



## Research Article

### Impact of Seasonal Flooding and Post-Flood Irrigation on Soil Fertility and Salinity along River Galma, Kaduna State, Nigeria

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#### ABSTRACT

Seasonal flooding and post-flood irrigation play important roles in modifying soil fertility and salinity in floodplain agricultural systems, yet information on their combined effects in the River Galma floodplain of Kaduna State, Nigeria, remains limited. This study assessed selected soil fertility indicators and salinity status across four categories: irrigated upland, irrigated lowland, unirrigated upland, and unirrigated lowland. Three composite samples were collected from each category at 0–30 cm depth; each composite comprised four subsamples. The 12 composite samples were analyzed for particle-size distribution, pH, organic carbon, total nitrogen, available phosphorus, electrical conductivity, exchangeable bases, and exchangeable acidity. Data were subjected to analysis of variance, and means were separated using Duncan's Multiple Range Test at  $P \leq 0.05$ . The soils were predominantly sandy loam and slightly acidic in water (pH 5.89–6.54). Organic carbon and total nitrogen were generally low. Available phosphorus was significantly higher in the lowland categories, while exchangeable-base patterns varied among categories. Electrical conductivity measured in a 1:5 soil–water extract ( $EC_{1:5}$ ) ranged from 79.93 to 135.93  $\mu S\ cm^{-1}$  and did not differ significantly among categories, indicating no significant accumulation of soluble salts at the time of sampling. The findings show category-specific nutrient distribution. Site-specific nutrient management, organic amendments, crop-residue recycling, and periodic monitoring of soil EC and irrigation-water quality are recommended for sustainable production.

**Keywords:** Northern Guinea Savanna; Post-Flood Irrigation; River Galma; Seasonal Flooding; Soil Fertility; Soil Salinity

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#### INTRODUCTION

Soil is the most vital and precious natural resource that sustains life on earth, and a comprehensive understanding of good farming begins with a thorough understanding of soil characteristics (Aliyu *et al.*, 2025). The inherent ability of soils to supply nutrients for crop growth and the maintenance of soil physical conditions to ensure optimum yields are the most essential components of soil fertility that define

the productivity of agricultural systems (Basavaraju *et al.*, 2005; Dawaki *et al.*, 2019; Abdulkadir *et al.*, 2022; Obasi *et al.*, 2023). Soil health serves as the cornerstone of sustainable agriculture, directly impacting crop productivity, water management, and vital ecosystem services, with Soil Organic Matter (SOM) and Cation Exchange Capacity (CEC) serving as two critical indicators of this stability (Sani *et al.*, 2025; Abdulkadir *et al.*, 2026). However, agricultural

productivity in Sub-Saharan African countries is increasingly threatened by falling soil fertility and a lack of replenishment strategies (Tabi *et al.*, 2013; Obasi *et al.*, 2023). In Nigeria, the primary problem restricting agricultural development is a lack of accurate information and proper scientific knowledge regarding specific land characteristics (Mukherjee, 2022; Obasi *et al.*, 2023).

Seasonal flooding is the most frequent and widespread natural hazard in Nigeria, accounting for approximately one-third of all natural disasters (Sadiq *et al.*, 2019; Sadiq, 2021). Flooding events typically occur when river flow rates exceed the capacity of their channels or when rainwater accumulates on heavily saturated ground (Sadiq *et al.*, 2019). These events have a dual influence on agricultural lands: while they move large amounts of sand and silt that can help replenish valuable topsoil components, they also cause significant damage to crops and reduce farm output (Sadiq *et al.*, 2019; Okonofua *et al.*, 2025). Furthermore, prolonged waterlogging often depletes soils of essential nitrogen, organic carbon, and structural stability (Echendu, 2020; Umar & Gray, 2022; Buhari & Babandi, 2025). Oxygen deficiency resulting from flooding is the most critical environmental factor that triggers growth inhibition and injury in flooded plants (Fournier *et al.*, 2016; Aliyu *et al.*, 2025).

