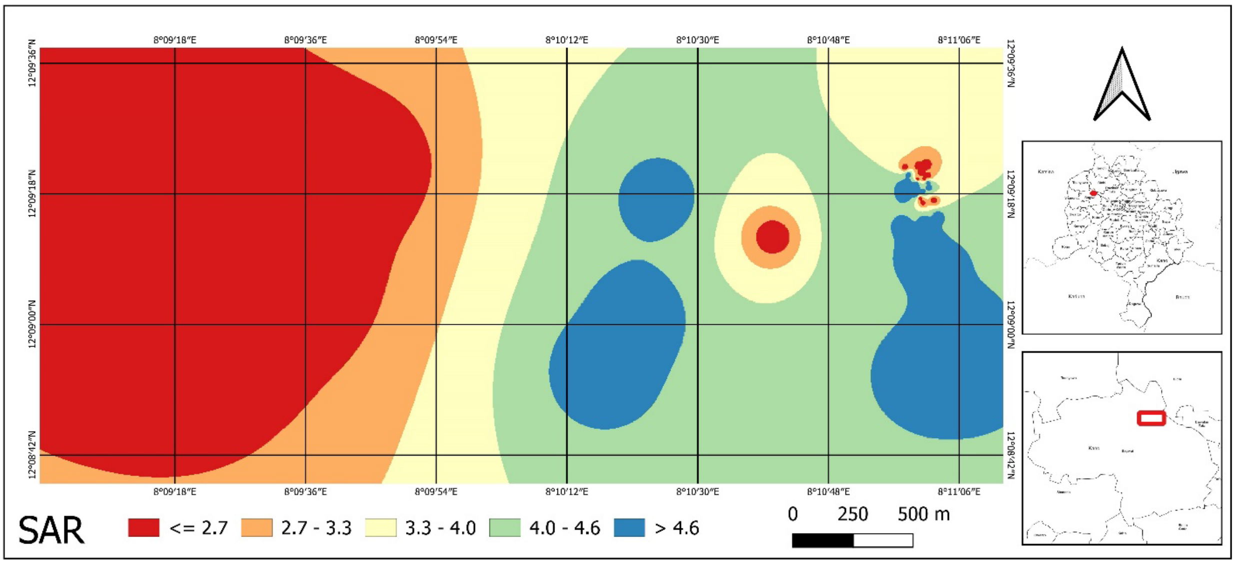

Figure 5: Kriged Map of Sodium Adsorption Ratio SAR

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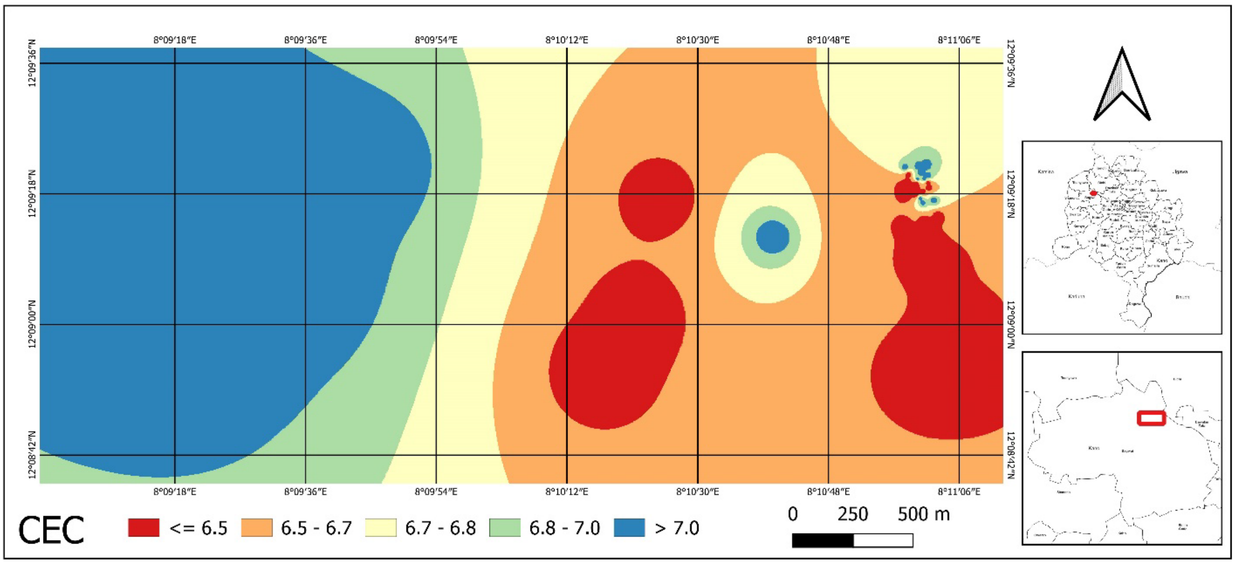

