

When the Soil Drinks Poor Water, Can the Crops Quench Our Hunger? An Analysis of Soil and Water Quality for Irrigation Farming and Its Effect on Crop Yield in Numan Local Government Area, Adamawa State, Nigeria

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Abstract

Soil and water are foundational resources for sustainable agriculture, and their quality directly determines the success of irrigation practices. This study assessed soil and water quality for irrigation farming and its effect on crop yield in Numan Local Government Area of Adamawa State, Nigeria, to identify chemical imbalances and evaluate compliance with Food and Agriculture Organization (FAO) standards. A mixed-methods approach was employed, combining field surveys, soil and water sampling, laboratory analyses, and questionnaire administration to 384 irrigation farmers across ten wards. Thirty soil samples and six water samples were analysed for key physical and chemical parameters, including texture, pH, electrical conductivity, nutrient content, turbidity and heavy metals. The results reveal that while some parameters remained within acceptable limits, several, particularly salinity, electrical conductivity and certain nutrient or metal concentrations, exceeded FAO thresholds, indicating emerging risks of soil degradation, reduced fertility and lower crop yields. Furthermore, among water variables, Nitrate (NO_3^-) ($r = 0.858$, $p = 0.029$) and Potassium (K) ($r = 0.449$, $p = 0.037$) positively correlated with yield, while NTU, Carbonate, Calcium, Iron, Sodium, Chloride, and Zinc showed significant negative correlations ($p = 0.016$ – 0.042). For soil variables, Available Nitrogen (AvN) ($r = 0.894$, $p = 0.004$), Potassium (K) ($r = 0.738$, $p = 0.002$), and Available Phosphorus (AvP) ($r = 0.587$, $p = 0.048$) positively influenced yield, whereas Sodium (Na) negatively correlated ($r = -0.813$, $p = 0.049$). Organic Carbon (Org.C) had a moderate positive effect ($r = 0.355$, $p = 0.03$). These results indicate that nitrogen, potassium, and phosphorus enhance crop productivity, while excessive sodium and certain water constituents reduce yield. These findings underscore the urgent need for improved soil and water management, regular monitoring, adoption of salt-tolerant crops, and institutional support to guide farmers on sustainable irrigation practices. By addressing these challenges, irrigation farming in Numan LGA can be made more resilient, productive and environmentally sustainable.

Keywords: Soil sustainability, Irrigation farming, Soil and water quality, Sustainable Land Management

INTRODUCTION

Soil and water are fundamental environmental resources for agriculture, forming the basis of productive farming (Smith, 2010). Soil is made up of mineral particles and provides the medium for plant growth, while its pore spaces store air

necessary for microbial activity and soil fertility. Organic matter, derived from decomposed plant and animal remains, enriches the soil with nutrients, improves structure, and enhances water-holding capacity (Brown, 2015; Smith & Johnson, 2012). Water is equally indispensable,

as soil moisture transports essential nutrients to plant roots (Jones, 2018). Ideally, soil comprises about 45% mineral matter, 25% air, 25% water, and 5% organic matter (Smith *et al.*, 2019). However, factors such as low rainfall and high evaporation can deplete soil moisture and reduce productivity (Smith & Thompson, 2021). Irrigation replenishes moisture during dry periods, ensuring continued crop growth (Joseph *et al.*, 2019). Its success depends on soil texture, moisture, temperature, and the quality and timing of water application (Nasidi, 2016). Properly managed irrigation prevents waterlogging, sustains fertility, and boosts yields.

Irrigation enhances crop productivity, stabilizes farmers' incomes, creates employment, and supports multiple cropping and diversification. When practiced sustainably, it increases food production while conserving natural resources. In Nigeria, irrigation enables year-round cultivation, meeting growing food demand and improving farmer livelihoods (Mohammed & Ali, 2021). Yet, many schemes in northern Nigeria underperform due to poor management by government agencies and farmers (Jibril *et al.*, 2017). Reviewing these schemes offers insight into their sustainability, functionality, and production levels. This study therefore aims to diagnose existing challenges, propose solutions, and improve irrigation practices for sustainable agricultural growth in Nigeria. Furthermore, a clear understanding of the socio-economic and environmental contexts of irrigation schemes is vital for improving their effectiveness. Elements such as water governance, infrastructure maintenance, access to credit, farmer training, and active community participation play decisive roles in the success and long-term sustainability of these projects (Akinsanya & Bello, 2020). In addition, the adoption of modern approaches, ranging from efficient water-use systems and climate-smart practices to the use of remote sensing for monitoring, helps to optimise resource allocation and minimise waste. When irrigation initiatives are tailored to local realities, institutional capacity and environmental safeguards, Nigeria can build more resilient agricultural systems that strengthen national food

security and support rural development (World Bank, 2022).

