INFLUENCE OF PERENNIAL FLOODING ON SOIL QUALITY INDICATORS OF A TROPICAL FLOODPLAIN IRRIGATION SYSTEM IN NORTHERN NIGERIA

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ABSTRACT

Perennial flooding is an important ecological process influencing soil quality and agricultural sustainability in tropical floodplain environments. This study evaluated the effects of repeated annual flooding on selected physical and chemical properties of soils within the Lake Geriyo Reclamation Irrigation Project, Adamawa State, Nigeria. Soil samples were collected from selected irrigation blocks before and after annual flood events at three depths (0–30, 30–60 and 60–90 cm) for two consecutive years. Soil physical properties, including particle-size distribution, bulk density, porosity, saturated hydraulic conductivity and aggregate stability, together with chemical fertility indicators, were analyzed. Results showed that perennial flooding produced only minor changes in soil quality indicators. Soil pH remained unchanged at 6.63 before and after flooding, while electrical conductivity remained very low, indicating no development of salinity hazards. Organic carbon, organic matter, total nitrogen and some exchangeable base cations showed slight reductions after flooding, whereas available phosphorus remained relatively stable. Physical properties exhibited small structural adjustments, with bulk density increasing from 1.33 to 1.35 g cm $^{-3}$ and porosity declining from 48.23 to 47.53%. Saturated hydraulic conductivity and wet aggregate stability decreased moderately after flooding but remained within favourable ranges for agricultural production. Soil fertility indices indicated high base saturation (mean 84.31%), low exchangeable sodium percentage (<1%) and very low sodium adsorption ratio, confirming the absence of sodicity risks. Overall, perennial flooding did not significantly degrade the chemical fertility or physical quality of the Geriyo floodplain soils. Instead, seasonal inundation appears to contribute to the maintenance of favourable soil conditions through periodic alluvial sediment deposition while causing only minor structural modifications. The findings demonstrate the resilience of tropical floodplain soils under recurrent flooding conditions and support their continued use for sustainable irrigated agriculture.

Keywords: Floodplain soils; perennial flooding; soil quality; soil fertility; alluvial sediments; irrigation agriculture.

1 INTRODUCTION

The increasing global demand for food production associated with population growth and urbanization has intensified pressure on agricultural land and freshwater resources. Irrigation has therefore become a critical component of modern agriculture by improving crop productivity, increasing cropping intensity and enhancing food security. However, the sustainability of irrigated agriculture depends not only on water availability but also on maintaining favourable soil conditions. Poor interactions between irrigation practices, soil properties and environmental processes may result in declining soil quality, reduced productivity and long-term land degradation [1, 2, 3]. Floodplain environments represent some of the most productive agricultural ecosystems because of their fertile alluvial soils and periodic supply of water and nutrients. In many tropical regions, particularly sub-Saharan Africa, irrigation schemes are commonly established within floodplain landscapes where seasonal flooding contributes to agricultural productivity through the deposition of sediments, organic materials and mineral nutrients. These processes enhance soil fertility, improve moisture availability and support crop production, making floodplain agriculture an important component of rural livelihoods [4, 5, 6]. Despite these benefits, repeated flooding can also influence important soil processes. Prolonged inundation modifies soil aeration by creating anaerobic conditions that affect microbial activity, nutrient cycling and redox reactions. Flooding may alter soil organic carbon, nitrogen dynamics, nutrient availability, exchangeable cations and structural properties through processes such as leaching, sediment deposition, aggregate disruption and pore modification. The magnitude of these effects depends on flood duration, sediment characteristics, soil texture, climatic conditions and land management practices [7, 8, 9, 10, 11]. Soil physical properties are particularly important indicators of flood impacts because they regulate water movement, aeration and root development. Flood-induced sediment deposition may increase soil bulk density, reduce pore continuity and modify saturated hydraulic conductivity, while prolonged wetting may influence aggregate stability and structural resilience. However, responses differ among floodplain systems, with some environments experiencing soil degradation under prolonged inundation, while others benefit from continuous renewal of nutrient-rich alluvial materials [12, 13, 14, 15, 16]. The Lake Geriyo Reclamation Irrigation Project in Adamawa State, Nigeria, is located within the River Benue floodplain and experiences annual flooding during the rainy season. The irrigation scheme supports agricultural activities and provides an important source of livelihood for surrounding communities [17, 18, 19, 20]. Previous studies have investigated selected soil characteristics within the project area; however, most assessments have focused on individual properties or limited sampling periods. Consequently, the cumulative influence of repeated annual flooding on the integrated physical and chemical quality of the irrigation soils remains insufficiently documented. Understanding soil responses to perennial flooding is essential for sustainable management of floodplain irrigation systems. Changes in soil fertility, structural stability and hydraulic behaviour can directly influence crop productivity, irrigation efficiency and long-term land sustainability. Therefore, evaluating soil properties before and after flood events provide insight into whether flooding represents a degrading process or a natural mechanism that maintains soil productivity [21, 22, 23]. This study assessed the effects of perennial flooding on selected physical and chemical properties of soils within the Lake Geriyo Reclamation Irrigation Project over two consecutive years. Specifically, the study evaluated changes in soil fertility indicators, exchange characteristics, salinity and sodicity status, soil texture, bulk density, porosity, saturated hydraulic conductivity and aggregate stability before and after annual flood events. The findings provide information on the resilience of tropical floodplain soils and contribute to improved management of irrigated agriculture under recurrent flooding conditions [4, 9, 12, 23]. Therefore, this study hypothesized that repeated annual flooding would significantly modify selected soil physical and chemical properties of the Geriyo floodplain soils. The evaluation of these changes is important because soil quality indicators provide measurable evidence of whether floodplain environments are undergoing degradation or maintaining their productive capacity under continuous agricultural use [22, 23].