The introduction and development of irrigation systems have improved yields but may also enhance secondary salinisation (Michot *et al.*, 2013). Salinisation results from inefficient human activities, primarily irrigation with poor-quality water and inadequate drainage (Michot *et al.*, 2013). In regions characterized by high evapotranspiration rates, the concentration and precipitation of water-soluble salts such as chlorides and sulfates of sodium, magnesium, or calcium can occur at the soil surface and in the subsoil (Michot *et al.*, 2013). This process is one of the most significant abiotic stresses affecting agriculture globally, as it creates osmotic stress that inhibits water uptake by plant roots (de Oliveira *et al.*, 2013; Bulama Gambo & Mumtaz, 2026).

River Galma is a major perennial tributary within the Upper Kaduna River Basin that supports extensive agricultural activities through seasonal flooding and dry-season irrigation (Obasi *et al.*, 2023; Sani *et al.*, 2025). The study area, located in Zaria, lies within the Northern Guinea Savanna agroecological zone and is characterized by a tropical wet-and-dry climate with mean annual rainfall between 900 and 1,200 mm (Abdulkadir *et al.*, 2026). The region is underlain by the Precambrian Basement Complex, consisting of

granites, gneisses, and schists, which influence the formation of well-drained ferruginous tropical soils on uplands and seasonally inundated alluvial soils on the floodplains (Obasi *et al.*, 2023). Despite the hydrological importance of these systems for year-round farming of cereals, legumes, and vegetables, only limited soil information is available to stakeholders, which restricts sustainable utilization (Obasi *et al.*, 2023). As global demand for food is projected to double by 2030, understanding the dynamics of these alluvial systems is critical for planning agricultural growth (Daily *et al.*, 1998; Sadiq *et al.*, 2019). Therefore, this study was conducted to assess the fertility and salinity status of soils along the River Galma, Kaduna State, Nigeria, in order to provide scientific evidence for site-specific soil management and sustainable agricultural production.

## **MATERIALS AND METHODS**

### **Description of the Study Area**

The study was conducted along the River Galma floodplain in Zaria, Kaduna State, northwestern Nigeria which located between latitude 10° 25' N to 11° 12' N and longitude 7° 31' E to 7° 45' E Raplh *et al.*, 2025). River Galma is an important perennial river within the Upper Kaduna River Basin and supports extensive agricultural activities through seasonal flooding and dry-season irrigation. The floodplain is intensively cultivated because periodic overbank flooding replenishes soil moisture and deposits alluvial sediments that enhance agricultural productivity, while residual moisture and river water sustain post-flood irrigation during the dry season (Sani *et al.*, 2025).

The study area lies within the Northern Guinea Savanna agroecological zone and is characterized by a tropical wet-and-dry climate, with a distinct rainy season extending from April/May to October and a dry season from November to March. Mean annual rainfall ranges between approximately 900 and 1,200 mm, while mean annual temperatures generally vary from 25 to 35 °C, with peak temperatures occurring during the late dry season before the onset of rainfall (Abdulkadir *et al.*, 2026). These climatic conditions regulate the annual flooding cycle of River Galma and influence the hydrological processes that govern floodplain soil development and agricultural water availability.

The area is underlain predominantly by Precambrian Basement Complex rocks consisting of granites, gneisses, and schists. The uplands are generally occupied by well-drained ferruginous tropical soils, whereas the floodplain is dominated by seasonally

inundated alluvial soils formed through repeated deposition of river-borne sediments during flood events (Obasi *et al.*, 2023). These contrasting landscape positions and irrigation practices provide a suitable environment for evaluating the effects of seasonal flooding and post-flood irrigation on soil fertility and salinity.