Farmers in Numan Local Government Area of Adamawa State have voiced concerns over declining crop yields and adverse changes in soil characteristics, despite the absence of formal records or organized data on productivity. These problems are largely linked to unsustainable soil management practices, which threaten the long-term viability of irrigation farming in the area. In response, there is an urgent need for a comprehensive evaluation of soil and water quality to safeguard the sustainability of irrigational activities. It is also essential to identify and invest in areas with potential for irrigation farming to expand productive land, boost agricultural output, and promote overall sustainability. Against this backdrop, the study set out to assess the sustainability of soil for irrigation farming in Numan Local Government Area and to explore investment opportunities for increasing productive land. In doing so, it sought to answer two central questions: first, what changes in soil and water quality may affect irrigation activities in the study area; and second, whether the soil and water quality at the irrigation sites meet Food and Agricultural Organization (FAO) and World Health Organization (WHO) standards.

Literature Review

Physical and chemical properties of soil for sustainable irrigation

Sustainable irrigation is a critical component of agricultural practices aimed at ensuring food security and environmental conservation. To achieve sustainability in irrigation, it is imperative to comprehend the intricate interplay between physical and chemical properties of soils. Physical properties, such as texture, structure, and porosity, play a pivotal role in determining water movement, retention, and availability in soils (Osman & Osman, 2013). Soil texture, characterized by the relative proportions of sand, silt, and clay, influences water retention capacity and drainage characteristics. Chemical properties, including

nutrient content, pH, and salinity, directly impact soil fertility and plant health. The availability of essential nutrients is crucial for crop growth, and understanding soil chemistry aids in formulating precise irrigation strategies. For instance, a study by Calegari et al. (2013) highlights the relationship between soil pH and nutrient availability, demonstrating that maintaining optimal pH levels enhances nutrient uptake efficiency.

Chemical properties of soil for sustainable irrigation

The chemical properties of irrigation water also significantly impact soil health and crop productivity.

I. Soil pH

Soil pH is a measure of the acidity or alkalinity of the soil. It profoundly influences nutrient availability to plants, with different crops thriving in specific pH ranges. Sustainable irrigation considers the adjustment of soil pH to ensure optimal nutrient uptake by crops. High salinity levels in water sources can lead to soil salinization, adversely affecting plant growth (Machado & Serralheiro., 2017). A study by Wu & Ma. (2015) explained how maintaining the appropriate pH range is crucial for efficient nutrient uptake by crops, reducing the need for excessive fertilization and mitigating environmental impacts.

ii. Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) influences the soil's ability to retain essential cations, including calcium, magnesium, and potassium. CEC is the soil's ability to retain and supply essential cations (positively charged ions) to plant roots. It is influenced by soil clay and organic matter content. Research by Manorama et al. (2021) emphasized the importance of understanding CEC in soil management to optimize nutrient supply, thus contributing to sustainable irrigation practices.

Advancements in technology have enabled the integration of soil sensing and monitoring tools in precision agriculture for sustainable irrigation. Real-time monitoring of soil moisture, salinity, and nutrient levels allows for adaptive irrigation

management (Levy *et al.*, 2013). This integration is crucial for optimizing water use efficiency and minimizing environmental impacts associated with irrigation. The changing climate introduces new challenges to sustainable irrigation. Alterations in temperature and precipitation patterns influence soil properties, affecting water availability and demand (Corwin, 2021). Understanding the dynamic interaction between climate change and soil properties is essential for developing resilient irrigation strategies.

iii. Nutrient Levels

Soil nutrient levels, including nitrogen (N), phosphorus (P), potassium (K), and other micronutrients, are crucial for plant growth and development. Fertility are adequate nutrient levels support healthy plant growth. Soil tests help assess nutrient levels, guiding the application of fertilizers to meet plant requirements and prevent excess, which can lead to environmental issues (Corwin, 2021).

MATERIALS AND METHODS

Study Area

Numan Local Government Area is located in the southern part of Adamawa State, Nigeria, between latitudes 9°25'N and 9°36'N and longitudes 11°47'E and 12°02'E (Figure 1), covering an area of approximately 746.38 km². The area is bounded by Guyuk, Shelleng, Demsa and Lamurde LGAs to the north, Girei and Yola South to the east, Fufore, Mayo-Belwa and Taraba State to the south and west, and Gombe State to the northwest. The area experiences a tropical climate with distinct wet (May–October) and dry (November–April) seasons, with mean annual rainfall ranging from 700 to 1600 mm and temperatures varying between approximately 15 °C and 41 °C.

The terrain is undulating, with elevations ranging from about 400 m in valley floors to over 600 m on isolated hills, underlain mainly by Precambrian Basement Complex rocks, including gneiss, granite, schist and amphibolites. Soils are predominantly sandy loam and sandy clay, derived from highly weathered parent materials, with generally good

drainage but varying water-holding capacities. Vegetation falls within the Northern Guinea Savanna, characterized by scattered woodlands, shrubs and tall grasses adapted to seasonal moisture stress.