2 MATERIALS AND METHODS

2.1 Study Area

The study was conducted at the Lake Geriyo Reclamation Irrigation Project located in Geriyo, Yola North Local Government Area of Adamawa State, Nigeria (Plate 1). It is bounded between latitude 9° 16′ to 91°9′N and longitudes 12° 21′ to 22° 18′E (Plate 1. It covers an area of 850 ha with 320 ha currently under cultivation. The area has two major seasons, the rainy and the dry season. The rainy season lasts from the beginning of May to the end of October, while the dry season last from November to the end of April. The driest months are January and February where the average minimum relative humidity is 13%. The wettest months are August and September where depth of rainfall reaches up to 25% of the total annual rainfall, the mean annual rainfall received is in the range of 150–1000 mm. The hottest month is April with monthly average temperature of 39.7°C, while the coldest months are December and January with minimum average temperature of 16°C, [16, 17, 18, 19]. Annual overflow of the River Benue during the rainy season inundates portions of the irrigation scheme, creating flooded and non-flooded agricultural fields suitable for assessing the influence of perennial flooding on soil properties. The project supports irrigation agriculture and serves as an important agricultural production area within the region [17, 20].

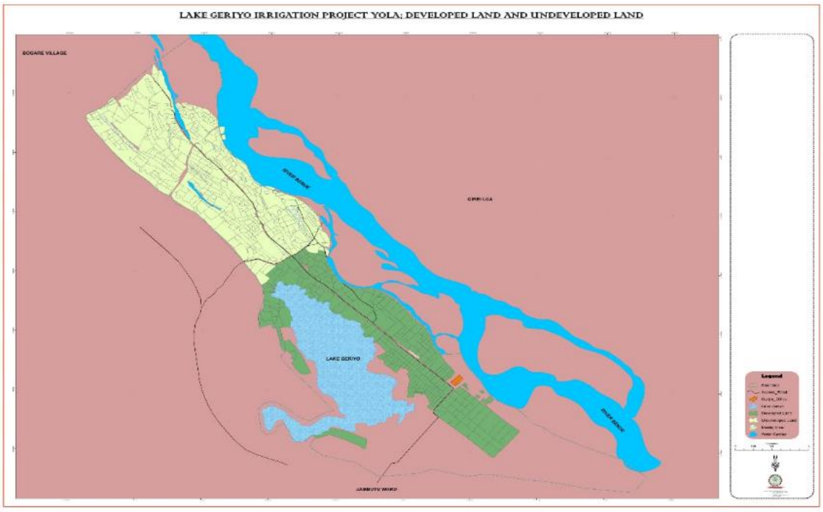

Plate 1. Digitized aerial view of Lake Geriyo Reclamation Project [18]

2.2 Experimental Design and Soil Sampling

A repeated sampling design was adopted to evaluate soil responses before and after annual flood events over two consecutive years (2023 and 2024). Soil samples were collected from selected irrigation blocks comprising 2B, 2C, 3A, 3B and Phase I. At each sampling location, soil samples were collected from three depth intervals of 0–30 cm, 30–60 cm and 60–90 cm. Sampling was conducted before flooding and after flood recession to determine changes associated with repeated inundation. The sampling approach was consistent with standard soil survey procedures for evaluating spatial and temporal variations in soil properties [25, 26]. Soil samples were collected for chemical analyses and physical measurements. Samples were labelled, transported to the laboratory and prepared according to standard procedures for soil physical and chemical analysis [25, 27].

