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Soil Fertility and Pollution Risk Assessment of Irrigated Agricultural Lands Along the Kubanni River, Zaria, Nigeria

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Abstract

Soil quality plays a pivotal role in supporting agricultural productivity and maintaining environmental integrity. Healthy soils not only supply essential nutrients to crops but also regulate water, sequester carbon, and support biodiversity. This study investigated the physicochemical characteristics of soils from farmlands irrigated with water from the Kubanni River in Tudun Wada, Zaria, Kaduna State, Nigeria, with the aim of assessing spatial variation in soil quality as influenced by proximity to the river. A total of 15 soil samples were systematically collected. Twelve samples were obtained from cultivated plots located at incremental distances of 20 ft, 40 ft, 60 ft, and 80 ft from the river, representing areas subjected to varying intensities of irrigation and potential sediment deposition. An additional three samples were collected from a control site situated approximately 20 km away on virgin land within the Ahmadu Bello University (ABU) campus. This control site, untouched by irrigation or cultivation, provided a reference point for assessing the extent of anthropogenic influence on soil quality in the irrigated areas. All laboratory analyses were conducted at the Soil Science Laboratory, Institute for Agricultural Research, ABU, Zaria. The following soil parameters were analyzed: pH, organic matter (OM), available phosphorus (P), exchangeable bases (potassium [K], sodium [Na], calcium [Ca], and magnesium [Mg]), cation exchange capacity (CEC), exchangeable acidity, and particle size distribution. These parameters were chosen due to their critical role in determining soil fertility and overall health. The results revealed a discernible gradient in soil quality, with higher values of pH, organic carbon, and essential nutrients recorded in plots closer to the river. This trend is likely driven by the deposition of nutrient-rich sediments and the continuous input of irrigation water, which may enhance nutrient cycling and soil biological activity. In contrast, soils from the control site exhibited significantly lower levels of fertility-related parameters, reflecting the undisturbed and less managed nature of the virgin land. Textural analysis showed that soils in the irrigated plots ranged from sandy loam to silty loam, textures generally favorable for cultivation due to their balanced water retention and drainage capabilities. Furthermore, moderate to high CEC values observed in these soils suggest a strong ability to retain and exchange nutrients, which is beneficial for sustaining crop growth under intensive agricultural use. These findings underscore the positive impact of river-based irrigation on soil fertility enhancement. However, they also highlight the need for regular soil monitoring to prevent potential long-term degradation, such as salinization, nutrient imbalances, or contamination from upstream sources. Maintaining soil health is essential for ensuring the sustainability of agricultural systems and achieving food security in the region. Future research should expand on these findings by investigating potential risks associated with irrigation, including heavy metal accumulation, pesticide residues, and changes in microbial communities. Such comprehensive assessments are crucial for developing integrated soil management strategies that balance productivity with environmental stewardship.

Keywords

Kubanni River,
Soil Fertility,
Irrigation,
Soil Contamination,
Characterizations,

INTRODUCTION

Soil characterization is pivotal for understanding nutrient dynamics and supporting sustainable agriculture (Adejumoh et al., 2021). In semi-arid regions like Zaria, northern Nigeria, where irrigation is important for year-round cultivation, rivers such as the Kubanni play a central role. However, the long-term impact of river-based irrigation on soil quality remains underexplored.

Previous studies have highlighted that continuous irrigation, especially with potentially contaminated surface waters, can alter soil physical and chemical properties (Oyinlola and Adebayo 2020). These include pH shifts, nutrient loading, and the possible accumulation of heavy metals. Identifying spatial discrepancies in soil characteristics along irrigation gradients helps in modifying soil management strategies for sustainable crop production.

This study aims to assess the effect of proximity to the Kubanni River on soil quality. It evaluates key indicators such as pH, organic matter, exchangeable bases, and textural composition to determine the influence of irrigation on soil fertility.