The area is primarily drained by the River Benue and its major tributary, the River Gongola, which form extensive floodplains that support dry-season farming and irrigation through shallow

groundwater and productive wash bores. Socio-economic activities are dominated by agriculture, fishing, livestock rearing and local trade, with maize, rice, guinea corn and beans as major crops. Land use is largely agricultural with patches of built-up areas, bare surfaces and water bodies, reflecting strong dependence on land and water resources for livelihoods.

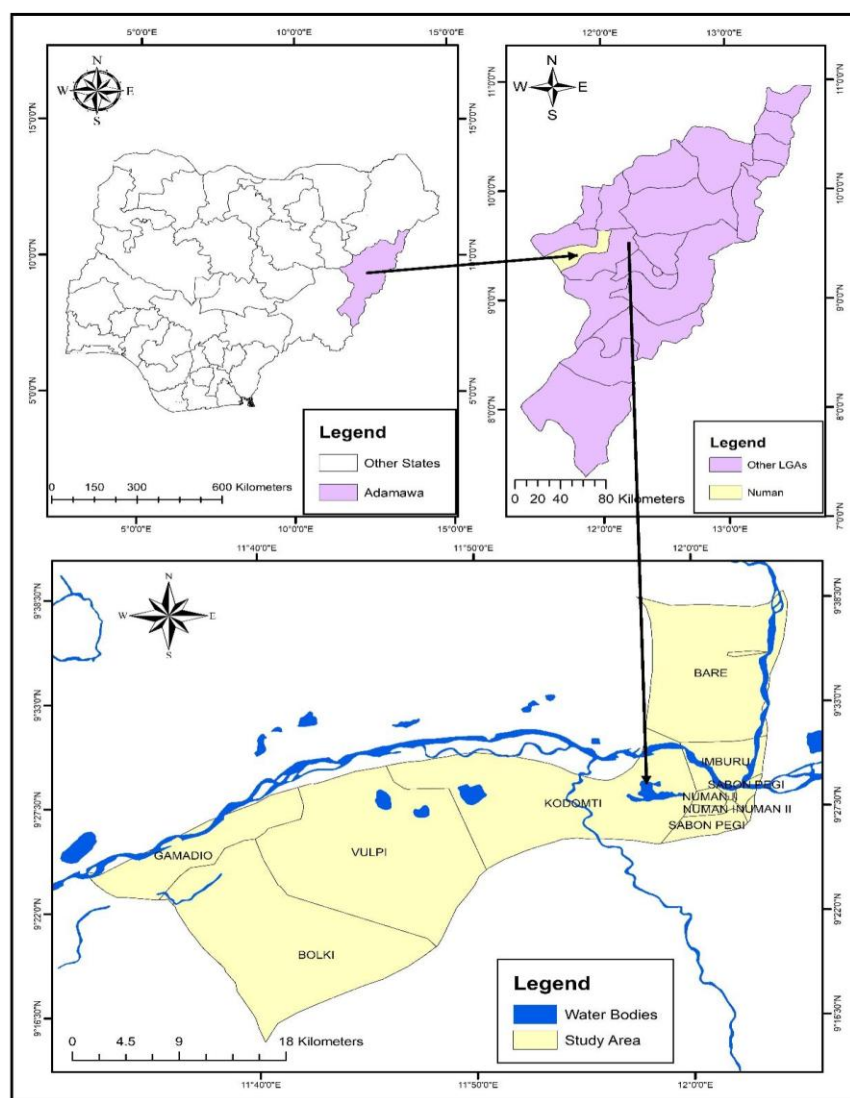


Figure 1.1: Adamawa State in Nigeria; Numan LGA in Adamawa State; Water Bodies in Numan LGA

Source: Adamawa State Geographic Information System (2023)

This study adopted a mixed-methods approach to assess the sustainability of soil for irrigation in Numan Local Government Area. It began with an extensive review of existing literature on soil

sustainability, irrigation practices, and related studies in similar regions to establish the research context. Thirty representative sites, covering diverse soil types, land uses, and agricultural

practices, were purposively selected across the ten wards of the study area, Sabon Pegi, Numan I, Numan II, Numan III, Bolki, Vulpi, Gamadio, Imburu, Kadomti, and Bare. Qualitative and quantitative data were obtained directly from the field through on-site surveys, soil and water sampling, and the administration of questionnaires. The qualitative data included land use, crop types, irrigation methods, and other factors influencing soil sustainability. Soil and water samples were collected from irrigation sites across the wards to generate quantitative data to determine water and chemical properties. In addition, 384 questionnaires were administered to irrigation farmers to collect data on crop yield and land management practices. Secondary data consisted of published and unpublished materials such as research reports, journal articles, textbooks, monographs, and other related documents. These were used to complement the primary data by providing background information and supporting evidence on soil and irrigation practices.