2.3 Laboratory Analysis

Soil physical and chemical properties were determined using standard laboratory procedures. Particle-size distribution was determined using the hydrometer method. Bulk density was measured using the core method, while particle density was determined using the pycnometer method. Total porosity was calculated from bulk density and particle density values. These procedures follow established methods for soil physical analysis described in standard soil laboratory manuals [25, 28, 29]. Saturated hydraulic conductivity was determined using the constant-head permeameter method. This method is widely applied for measuring water transmission characteristics of relatively permeable soils under saturated conditions [28, 30, 31]. Wet and dry aggregate stability were determined using standard aggregate stability procedures. Aggregate stability assessment provides an important indicator of soil structural condition and resistance to disruption under wetting processes [32, 33]. Chemical analyses included soil pH, electrical conductivity (EC), organic carbon, organic matter, total nitrogen and available phosphorus. Soil pH determination and routine soil chemical analyses followed recognized soil laboratory procedures [25, 34]. Total nitrogen was determined using standard nitrogen analytical procedures including the Kjeldahl method [35, 36]. Exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) were determined together with other selected micronutrients. These exchangeable cations were used to evaluate soil fertility status and nutrient availability under changing flooding conditions [37, 38, 39]. Soil fertility indices including total exchangeable acidity (TEA), total exchangeable bases (TEB), effective cation exchange capacity (ECEC), exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR) and base saturation (BS) were calculated from measured exchangeable cations. These indices are commonly used for assessing soil fertility status, salinity and sodicity conditions [40, 41, 42].

2.4 Statistical Analysis

Descriptive statistics were used to summarize the measured soil properties before and after flooding. Two-way analysis of variance (ANOVA) was used to assess the effects of flooding status and sampling year, including their interaction, on the measured soil parameters [43]. Because measurements were repeatedly obtained from the same sampling locations, linear mixed-effects models (LMEMs) were additionally applied to account for the dependence among observations arising from repeated measurements at the same locations [44]. In the LMEMs, flooding status and sampling year were considered fixed effects, while sampling location was included as a random effect [44]. Statistical significance was assessed at the 5% probability level ($p < 0.05$) [17]. All statistical analyses were performed using R version 4.4.1 [45].

3 RESULTS AND DISCUSSIONS

3.1 Effects of Perennial Flooding on Soil Chemical Properties

The changes in selected chemical properties of the Geriyo floodplain soils before and after perennial flooding are summarized in Table 1. Overall, annual flooding produced only minor modifications in soil chemical characteristics during the two-year monitoring period. This finding suggests that the floodplain soils maintained considerable chemical resilience despite repeated seasonal inundation, a characteristic commonly reported for alluvial floodplain environments where sediment deposition and soil buffering processes help sustain soil fertility [9, 10]. Soil pH remained unchanged at 6.63 before and after flooding, indicating that repeated inundation did not significantly alter soil reaction. The observed slightly acidic to near-neutral condition is favourable for nutrient availability and crop production. The stability of soil pH suggests that the buffering capacity of the alluvial soils effectively resisted changes induced by seasonal flooding. Clay minerals, organic matter and exchangeable base cations likely contributed to maintaining the relatively stable soil reaction [9, 38, 46]. Electrical conductivity (EC) remained very low throughout the study period, increasing slightly from 0.04 to 0.05 dS m^{-1} after flooding. These values are far below levels associated with salinity constraints in agricultural soils, indicating that repeated flooding did not cause salt accumulation [47]. The slight increase observed after flooding may be attributed to the deposition of dissolved minerals transported by floodwaters and the redistribution of soluble salts within the floodplain [9, 10]. However, the relatively high variability among samples indicates differences in sediment deposition and floodwater distribution across the irrigation blocks. Total dissolved solids increased from 26.58 to 32.30 mg kg^{-1} after flooding. This increase suggests the addition of diss2olved materials and fine sediments during flood recession, as floodwaters commonly transport suspended sediments and dissolved constituents that are deposited across floodplain surfaces during inundation [5, 10]. However, the magnitude of change was insufficient to significantly modify soil chemical conditions, demonstrating that the flood regime did not create adverse accumulation of soluble materials. Organic carbon and organic matter declined slightly after flooding, decreasing from 1.38 to 1.29% and from 2.38 to 2.23%, respectively. These reductions may be associated with redistribution of organic materials during inundation and enhanced decomposition following drainage. Flood-induced anaerobic conditions can temporarily slow decomposition, but subsequent drying periods may accelerate mineralization of organic residues [5, 48]. The small magnitude of change indicates that soil organic matter reserves remained relatively stable, reflecting the capacity of floodplain ecosystems to retain and recycle organic materials under periodic flooding [9, 48].