Figure 6: Kriged Map of Cation Exchange Capacity CEC (cmol/kg)

Figure 6 shows a Kriged map for CEC for the sector 2 area. CEC distribution of higher values (> 7.0 cmol/kg) were recorded in the Western zone in blue, while Central and Southeastern zones (irrigated plots) in red and orange had values ≤ 6.5 cmol/kg. This pattern has been documented in similar studies by [7], in their study on soils in Wudil and Kura (adjacent to Watari), observed that soils with poor organic matter and elevated SAR had significantly reduced CEC and poor productivity, highlighting the need for site-specific soil fertility restoration.

The Kriging maps clearly demonstrated that soil degradation was spatially variable rather than uniformly distributed across the study area. Areas under continuous irrigation consistently exhibited higher electrical conductivity, sodium adsorption ratio, bulk density and soil ph, whereas higher organic matter and cation exchange capacity were associated with non-irrigated locations. These spatial patterns indicate that irrigation practices have significantly influenced soil quality and justify the adoption of site-specific management strategies rather than uniform field-wide interventions.

4.0 Conclusion

This study successfully characterized the physical and chemical properties of soils within sector 2 of the Watari Irrigation Project, Kano State, and demonstrated the influence of long-term irrigation on soil quality. The findings show differences between irrigated and non-irrigated soils, highlighting the extent and underlying causes of declining productivity in the area. Physical properties such as bulk density and porosity reflected moderate compaction in irrigated areas compared to non-irrigated areas. Available water content and porosity were lower in the irrigated field, indicating reduced structural integrity due to long-term water application without organic amendments. Chemical analysis showed that irrigated soils had significantly higher electrical conductivity (EC) and sodium adsorption ratio (SAR), both indicating salt accumulation. These values exceeded critical thresholds for crop tolerance, confirming the presence of salinity and early sodicity. Non-irrigated soils maintained higher organic carbon and cation exchange capacity (CEC), critical indicators of soil fertility and resilience. The analysis confirmed statistically significant increases in SAR ($p = 0.0187$) and Mg ($p = 0.0374$), while CEC showed a marginally significant decline ($p = 0.0509$). Other parameters such as EC, OM, Ca^{2+} and K^+ showed noticeable changes but were not statistically significant ($p > 0.05$). This points to the loss of essential nutrients and exchange sites, rendering the soil less productive over time. Spatial analysis using kriging interpolation further revealed that soil degradation is not uniform. Maps of EC, BD, SAR, OM, pH and CEC showed specific zones of concern, primarily concentrated in irrigated areas of the low-yield sector. This spatial variability reinforces the need for location-specific management strategies. The evidence from this study demonstrates that the combination of prolonged irrigation, insufficient organic input, and poor drainage has led to significant chemical degradation of soil in the area. Without urgent and tailored intervention, long-term agricultural sustainability in the area is at risk.

The findings demonstrate that continuous irrigation without adequate drainage and soil fertility management has contributed to progressive soil degradation within the study area. Adoption of integrated soil fertility management, improved drainage systems, periodic soil monitoring, gypsum application where appropriate and incorporation of organic amendments are recommended to restore soil productivity and ensure the long-term sustainability of irrigated agriculture.

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