Field Sampling

Soil and water samples were collected from six wards (Sabon Pegi, Numan 2, Numan 3, Imburu, Kadomti and Bare) selected for active irrigation. A total of 30 soil samples (five per ward) were collected using a GIS-based grid sampling method, with samples obtained from the centre of each grid at a depth of 0–15 cm using a soil auger. For water, 36 samples (six per ward) were randomly collected from irrigation points using clean, sterile plastic bottles, with duplicate samples taken from selected sites for quality control. Water was collected directly from irrigation pumps after flushing the pipes to remove stagnant water. Purposive sampling was used to select communities practicing irrigation farming, while simple random sampling was used for the questionnaire administration. The sample size of 384 respondents was determined using Bolarinwa's (2020) formula, which incorporated the desired confidence level (95%), population standard deviation (0.5), and margin of error (5%).

Physicochemical Analysis

Soil samples were analysed for key physical and chemical properties including pH, electrical conductivity (EC), organic carbon, available nitrogen (Kjeldahl method), available phosphorus (Olsen method), and exchangeable bases (Ca, Mg, Na, K) using ammonium acetate extraction and atomic absorption spectrophotometry (AAS). Other indices such as total exchangeable bases (TEB), total exchangeable acidity (TEA), effective cation exchange capacity (ECEC), percent base saturation (PBS), and exchangeable sodium percentage (ESP) were computed. Soil physical properties including texture (hydrometer method), bulk density, particle density, moisture content, water holding capacity, and porosity were also determined.

Water samples were analyzed for turbidity, total dissolved solids (TDS), pH, and electrical conductivity (EC). Major ions, including carbonate and bicarbonate, were determined by titration, while Ca^{2+} , Mg^{2+} , K^{+} , Fe^{2+} , Mn^{2+} , Zn^{2+} , and Pb^{2+} were measured using atomic absorption spectrophotometry. Nitrate was analyzed using UV spectrophotometry, chloride using silver nitrate titration, and fluoride using an ion-selective electrode.

Data Analysis

Questionnaire data were coded and analyzed using descriptive statistics (frequencies and percentages) to assess land management practices. Laboratory data were summarized using means to describe variations in soil and water properties. Pearson product-moment correlation was used to examine relationships between soil and water quality and crop yield.

RESULTS AND DISCUSSION

Chemical Properties of Irrigation Water in Numan Local Government Area

The assessment of water quality across the six communities on Table 1 reveals considerable spatial variation in physicochemical characteristics, many of which exceed FAO permissible limits for irrigation water.

Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), magnesium (Mg^{2+}), calcium (Ca^{2+}) and potassium (K^{+}) consistently showed elevated values in nearly all the communities. For instance, pH levels ranged from 7.48 in Sabon Pegi to as high as 9.93 in Imbru Ward, surpassing recommended thresholds and indicating increasing alkalinity. This trend mirrors recent findings in semi-arid

regions of northern Nigeria where alkaline groundwater has been linked to reduced micronutrient availability and long-term soil infertility (Ahmed *et al.*, 2022). Elevated alkalinity is known to precipitate essential micronutrients such as iron and manganese, thereby reducing crop uptake efficiency and potentially lowering yields over time.

Table 1: Quality of Soil Parameters in the Irrigation Sites in Relation to Food and Agricultural Organization (FAO) Standard

Parameter	Kodonti	Bare ward	Numan ward II	Numan 3	Sabon pegi	Imbru ward
pH (6.85)	7.98	7.83	9.88	9.9	7.48	9.93
EC (30)	273	220	367	285	499	407
NTU (5)	0.012	0.007	36.07	0.018	53.22	56.17
TDS (2000)	186.55	148.5	247.5	190.31	335.2	273
CO ₃ (1)	0	0	4.66	0	6.8	6.48
HCO ₃ (10)	268	242	295	276	567	425
Mg ²⁺ (5)	9.42	9.49	9.44	7.88	8.42	8.87
Ca ²⁺ (20)	24.67	24.87	34.32	23.98	35.55	36.103
K ⁺ (2)	9.22	9.2	9	8.9	6.9	8.73
Fe ²⁺ (5)	0.155	0.169	3.98	0.273	2.177	4.27
NO ₃ (10)	8.67	9.05	28.93	11.43	39.81	37.14
Na ⁺ (40)	1.022	1.042	1.867	1.067	2.399	2.44
Mn ²⁺ (0.2)	0.001	0.003	0.009	0.002	0.014	0.012
F (1)	0	0.001	0.002	0	0	0.004
Cl ⁻ (30)	10.4	9.85	36.15	12.84	40.92	41.27
Zn (2)	0.011	0.013	0.039	0.012	0.047	0.042
Pb (5)	0	0	0.001	0	0.003	0.002

Similarly, EC and TDS values were substantially higher than FAO limits, particularly in Numan Ward II, Sabon Pegi, and Imbru Ward, reflecting significant salinity hazards. The high EC values, reaching up to 499 $\mu S/cm$, suggest increased concentrations of dissolved ions capable of impairing soil structure and increasing osmotic stress for plants. This aligns with the studies of Abubakar *et al.* (2021) and Adeniran *et al.* (2023), who found that irrigation with saline water in northern Nigerian agricultural zones leads to the progressive salinization of soils, reduced infiltration rates, and considerable declines in crop performance especially for salt-sensitive crops. The high TDS concentrations, which exceeded 200 mg/L in most communities,

further underscore the risk of long-term soil degradation through salt accumulation, which is a common problem in arid and semi-arid irrigation environments (Haruna *et al.*, 2021).