2. Methodology

2.1 Study Area and Sampling

The study was conducted in Tudun Wada, Zaria, Kaduna State, Nigeria. Twelve soil samples were collected from farms irrigated by the Kubanni River. Soil auger was used to collect the samples at a depth of 15cm, which is the recommended for vegetables irrigated farms. These samples were placed inside clean labelled sampled bags. They were grouped based on distance from the riverbank: 20 ft,

40 ft, 60 ft, and 80 ft. The control samples were collected from a virgin land at Ahmadu Bello University, located 20 km away from the study location.

2.2 Laboratory Analysis

All analyses were conducted at the Soil Science Laboratory, Institute for Agricultural Research, Ahmadu Bello University, Zaria. The following standard procedures were adopted:

- i. Soil pH (H_2O and $CaCl_2$): Measured using a 1:2.5 soil-to-solution ratio.
- ii. Organic Carbon (OC): Walkley-Black method.
- iii. Total Nitrogen (N): Kjeldahl digestion.
- iv. Organic Matter (OM): Derived from $OC \times 1.724$.
- v. Available Phosphorus (P): Bray-1 method and spectrophotometry.
- vi. Exchangeable Bases (K, Na, Ca, Mg): Extracted with ammonium acetate and analyzed via AAS and flame photometry.
- vii. Cation Exchange Capacity (CEC): Sum of exchangeable bases and acidity.
- viii. Exchangeable Acidity ($H^+ + Al^{3+}$): Titration after KCl extraction.
- ix. Particle Size Distribution: Hydrometer method, temperature-corrected to 20°C.

3. Results

The analysis of soil properties from farmlands irrigated with Kubanni River water discovered distinct physicochemical shifts compared to the controlled soil obtained from an uncontaminated virgin site 20km away. These differences highlight the effects of irrigation

practices on soil fertility, productivity potential, and the likelihood for environmental contamination.

3.1 Soil pH and Alkalinity Trends

Soil pH ranged from 6.20 in the control plots to 8.00 in irrigated areas, indicating a progressive drift toward alkalinity near the river. This alkalization is likely driven by the accumulation of bicarbonate and carbonate ions from irrigation water, especially in regions

influenced by urban and peri-urban activities. Similar findings were reported by Adejumo *et al.* (2021) and Oyinola and Adebayo (2020), who noted higher pH levels in river-irrigated soils in northern Nigeria. While moderate alkalinity can support certain crops, excessively alkaline conditions may lessen the availability of micronutrients such as iron, zinc, and manganese, ultimately impairing crop nutritional quality.