#### **Experimental Design**

A comparative field sampling design was used to evaluate selected soil fertility and salinity indicators under four existing categories: irrigated upland, irrigated lowland, unirrigated upland, and unirrigated lowland. The categories represented contrasting landscape positions and irrigation conditions along the River Galma floodplain.

Three sampling locations were selected within each category, giving 12 sampling locations. One composite sample was obtained from each location and treated as a field replicate for comparison among the four categories. Because the categories were existing field conditions rather than randomly assigned experimental treatments, the study was analysed as a comparative field investigation.

#### **Soil Sampling and Sample Preparation**

Soil sampling was conducted in December 2025 within the four categories along the River Galma floodplain: irrigated upland, irrigated lowland, unirrigated upland, and unirrigated lowland. Three representative sampling locations were selected within each category. At each location, four subsamples were collected from the 0–30 cm depth using a soil auger and thoroughly mixed to form one composite sample. This produced 12 composite soil samples, with three composite samples representing each category.

Each composite sample was placed in a labelled polythene bag and transported to the laboratory. The samples were air-dried, gently crushed, and passed through a 2-mm sieve before physicochemical analysis.

#### **Laboratory Analysis of Soil Physical and Chemical Properties**

The prepared soil samples were analyzed for selected physical and chemical properties following standard laboratory procedures. Soil pH was determined in 1:2.5 soil-to-water and 1:2.5 soil-to-1 M KCl suspensions using a glass electrode pH meter as described by Thomas (1996). Organic carbon (OC) was determined by the Walkley and Black wet oxidation method as described by Nelson and Sommers (1996), while total nitrogen (TN) was determined using the macro-Kjeldahl method as described by Bremner (1996). Available phosphorus (Av. P) was extracted

using the Bray I method and determined calorimetrically as described by Bray and Kurtz (1945). Electrical conductivity (EC) was measured in a 1:5 soil-to-water suspension using a conductivity meter.

Exchangeable calcium (Ca) and magnesium (Mg) were extracted with 1 N ammonium acetate (NH<sub>4</sub>OAc) at pH 7.0 and determined using an atomic absorption spectrophotometer, whereas exchangeable potassium (K) and sodium (Na) were determined using a flame photometer. Exchangeable acidity (EA) was determined after extraction with 1 M KCl by titration. Particle-size distribution was determined using the Bouyoucos hydrometer method as described by Bouyoucos (1962).

#### **Data Analysis**

Data generated from the field and laboratory analyses were subjected to one-way analysis of variance using GenStat statistical software, with the four field categories as the comparison factor and three composite samples per category as replicates. Where the F-test indicated significant differences among category means, Duncan's Multiple Range Test was used for mean separation at  $P \leq 0.05$ .

## **RESULTS AND DISCUSSION**

### **Influence of Flooding and Post-Flood Irrigation on Soil Chemical Properties and Electrical Conductivity**

The influence of seasonal flooding and post-flood irrigation on the primary chemical properties of soils along the River Galma is presented in Table 1. The results indicate that soil pH (H<sub>2</sub>O) ranged from 5.89 in the irrigated lowland to 6.54 in the unirrigated lowland, indicating slightly acidic conditions across all sites. These findings are similar to the results reported by Aliyu *et al.* (2025) and Adesoji *et al.* (2025), who observed a pH range of 6.23 to 6.66 along the Kamanda River in Kano State. The persistence of slightly acidic conditions is consistent with findings in other Northern Nigerian floodplains, where minimal variation in soil acidity is attributed to the natural pH buffering capacity of exchangeable cations (Pessoa *et al.*, 2022; Sani *et al.*, 2025).