The concentrations of Ca^{2+} and Mg^{2+} , which were well above permissible limits in nearly all the sampled communities, also present potential challenges for irrigation sustainability. Excess calcium and magnesium contribute to water hardness and promote soil calcification, which reduces soil permeability and hinders root zone aeration. Studies from northern Nigeria have demonstrated that such water quality conditions accelerate surface crusting and reduce nutrient mobility, consequently affecting crop establishment and yield (Olatunde & Bello,

2020). Furthermore, the elevated potassium (K^+) levels as high as 9.2 mg/L pose additional concerns for nutrient imbalance. Although potassium is beneficial for plant growth, excessive K^+ in irrigation water can lead to sodicity problems, displacing calcium and magnesium on soil exchange sites and causing soil structure deterioration, as reported in recent West African hydrochemical analyses (Adeniran *et al.*, 2023).

Nitrate (NO_3^-) concentrations showed variation across communities, with Numan Ward II (3.98 mg/L) and Sabon Pegi (2.177 mg/L) recording notably higher levels compared to other locations. While moderate nitrate levels can enhance plant growth, excessively high concentrations, especially when combined with nitrogen fertilizer application, increase the risk of nutrient leaching and groundwater pollution. This aligns with Kihampa (2021), who found that nitrate-rich irrigation water in East African farming systems resulted in reduced nitrogen-use efficiency, increased fertilizer losses, and rising environmental contamination. The relatively higher nitrate concentrations in Numan Ward II and Sabon Pegi likely reflect agricultural runoff and domestic waste infiltration from surrounding land uses.

Chloride concentrations in three communities Numan Ward II, Sabon Pegi, and Imbru Ward also exceeded FAO limits. High chloride levels in irrigation water have been widely associated with leaf burn, reduced biomass accumulation, and yield decline in chloride-sensitive crops such as beans, potatoes, and citrus (Mohammed & Ismail, 2019). The presence of elevated chloride in these communities therefore represents a significant agronomic risk that could reduce crop suitability and limit the diversity of crops grown. The chemical properties show that water quality in the six communities is generally unsuitable for long-term irrigation without proper management interventions. The prevalence of salinity, alkalinity, hardness, nutrient contamination, and chloride toxicity suggests that current water conditions may already be contributing to soil degradation, especially in areas with continuous irrigation. These findings are consistent with

regional assessments indicating that declining water quality is an emerging threat to irrigation sustainability and agricultural productivity in northern Nigeria and the wider Sahel (Adeniran *et al.*, 2023). To ensure long-term agricultural resilience, farmers in these communities will need to adopt mitigation strategies such as gypsum application to counteract sodicity, organic matter incorporation to improve soil structure, careful crop selection based on salt tolerance, and the adoption of irrigation scheduling practices that minimize salt buildup. Without such interventions, the combined effects of poor water quality and existing environmental pressures may severely constrain crop yields and threaten the sustainability of irrigation agriculture in the region.

Quality of Soil Parameters in the Irrigation Sites in Relation to Food and Agricultural Organization (FAO) Standard

The chemical properties of the soils from irrigated farms in various wards of Numan Local Government Area presented in Table 2 and generally show compliance with some of the FAO limits, but there are areas of concern that could affect soil health and crop productivity.

The soil quality parameters across the six wards reveal generally favorable conditions for irrigation farming, with some emerging risks that could affect long-term sustainability. The soil pH values (7.14–7.35) fall within the near-neutral to slightly alkaline range, which is considered optimal for most irrigated crops because it maximizes nutrient availability and minimizes metal toxicity. Similar findings were reported by Abdullahi *et al.* (2021) and Gbegbelegbe *et al.* (2020), who observed that neutral to mildly alkaline soils in semi-arid savanna regions enhance nutrient uptake and irrigation efficiency. These pH levels therefore indicate that the soils can effectively support irrigated crop production. Electrical conductivity values (0.27–0.32 dS m^{-1}) are well below the FAO threshold for saline soils, indicating low salinity hazard and minimal risk of osmotic stress on crops. This is consistent with findings by Ayers and Westcot (2019) and Khan *et al.* (2022), who reported that soils with EC

values below 0.7 dS m^{-1} are generally safe for irrigation and allow unrestricted root water uptake. The low EC levels suggest that salt accumulation is not yet a limiting factor in the study area, although continuous irrigation may increase salinity over time without proper drainage management.