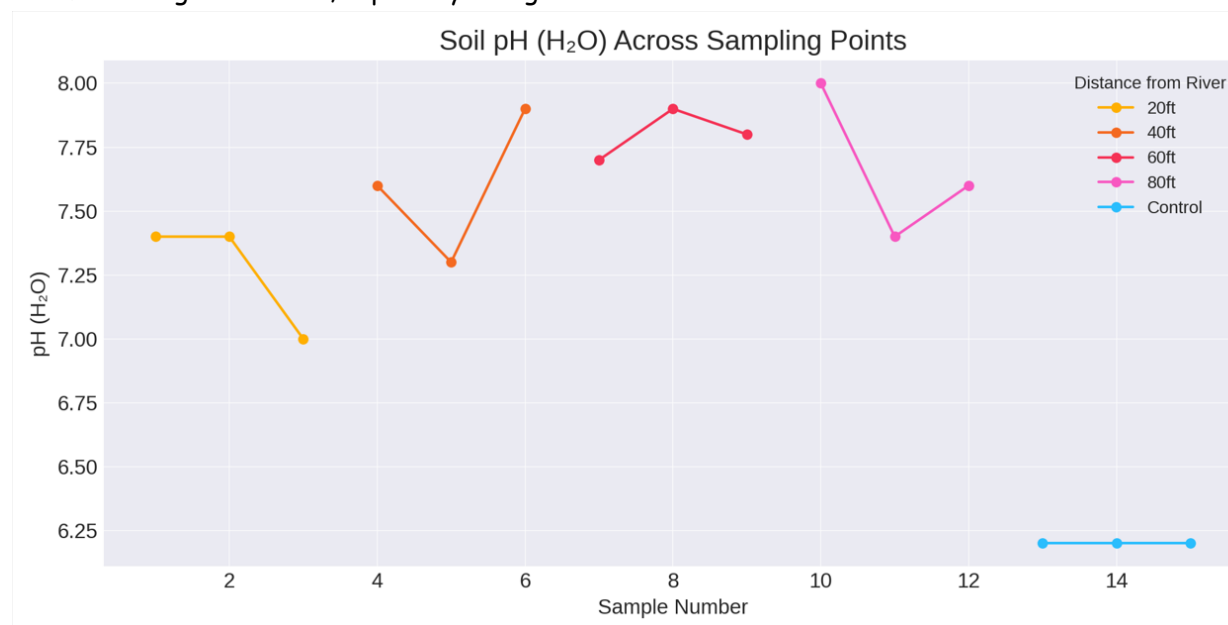


Figure 1: Soil pH readings across the Kubanni Sampled farms and the Control

3.2 Organic Matter Content

Organic matter (OM) levels reached up to 6.12% in Kubanni plots, contrasting sharply with the 1.27% observed in control soils. This substantial increase is probably due to the continuous input of decomposing plant residues, sedimentation, and potentially

organic-rich wastewater from the river. High OM enhances microbial activity, soil aggregation, and nutrient retention (Nwajei & Gagophien, 2007). However, OM can also serve as a required medium for pollutants, potentially facilitating the accumulation of heavy metals or organic contaminants if the irrigation water is compromised.