Organic Carbon (OC) and Total Nitrogen (TN) levels exhibited moderate to low concentrations, which is typical for Northern Guinea Savanna soils. The mean OC content was 0.84%, with the highest concentration recorded in the irrigated lowland (1.06%). This result aligns with Abdulkadir *et al.* (2020) and Sani *et al.* (2025) in the Dutsin-Ma floodplain, where moderate organic matter levels were attributed to the deposition of nutrient-rich sediments by floodwaters (Abdulkadir *et al.*, 2025);

Sani *et al.*, 2025). Similarly, the relatively low TN values (mean 0.225%) are consistent with observations along the River Kaduna watershed, where continuous farming activities and moisture dynamics often deplete exchangeable cations and nitrogen (Obasi *et al.*, 2015; Obasi *et al.*, 2023). The low nitrogen levels in these flood-prone areas are often the result of leaching and denitrification during periods of soil saturation (Buhari & Babandi, 2025). Available Phosphorus (Av. P) showed significant variation, with notably higher concentrations in the lowland areas compared to the uplands. The irrigated lowland recorded the highest Av. P at 35.32 mg/kg, while the irrigated upland had the lowest at 5.21 mg/kg. This trend of lowland enrichment is supported by studies along the River Kaduna, where debris deposited by occasional flooding increases the nutrient potential of "Backswamp" depositional areas compared to higher terrace locations (Asselman,

1999; Obasi *et al.*, 2023). Furthermore, higher phosphorus in lowlands can be explained by anaerobic conditions in waterlogged soils, which render phosphate more soluble and facilitate its accumulation in topographic depressions (Srivastava *et al.*, 2024; Aliyu *et al.*, 2025).

Electrical conductivity measured in a 1:5 soil–water extract ( $EC_{1:5}$ ) ranged from 79.93 to 135.93  $\mu S\ cm^{-1}$  and did not differ significantly among categories. The statistically similar  $EC_{1:5}$  values indicate that neither irrigation condition nor landscape position caused a significant difference in soluble-salt concentration at the time of sampling. Nevertheless, periodic monitoring of irrigation-water quality and soil EC remains advisable because repeated irrigation, inadequate drainage and high evaporative demand may increase salt accumulation over time (Pessoa *et al.*, 2022; Bulama Gambo & Mumtaz, 2026).

**Table 1: Influence of flooding and post-flood irrigation on soil pH, organic carbon, total nitrogen, available phosphorus and electrical conductivity along River Galma**

| Site                | pH (H <sub>2</sub> O) | pH ( KCl )        | OC (%)            | TN (%)             | Av. P (Mg/kg)      | EC ( $\mu S/cm$ )   |
|---------------------|-----------------------|-------------------|-------------------|--------------------|--------------------|---------------------|
| Irrigated Upland    | 6.13 <sup>ab</sup>    | 4.79 <sup>a</sup> | 0.56 <sup>a</sup> | 0.222 <sup>a</sup> | 5.21 <sup>b</sup>  | 135.93 <sup>a</sup> |
| Irrigated Lowland   | 5.89 <sup>b</sup>     | 4.90 <sup>a</sup> | 1.06 <sup>a</sup> | 0.235 <sup>a</sup> | 35.32 <sup>a</sup> | 84.73 <sup>a</sup>  |
| Unirrigated Upland  | 6.23 <sup>ab</sup>    | 4.29 <sup>a</sup> | 0.93 <sup>a</sup> | 0.248 <sup>a</sup> | 11.29 <sup>b</sup> | 91.87 <sup>a</sup>  |
| Unirrigated Lowland | 6.54 <sup>a</sup>     | 4.29 <sup>a</sup> | 0.78 <sup>a</sup> | 0.196 <sup>a</sup> | 31.23 <sup>a</sup> | 79.93 <sup>a</sup>  |
| Grand Mean          | 6.20                  | 4.57              | 0.84              | 0.225              | 20.761             | 98.12               |

Source: Field survey, November 2025, and laboratory analysis, December 2025

#### **Influence of Flooding and Post-Flood Irrigation on Soil Exchangeable Bases and Exchangeable Acidity**

The status of exchangeable bases (Calcium, Magnesium, Potassium, and Sodium) and exchangeable acidity (EA) across the different land-use categories along the River Galma is presented in Table 2. The results show a general dominance of Calcium (Ca), which ranged from 3.398 to 6.654 cmol/kg, followed by Magnesium (Mg), ranging from 1.480 to 3.859 cmol/kg. This pattern of cation distribution is similar to the findings of Obasi *et al.* (2023), who reported a dominance of Ca and Mg in their characterization of soils along the nearby River Kaduna watershed. The explanation for this similarity lies in the common geological foundation of the region; both watersheds are underlain by the Precambrian Basement Complex, which consists of granites and gneisses that release these base cations during the weathering process.