Organic carbon values (1.19–1.37%) indicate moderate organic matter status. While not critically low, these levels are relatively marginal for sustaining soil structure and moisture retention under intensive irrigation. Recent studies in West African irrigated systems have shown that soils with organic carbon below 2% tend to exhibit reduced aggregate stability and lower water-holding capacity (Adewopo *et al.*, 2019; Bationo *et al.*, 2020). This suggests that

although the soils can currently support irrigation, long-term productivity would benefit from organic amendments such as compost, crop residues, and manure to enhance soil organic matter.

Available nitrogen and phosphorus concentrations were generally within FAO acceptable limits, indicating adequate fertility for crop production. This agrees with recent observations by Lawal *et al.* (2021) and Tetteh *et al.* (2020), who reported that moderately fertile savanna soils respond well to irrigation when macronutrients are within recommended ranges. Exchangeable calcium, magnesium, and potassium also fell within productive thresholds, supporting nutrient balance and soil structural stability.

Table 2: Soil Parameters in the Irrigation Sites in Relation to Food and Agricultural Organization (FAO) Standard

Ward	Kodonti	Bare ward	Numan ward II	Numan 3	Sabon pegi	Imbru ward
PH (7.5)	7.15	7.24	7.29	7.35	7.21	7.14
EC (30)	0.27	0.32	0.3	0.32	0.3	0.29
Org.c (2)	1.19	1.37	1.25	1.3	1.36	1.21
Av-N (10)	0.002	0.0024	0.003	0.006	0.002	0.002
Av-P (10)	8.82	8.66	7.94	8.58	9.3	8.26
Ca (2)	5.33	3.8	4.87	5.9	4.8	5.16
Mg (1)	2.47	2.3	2.53	2.13	2.27	2.64
Na (15)	0.87	0.88	0.99	0.85	0.94	0.93
K (5)	0.62	0.62	0.74	0.63	0.88	0.74
ECEC (50)	10.68	9.01	10.53	11.07	10.17	10.91
PBS (80)	86.56	84.17	86.16	85.9	87.62	86.44
ESP (5)	8.08	9.88	9.44	7.64	9.73	8.54

However, sodium levels and sodicity indicators present emerging concerns. Exchangeable sodium values, together with ESP values ranging from approximately 7.6% to 9.9%, approach the FAO critical threshold of 10%, above which soils begin to experience structural degradation and reduced permeability. Similar trends have been observed in irrigated soils in northern Nigeria and Sudan, where growing sodium dominance led to reduced infiltration rates and surface crusting over time (Mohammed *et al.*, 2020; Zhang *et al.*, 2021). The relatively high percent base saturation (84–88%) indicates a dominance of base cations, which is generally positive, but

the increasing contribution of sodium may pose a long-term risk of soil sodicity if not properly managed.

The effective cation exchange capacity (ECEC) values suggest moderate nutrient-holding capacity, which is consistent with sandy loam and sandy clay soils typically found in savanna floodplain environments. Recent studies have highlighted that moderate ECEC supports short-term crop performance under irrigation but requires careful nutrient and water management to avoid leaching losses (Kogbe *et al.*, 2022).

The soils in the study area are presently suitable for irrigation farming, as indicated by favorable

pH, low salinity, and balanced nutrient levels. Nonetheless, the combination of moderate organic carbon and rising sodicity indicators suggests that sustainable irrigation will depend on proactive management, including organic matter enhancement, controlled irrigation scheduling, leaching of excess sodium, and possible gypsum application. These observations align with contemporary findings in irrigated agro-ecosystems across sub-Saharan Africa,

which emphasize that long-term soil health under irrigation depends more on management than on initial soil quality (FAO, 2020; Abdel-Fattah *et al.*, 2023).

Farmers' Land Management Practices

Table 3 shows the different land management practices adopted by irrigation farmers in the study, including measures to prevent soil erosion and methods of irrigation.

Table 4.3 Farmers' Land Management Practices

Variable	No. of Respondents	% respondent
Measures to prevent soil erosion		
Crop rotation	140.16	36.5
Wind break	9.98	2.6
Mulching	230.02	59.9
Others	3.84	1.0
Total	384	100
Method of Irrigation		
Drip	8	2.1
Sprinkler	10	2.6
Flood irrigation	357	93
Others	11	2.9
Total	384	100

The results in Table 3 show that farmers in the study area adopt a limited range of land management and irrigation practices, with a strong dominance of traditional methods. With respect to soil erosion control, mulching was the most widely practiced measure (59.9%), followed by crop rotation (36.5%), while only a very small proportion of farmers used wind breaks (2.6%) or other erosion-control methods (1.0%). The high adoption of mulching suggests a strong awareness among farmers of the role of surface cover in reducing runoff, conserving soil moisture, and minimizing soil degradation. Similar patterns were reported in recent studies in northern Nigeria and semi-arid Africa, where mulching and crop rotation were found to be the most common, low-cost soil conservation strategies among smallholder farmers (Abdulrahman *et al.*, 2020; Olorunfemi *et al.*, 2022). However, the low adoption of wind breaks indicates limited implementation of structural

erosion control measures, which are important in areas prone to wind and water erosion.