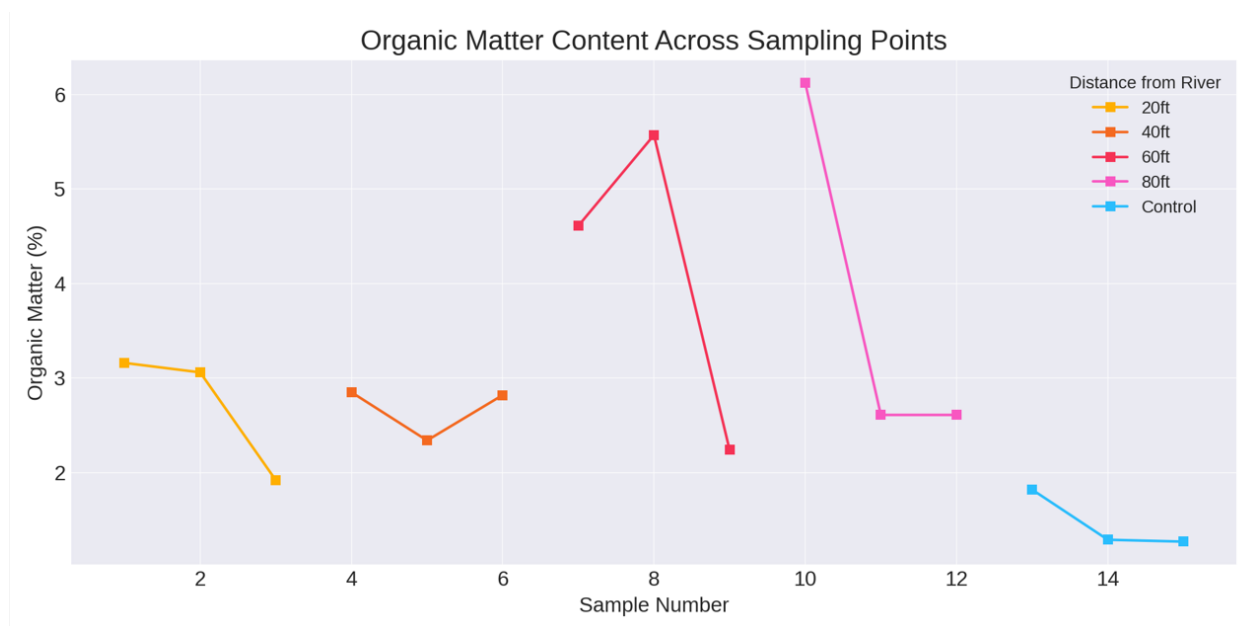


Figure 2: Organic matter content across Kubanni Sampled farms and the Control

3.3 Available Phosphorus

The concentration of available phosphorus peaked at 53.03 mg/kg in the irrigated soils, indicating significant nutrient enrichment. This phosphorus likely originates from agricultural runoff or household waste discharged into the river. While phosphorus is essential for plant development particularly root formation and energy transfer excessive levels increase the risk of eutrophication in nearby water bodies (Okunola et al., 2018). Therefore, careful monitoring is needed to maintain an ecological balance.

3.4 Exchangeable Bases: Calcium and Magnesium

Exchangeable calcium and magnesium levels increased with proximity to the river, with values as high as 13.20 cmol/kg and 18.58 cmol/kg, respectively. These base cations improve soil structure, help neutralize acidity,

and are crucial for enzymatic and cellular functions in crops. Similar enrichment patterns were reported by Lawal et al. (2019) in riparian soils of Kaduna State. While beneficial in moderation, imbalances or accumulation most especially alongside sodium usually affect soil permeability and result in sodicity issues.

3.5 Cation Exchange Capacity (CEC)

CEC values ranged from 7.11 to 33.01 cmol/kg, with the highest values recorded near the river. The elevated CEC is likely linked to higher organic matter content and finer soil textures in these areas. Soils with higher CEC are generally more fertile due to their ability to retain and exchange nutrients effectively. According to Ayuba et al. (2020), soils in floodplain areas often exhibit high CEC due to sedimentation and organic input from upstream sources.