Table 1. Summary of Selected Soil Chemical Properties Before and After Flooding

S/No	Property	Before flooding	After flooding
1	pH	6.63 ± 0.16	6.63 ± 0.34
2	EC (dS m^{-1})	0.04 ± 0.02	0.05 ± 0.05
3	TDS (mg kg^{-1})	26.58 ± 14.75	32.30 ± 28.85
4	Organic carbon (%)	1.38 ± 0.18	1.29 ± 0.29
5	Organic matter (%)	2.38 ± 0.30	2.23 ± 0.50
6	Total nitrogen (%)	0.12 ± 0.02	0.11 ± 0.03
7	Available phosphorus (mg kg^{-1})	6.69 ± 1.02	6.76 ± 1.10
8	Calcium (cmol kg^{-1})	3.63	3.08
9	Magnesium (cmol kg^{-1})	1.41	1.04
10	Sodium (cmol kg^{-1})	0.81	0.71
11	Potassium (cmol kg^{-1})	0.66	0.68

Total nitrogen followed a similar pattern, decreasing slightly from 0.12 to 0.11%. Nitrogen losses under flooded conditions may occur through denitrification, leaching and volatilization processes as alternating aerobic and anaerobic conditions promote microbial nitrogen transformations [49, 50]. However, the observed reduction was small, suggesting that annual flooding did not substantially reduce soil nitrogen availability during the study period. Available phosphorus remained relatively stable, increasing slightly from 6.69 to 6.76 mg kg^{-1}. Flooding can influence phosphorus availability through changes in soil redox conditions and iron mineral transformations, which may either increase phosphorus release into the soil solution or enhance its retention depending on site conditions [5, 10]. However, the minimal variation observed indicates that phosphorus retention processes remained effective in the Geriyo floodplain soils. Exchangeable calcium, magnesium and sodium decreased after flooding, from 3.63 to 3.08 cmol kg^{-1}, 1.41 to 1.04 cmol kg^{-1} and 0.81 to 0.71 cmol kg^{-1}, respectively. These reductions indicate possible short-term movement of soluble cations during inundation. Conversely, exchangeable potassium remained relatively unchanged, increasing slightly from 0.66 to 0.68 cmol kg^{-1}. Despite these changes, the soils maintained favourable nutrient status, indicating that nutrient losses were compensated by the natural renewal processes associated with floodplain environments [21, 38, 46].

3.2 Soil Fertility Status and Flooding Effects

The calculated soil fertility indices demonstrated that perennial flooding did not adversely affect the chemical fertility status of the Geriyo floodplain soils (Table 2). Total exchangeable acidity (TEA) ranged from 0.07 to 2.21 cmol kg^{-1} across the irrigation blocks, indicating generally low acidity levels. The low TEA values correspond with the measured soil pH and suggest minimal risk of aluminium toxicity. These conditions are favourable for root development and nutrient uptake because exchangeable acidity remains sufficiently low to avoid adverse effects on nutrient availability and plant growth [38, 46]. Total exchangeable bases (TEB) ranged from 3.81 to 8.17 cmol kg^{-1}, reflecting moderate to high concentrations of exchangeable nutrient cations. The maintenance of relatively high exchangeable bases after repeated flooding indicates that the soils retained adequate nutrient reserves. This is consistent with floodplain systems where periodic sediment deposition replenishes essential elements and maintains soil fertility despite seasonal inundation [5, 9, 10].