In terms of irrigation methods, the study reveals a very heavy reliance on flood irrigation (93%), while sprinkler (2.6%) and drip irrigation (2.1%) were rarely used. This dominance of flood irrigation suggests low access to modern irrigation technologies and limited technical support. Flood irrigation is generally associated with low water-use efficiency and higher risks of waterlogging, salinization, and nutrient leaching when not properly managed. Comparable findings have been reported in recent studies across West Africa, where over 80% of smallholder irrigators continue to use surface flooding due to its low initial cost and ease of application (Akinwale *et al.*, 2021; FAO, 2020). The minimal use of drip and sprinkler systems may inhibit optimal water conservation and precision farming, especially in the context of increasing water scarcity and climate variability.

The land management practices observed suggest that while farmers demonstrate awareness of basic soil conservation measures, irrigation practices remain largely traditional and inefficient. This combination may sustain short-term productivity but poses risks to long-term soil health and water resource sustainability. The findings align with recent evidence that improved access to irrigation technologies and farmer training significantly enhances water-use efficiency, reduces soil degradation, and

improves crop yields in smallholder farming systems (World Bank, 2019; FAO, 2021).

Relationship between Chemical Properties of Water and Crop Yield

Table 4 shows the Pearson correlation between chemical properties of water and crop yield in the study area.

Table 4: Pearson Correlation between Chemical Properties of Water and Crop Yield

Chemical Properties	r	p-value
NTU	-.838*	.037
PH	-.507	.305
EC	-.751	.085
TDS	-.744	.090
Co3	-.847*	.033
HCO32	-.563	.245
Mg2	.241	.645
Ca2	-.868*	.025
K	.449	.037
Fe2	-.879*	.021
NO32	.858*	.029
Na	-.828*	.042
Mn	-.876	.052
F	-.553	.256
Cl	-.896*	.016
Zn	-.876*	.022
Pb	-.708	0.11

The Pearson correlation results in Table 4 demonstrate that the chemical quality of irrigation water plays a significant role in influencing crop yield in the study area. Strong and statistically significant negative correlations were observed between crop yield and turbidity (NTU; $r = -0.838$, $p = .037$), carbonate (CO_3^{2-} ; $r = -0.847$, $p = .033$), calcium (Ca^{2+} ; $r = -0.868$, $p = .025$), iron (Fe^{2+} ; $r = -0.879$, $p = .021$), sodium (Na^+ ; $r = -0.828$, $p = .042$), chloride (Cl^- ; $r = -0.896$, $p = .016$), and zinc (Zn^{2+} ; $r = -0.876$, $p = .022$). These relationships indicate that increasing concentrations of dissolved solids, suspended particles, salts, and heavy metals in irrigation water are associated with reduced crop productivity. Similar observations have been

reported in recent studies, where high turbidity and elevated ionic concentrations reduced photosynthetic efficiency, impaired root water uptake, and caused osmotic stress in crops (Yadav *et al.*, 2019; Sharma *et al.*, 2021).

The moderate but non-significant negative relationships between yield and electrical conductivity (EC; $r = -0.751$, $p = .085$) and total dissolved solids (TDS; $r = -0.744$, $p = .090$) nevertheless suggest a tendency toward salinity stress effects on crop growth. Even when not statistically significant, such trends have been shown in contemporary irrigation studies to reduce soil permeability, increase osmotic potential in the root zone, and ultimately suppress yield under prolonged exposure (Al-

Amery *et al.*, 2020; Khorsandi *et al.*, 2022). The absence of significant correlation with pH ($r = -0.507$, $p = .305$) indicates that water acidity/alkalinity had less direct influence on yield under current field conditions, likely because pH values remain within the tolerable range for the cultivated crops.

Conversely, positive and significant associations were recorded for potassium (K^+ ; $r = .449$, $p = .037$) and nitrate (NO_3^- ; $r = .858$, $p = .029$), indicating that irrigation water enriched with essential plant nutrients enhances crop yield. These results are consistent with recent field-scale studies demonstrating that nitrate-rich irrigation waters can supplement soil nitrogen and improve vegetative growth, photosynthetic capacity, and yield in irrigated cropping systems (Hossain *et al.*, 2020; Choudhary *et al.*, 2021). The weak, non-significant relationships observed for magnesium (Mg^{2+}), bicarbonate (HCO_3^-), fluoride (F^-), and lead (Pb^{2+}) suggest that their concentrations were either too low to exert strong physiological effects or that crop tolerance thresholds were not exceeded.