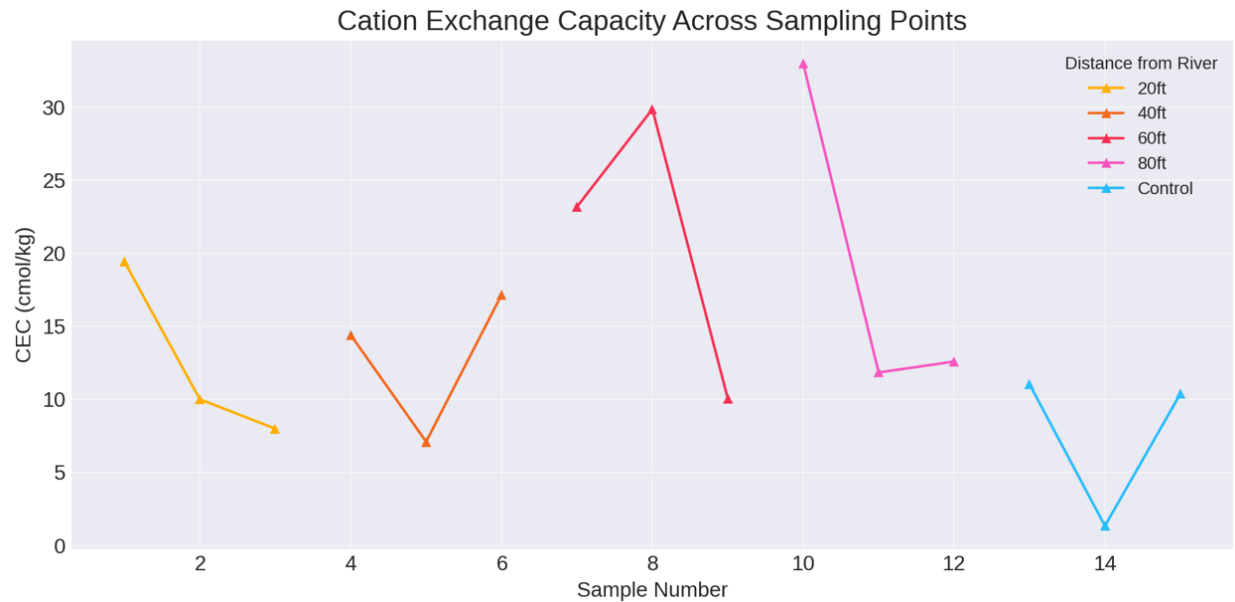


Figure 3: Cation Exchange Capacity across Kubanni Sampled farms and the Control

3.6 Soil Texture

Textural analysis indicated a dominance of silty loam to loam textures across irrigated plots. These textures are advantageous for water retention, drainage, and aeration,

creating optimal conditions for root development and microbial activity. The gradual deposition of silt and organic materials from the river likely contributes to this textural refinement over time.

Summary Table of Key Soil Properties

Soil Property	Control	Kubanni farms	Trend with River Proximity
pH	6.20	8.00	Increases (more alkaline)
Organic Matter (%)	1.27	6.12	Increases
Available Phosphorus (mg/kg)	~10 (avg)	53.03	Increases
Exchangeable Calcium (cmol/kg)	~5.00	13.20	Increases
Exchangeable Magnesium (cmol/kg)	~7.00	18.58	Increases
C.E.C (cmol/kg)	7.11	33.01	Increases
Texture	Loamy sand	Silty loam / Loam	Finer textures near river

4. Discussion

The enhancement in soil quality parameters like pH, OM, available P, and CEC clearly shows the beneficial effects of irrigation from the Kubanni River. Similar findings have been reported by Adejumbi *et al.* (2016), who observed elevated OM and CEC values in long-term irrigated fields in Oyo State, Nigeria.

The increase in pH from acidic to neutral/alkaline may be linked to the base rich sediment input aligning with a study in riparian zones in Northern Nigeria (Nzamuhe & Omar, 2020), which reported a buffering effect of irrigation on soil pH.

Organic matter accumulation is critical for soil structure and nutrient cycling. The higher values seen in the irrigated soils (up to 6.12%) are consistent with a study by Maniyunda *et al.* (2020), indicating increased organic residue input and microbial activity due to frequent irrigation and cultivation.

Elevated phosphorus and exchangeable bases indicate enrichment from fertilizers and irrigation return flows. However, unchecked accumulation could risk eutrophication or heavy metal mobilization, which warrants further investigation due their deleterious effects on human health.

5. Conclusion

This study demonstrates that irrigation using Kubanni River water enhances the fertility of nearby farmlands. Elevated OM, P, exchangeable bases, and CEC reflect improved soil nutrient status. Comparisons with similar agroecological studies reinforce these findings. To maintain soil health, it is essential

to monitor for salinity and contamination risks over time.

Furthermore, the results point to improved soil fertility conditions in the irrigated zones, which has a positive impact in intensive cropping and thereby potentially increase yield. Higher nutrient concentrations, better moisture retention, and favorable physical conditions collectively enhance crop productivity. However, these benefits come with potential risks; irrigation water sourced from rivers receiving domestic and industrial waste can introduce harmful substances including heavy metals (HMs) like lead (Pb), cadmium (Cd), and arsenic (As) into the soil. These contaminants can be absorbed by crops and enter the food chain, posing risks to human health serving as the end users along the food chain.

Long-term irrigation from such sources without routine monitoring may lead to the gradual degradation of soil quality and bioaccumulation of toxic elements. Therefore, sustainable soil management strategies, periodic water quality assessments, and adoption of phytoremediation practices are strongly recommended.

Future studies should explore microbial diversity, heavy metal content, and crop yield correlations to comprehensively understand irrigation's long-term impact.

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