Table 2. Soil Fertility Indices across Irrigation Blocks

S/No.	Index	Range observed
1	TEA (cmol kg^{-1})	0.07–2.21
2	TEB (cmol kg^{-1})	3.81–8.17
3	ECEC (cmol kg^{-1})	6.03–10.02
4	ESP (%)	0.21–0.67
5	SAR	0.05–0.17
6	Base saturation (%)	63.29–96.79
7	Mean base saturation (%)	84.31

Effective cation exchange capacity (ECEC) varied between 6.03 and 10.02 cmol kg^{-1}, indicating a moderate capacity for nutrient retention. The relatively stable ECEC values suggest that flooding did not impair the soil exchange complex. The combined influence of clay minerals and soil organic matter likely contributed to maintaining nutrient-holding capacity by providing negatively charged exchange sites for essential cations [38, 46]. The observed ECEC values therefore indicate that the Geriyo floodplain soils retained adequate capacity to adsorb and supply nutrients for plant growth. Exchangeable sodium percentage (ESP) ranged from 0.21 to 0.67%, while sodium adsorption ratio (SAR) ranged from 0.05 to 0.17. These values are substantially below internationally accepted critical limits associated with sodic soil development, indicating that perennial flooding did not promote sodium accumulation or structural deterioration caused by clay dispersion [47. 48]. The negligible sodium hazard further confirms that the floodwaters did not introduce sufficient soluble sodium to adversely affect soil physical or chemical quality. Base saturation ranged from 63.29 to 96.79%, with a mean value of 84.31%. The high base saturation confirms that most exchange sites were occupied by beneficial nutrient cations, particularly calcium, magnesium and potassium, rather than acidic cations. High base saturation is generally associated with fertile soils, efficient nutrient cycling and favourable conditions for crop production [21, 38, 46,]. Together with low acidity, moderate ECEC and negligible sodium hazards, these results demonstrate that the Geriyo floodplain soils retained favourable chemical conditions for sustained agricultural production. The findings further suggest that periodic flooding contributed to maintaining soil fertility through sediment deposition and nutrient renewal without inducing soil degradation [9, 10, 48].

3.3 Effects of Perennial Flooding on Soil Physical Properties

The physical properties of the Geriyo floodplain soils before and after flooding are presented in Table 3. The soils were classified mainly as sandy clay loam, sandy clay and clay loam. Average particle-size distribution consisted of 50.35% sand, 17.51% silt and 32.14% clay. No change in textural classification occurred following flooding, indicating that sediment deposition during the study period was insufficient to modify the basic particle-size composition of the soils. Soil texture is primarily controlled by parent material and long-term pedogenic processes; consequently, short-term flooding events generally have limited influence on textural class [38, 46]. Similar observations have been reported for floodplain soils where periodic flooding modifies surface sediments but does not substantially alter the inherent particle-size distribution of the soil profile [9, 10]. Bulk density increased slightly from 1.33 to 1.35 g cm^{-3} after flooding. This increase suggests minor soil consolidation associated with sediment deposition and particle rearrangement during inundation [13, 17]. However, the observed values remain within the optimum range for most agricultural soils and are unlikely to restrict root penetration or crop growth [3,14].

Table 3. Summary of Soil Physical Properties before and After Flooding

S/NO.	Property	Before flooding	After flooding
1	Sand (%)	50.35	50.35
2	Silt (%)	17.51	17.51
3	Clay (%)	32.14	32.14
4	Bulk density (g cm^{-3})	1.33	1.35
5	Particle density (g cm^{-3})	2.58	2.58
6	Porosity (%)	48.23	47.53
7	Saturated hydraulic conductivity (cm h^{-1})	28.67	24.67
8	Wet aggregate stability (%)	69.44	66.11
9	Dry aggregate stability (%)	~58	~58

Particle density remained constant at approximately 2.58 g cm^{-3}, indicating that flooding did not alter the mineral composition of the soils. The observed changes in bulk density were therefore associated with structural rearrangement rather than changes in soil mineralogy, since particle density is largely determined by the mineral constituents of the soil and remains relatively stable under normal field conditions [46, 51]. Total porosity declined slightly from 48.23 to 47.53%, corresponding with the increase in bulk density. Flood-induced deposition of fine materials may reduce the proportion of conducting pores and temporarily modify pore continuity [52, 53]. Nevertheless, the remaining porosity values indicate that adequate air and water movement were maintained, suggesting that flooding did not substantially impair the physical quality of the soils [21]. Saturated hydraulic conductivity decreased from 28.67 to 24.67 cm h^{-1} following flooding. The reduction may be attributed to partial pore blockage by deposited sediments and temporary consolidation under saturated conditions [10, 52]. Despite this decrease, hydraulic conductivity remained favourable for irrigated agriculture, indicating that soil permeability was not significantly impaired [51]. Wet aggregate stability decreased from 69.44 to 66.11% after flooding. Prolonged wetting can weaken aggregate bonds through slaking and the disruption of cementing agents that stabilize soil aggregates [31]. However, the remaining stability values indicate that soil structural integrity was largely preserved. Dry aggregate stability remained approximately unchanged at about 58%, demonstrating that flooding effects were mainly temporary and associated with wet conditions rather than permanent structural degradation [21, 31].