The findings suggest that water salinity and specific ion toxicity, rather than general acidity, are the primary chemical constraints on irrigation performance in the study area. The strong negative influence of sodium, chloride, iron, zinc and turbidity highlights the risk of soil sodicity, leaf burn, and heavy metal accumulation under continued use of poor-quality irrigation water. These results align closely with recent findings in irrigated systems across Africa and Asia, where elevated Na^+ and Cl^- concentrations were identified as primary drivers of yield reduction and soil structural decline (Al-Taani *et al.*, 2019; Wu *et al.*, 2023).

Relationship between Chemical Properties of Soil and Crop Yield

The Pearson correlation analysis between soil chemical properties and crop yield on Table 5 reveals strong evidence that soil fertility status and sodicity are key determinants of irrigation performance. The Pearson correlation results indicate that soil fertility and sodicity are the dominant chemical factors influencing crop yield

under irrigation in the study area. A very strong positive and significant relationship was found between crop yield and available nitrogen (AvN; $r = .894$, $p = .004$), confirming nitrogen as the most critical nutrient for biomass production and grain formation in irrigated systems. Available phosphorus (AvP) also showed a moderate positive and significant correlation ($r = .587$, $p = .048$), highlighting its role in root development and reproductive growth. Organic carbon (Org. C) was positively and significantly related to yield ($r = .355$, $p = .030$), indicating that soils with higher organic matter improve water retention, soil structure, and nutrient availability under irrigation. This agrees with recent studies which have shown that nitrogen is the primary limiting nutrient in irrigated agro-ecosystems, directly influencing chlorophyll development, biomass accumulation, and grain production (Li *et al.*, 2020; Ademiluyi & Omotoso, 2022).

Exchangeable potassium (K) exhibited a strong positive association with yield ($r = .738$, $p = .002$), reflecting its importance in stomatal regulation and water-use efficiency. Similarly, effective cation exchange capacity (CEC) was significantly and positively correlated with yield ($r = .460$, $p = .019$), suggesting greater nutrient buffering and reduced leaching losses in soils with higher CEC.

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Table 5: Pearson Correlation between Chemical Properties of Soil and Crop Yield

Variable	r	p-value
pH	-.175	.040
EC	-.181	.732
Org.c	.355	.03
AvN	.894	.004
AvP	.587	.048
Ca	-.050	.926
Mg	-.285	.585
Na	-.813*	.049
K	.738	.002
ECEC	.460	.019
PBS	-.384	.453
ESP	-.315	.043

In contrast, exchangeable sodium (Na) showed a strong negative and significant relationship with yield ($r = -.813$, $p = .049$), while exchangeable sodium percentage (ESP) was also negatively correlated ($r = -.315$, $p = .043$). These results indicate that sodicity reduces soil permeability, limits root development, and lowers crop performance. Similar patterns have been reported in irrigated soils in semi-arid regions, where sodicity was identified as a major cause of yield decline and soil degradation (Qadir *et al.*, 2018; Abbas *et al.*, 2020). Soil pH, EC, Ca, Mg, and PBS showed weak and non-significant relationships, suggesting they are not current limiting factors in the study area.

The results align with recent evidence that balanced nitrogen–phosphorus–potassium availability enhances irrigated crop yield, whereas sodium accumulation is the major chemical threat to sustainable irrigation farming.

CONCLUSION AND RECOMMENDATIONS

The chemical analysis of soils from irrigated farms in Numan Local Government Area provides important evidence about the state of soil and water quality. Results show that several key parameters, including salinity, electrical conductivity and certain nutrient or heavy-metal concentrations, exceed the limits recommended by the Food and Agriculture Organization (FAO) for irrigation use. These imbalances point to a gradual decline in soil health, which can restrict nutrient uptake, damage soil structure and increase the risk of salinisation. Elevated salt levels and poor water quality can also harm beneficial soil organisms and reduce crop yields over time. Correlation analyses further emphasized the positive impact of available nitrogen and potassium on crop yield, while highlighting the detrimental effects of elevated sodium levels and other chemical elements. These findings highlight an urgent need for improved management of soil and water

resources in the area. Regular testing of irrigation water and soils, careful scheduling of irrigation to avoid over-application, adoption of salt-tolerant crop varieties and the use of organic amendments to improve soil chemistry are all measures that could help restore balance. Strengthening institutional support for farmers through training, improved access to testing facilities, and adherence to FAO and WHO irrigation guidelines would also contribute to long-term soil productivity and protect the livelihoods of farming households in the Numan Local Government Area. Federal Government should fund the development and dissemination of effective treatment solutions to lower concentrations of problematic chemicals as well as develop and enforce policies that set stricter limits on permissible levels of contaminants in irrigation water. State Government and other stakeholders such as NGO's should organize hands-on workshops and demonstrations to teach farmers about the installation, operation, and maintenance of drip and sprinkler irrigation systems so they can reduce the use of flood irrigation

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