Organic matter levels and exchangeable bases exhibited higher concentrations in the irrigated lowland compared to the unirrigated lowland. Specifically, Magnesium (3.859 cmol/kg) and

Potassium (0.429 cmol/kg) were highest in the irrigated lowland. This result aligns with the findings of Aliyu *et al.* (2025), who observed that irrigated land uses along the Kamanda River often showed signs of nutrient enrichment compared to their unirrigated counterparts. The reason for this agreement is that post-flood irrigation management typically involves the application of organic amendments and inorganic fertilizers, which help to replenish the nutrient pool that might otherwise be depleted by continuous farming and flooding.

The exchangeable sodium (Na) levels remained low across all sites (mean 0.240 cmol/kg), while exchangeable acidity (EA) values were also minimal. This aligns with the findings of Sani *et al.* (2025) in the Dutsin-Ma floodplain, where moderate to low cation concentrations were attributed to the natural buffering capacity of Northern Nigerian savanna soils. The reason for these low values is that seasonal flooding in these inland systems often facilitates the leaching of soluble salts and acidic components, maintaining a relatively balanced ionic state.

However, the unirrigated lowland along the River Galma recorded the lowest concentrations of Calcium, Magnesium, and Potassium. This result is at variance with Aliyu *et al.* (2025), who reported that the unirrigated lowland along the Kamanda River actually had the highest concentrations of Magnesium, Potassium, and Cation Exchange Capacity due to sediment deposition. The reason for this contrast may be due to differences in the composition of transported materials or the duration of flood inundation along the River Galma; in this specific system, the energy of the floodwaters may cause more significant leaching and erosion of topsoil nutrients in the lowland rather than the beneficial deposition of nutrient-rich sediments observed in other regional floodplains.

#### **Influence of Flooding and Post-Flood Irrigation on Particle Size Distribution**

The particle-size distribution of the soils along River Galma is presented in Table 3. Sand was the dominant fraction, ranging from 53.47% in the irrigated lowland to 72.13% in the irrigated upland, with a mean of 63%. Based on the USDA textural triangle, all four categories were classified as sandy loam. Sand, silt, and clay did not differ significantly among categories, as indicated by the common superscript letter within each column. The sandy-loam texture agrees with reports of coarse-textured soils in parts of the Northern Nigerian savanna (Sani *et al.*, 2025).

Silt ranged from 19.27% to 34.60%, while clay ranged from 8.60% to 12.60%. Although the irrigated lowland recorded numerically more silt and less sand than the other categories, these differences were not statistically significant. The numerical pattern may reflect floodplain sediment sorting as flow energy declines, but a larger spatial dataset would be required to confirm this process along River Galma (Asselman, 1999; Wohl, 2021).

The findings of this study differ significantly from the soil characterization along the River Kaduna watershed reported by Obasi *et al.* (2023). While the River Galma soils are dominated by sand (63% mean), the River Kaduna study reported soils dominated by silt clay loam with very low sand content, ranging from only 4% to 12.8% in most profile pits. The reason for this sharp contrast lies in the specific geomorphological units sampled; the sites along River Kaduna were specifically located in "Backswamp" depositional areas where debris from occasional flooding activities results in heavy depositions of clay and silt (Asselman, 1999; Obasi *et al.*, 2023). In comparison, the study area along the River Galma appears to be characterized by higher-energy flow dynamics or different terrace positions that favor the deposition of coarser alluvial materials over finer sediments.

**Table 2: Influence of flooding and post-flood irrigation on exchangeable bases, exchangeable acidity and CEC along River Galma**

| Site                | Ca (cmol/kg)        | Mg (cmol/kg)       | K (cmol/kg)        | Na (cmol/kg)       | EA (cmol/kg)        |
|---------------------|---------------------|--------------------|--------------------|--------------------|---------------------|
| Irrigated Upland    | 4.989 <sup>ab</sup> | 2.190 <sup>a</sup> | 0.249 <sup>b</sup> | 0.448 <sup>a</sup> | 0.334 <sup>b</sup>  |
| Irrigated Lowland   | 5.861 <sup>a</sup>  | 3.859 <sup>a</sup> | 0.429 <sup>a</sup> | 0.239 <sup>a</sup> | 0.557 <sup>a</sup>  |
| Unirrigated Upland  | 6.654 <sup>a</sup>  | 2.993 <sup>a</sup> | 0.252 <sup>b</sup> | 0.150 <sup>a</sup> | 0.445 <sup>ab</sup> |
| Unirrigated Lowland | 3.398 <sup>b</sup>  | 1.480 <sup>a</sup> | 0.164 <sup>b</sup> | 0.121 <sup>a</sup> | 0.390 <sup>ab</sup> |
| Grand Mean          | 5.225               | 2.631              | 0.274              | 0.240              | 0.432               |
| SED                 | 0.8015              | 1.1951             | 0.0670             | 0.1856             | 0.0754              |

Source: Field survey, November 2025, and laboratory analysis, December 2025

**Table 3: Influence of flooding and post-flood irrigation on particle size distribution along River Galma**

| Site / Treatment    | Sand (%)           | Silt (%)           | Clay (%)           |
|---------------------|--------------------|--------------------|--------------------|
| Irrigated Upland    | 72.13 <sup>a</sup> | 19.27 <sup>a</sup> | 8.60 <sup>a</sup>  |
| Irrigated Lowland   | 53.47 <sup>a</sup> | 34.60 <sup>a</sup> | 11.93 <sup>a</sup> |
| Unirrigated Upland  | 60.80 <sup>a</sup> | 26.60 <sup>a</sup> | 12.60 <sup>a</sup> |
| Unirrigated Lowland | 64.80 <sup>a</sup> | 24.60 <sup>a</sup> | 10.60 <sup>a</sup> |
| Grand Mean          | 63.00              | 26.00              | 11.00              |
| SED                 | 8.4                | 6.9                | 1.9                |

Source: Field survey, November 2025, and laboratory analysis, December 2025

#### **CONCLUSION**

The assessment of soils along River Galma in Zaria showed category-related variation in selected

chemical properties across irrigated and unirrigated upland and lowland positions. All categories had sandy-loam texture and slightly acidic soil reaction.

Organic carbon and total nitrogen were generally low, indicating the need to strengthen organic matter and nutrient management under continuous cultivation. Available phosphorus was higher in the lowland categories, while individual exchangeable bases showed different patterns among categories. The irrigated lowland recorded the highest magnesium and potassium, whereas calcium was highest in the unirrigated upland.  $EC_{1:5}$  values ranged from 79.93 to 135.93  $\mu S\ cm^{-1}$  and were statistically similar among categories, indicating no significant difference in soluble-salt concentration at the time of sampling. While the River Galma floodplain possesses high potential for year-round agricultural production, its long-term sustainability depends on addressing low organic matter and nitrogen levels. Site-specific soil management is recommended, including the application of organic amendments, crop-residue recycling and soil-test-guided fertilizer use to improve nutrient retention and soil fertility. Although  $EC_{1:5}$  did not differ significantly among categories, periodic monitoring of soil EC and irrigation-water quality is recommended to detect possible salt accumulation under continued irrigation.

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