3.4 Statistical Evaluation of Flooding Effects on Selected Soil Properties

Two-way analysis of variance (ANOVA) was performed to determine the effects of sampling year, flooding condition, and their interaction on selected soil chemical properties. The results showed (Table 4) that soil pH was significantly influenced by sampling year ($F = 4.23$, $p = 0.04$), indicating temporal variation in soil reaction during the study period. However, flooding had no significant effect on soil pH (F = 0.45, $p = 0.50$), and the interaction between sampling year and flooding condition was also not significant (F = 0.21, $p = 0.65$). These findings suggest that seasonal or interannual environmental variability exerted a greater influence on soil pH than flooding itself, consistent with observations in resilient floodplain soils where temporal changes often exceed the effects of individual flood events [5, 9, 10]. Electrical conductivity (EC) exhibited no significant response to either sampling year or flooding treatment. The effects of year (F = 1.23, $p = 0.27$), flooding (F = 1.51, $p = 0.22$), and their interaction (F = 0.12, $p = 0.73$) were statistically insignificant, confirming that perennial flooding did not promote measurable changes in soil salinity status during the study period. Similar findings have been reported for alluvial floodplain soils where seasonal flooding had limited influence on soil salinity because deposited sediments and floodwaters contained relatively low concentrations of soluble salts [9, 10]. Similarly, total dissolved solids (TDS) showed no significant differences attributable to sampling year (F = 0.23, $p = 0.63$), flooding condition (F = 1.01, $p = 0.32$), or the year × flooding interaction (F = 0.05, $p = 0.82$). These results confirm that although minor numerical variations occurred after flooding, the observed changes were insufficient to produce statistically detectable effects. This finding further supports the conclusion that the flood regime-maintained soil chemical stability throughout the monitoring period [10, 21]. A Linear Mixed-Effects Model (LMEM) was further applied to account for the repeated measurements obtained from the same sampling locations over the two-year monitoring period. The model indicated that sampling year significantly influenced soil pH ($\beta = 0.23$, $p = 0.04$), whereas flooding had no significant effect ($\beta = -0.01$, $p = 0.95$). The estimated variance associated with sampling location was 0.02, indicating limited variability among sampling points after accounting for temporal and flooding effects. Mixed-effects models are particularly appropriate for repeated-measures environmental studies because they account for correlations among observations collected from the same sampling units while separating fixed treatment effects from random site-to-site variation [55, 56]. Overall, both ANOVA and LMEM analyses demonstrate that perennial flooding produced no statistically significant deterioration in the measured soil chemical properties. The significant year effect observed for pH suggests that temporal environmental variations contributed more strongly to changes in soil reaction than flooding itself, highlighting the resilience of the Geriyo floodplain soils under repeated seasonal inundation [9, 10, 21].

Table 4. Summary of ANOVA and Linear Mixed-Effects Model results for selected soil properties

S/No.	Soil property	Statistical test	Factor	Test statistic / Estimate	p-value	Interpretation
1	pH	Two-way ANOVA	Year	F = 4.23	0.04	Significant
2	pH	Two-way ANOVA	Flooding	F = 0.45	0.5	Not significant
3	pH	Two-way ANOVA	Year× Flooding	F = 0.21	0.65	Not significant
4	EC	Two-way ANOVA	Year	F = 1.23	0.27	Not significant
5	EC	Two-way ANOVA	Flooding	F = 1.51	0.22	Not significant
6	EC	Two-way ANOVA	Year×Flooding	F = 0.12	0.73	Not significant
7	TDS	Two-way ANOVA	Year	F = 0.23	0.63	Not significant
8	TDS	Two-way ANOVA	Flooding	F = 1.01	0.32	Not significant
9	TDS	Two-way ANOVA	Year×Flooding	F = 0.05	0.82	Not significant
10	pH	LMEM	Year	$\beta = 0.23$	0.04	Significant
11	pH	LMEM	Flooding	$\beta = -0.01$	0.95	Not significant

Random effect (LMEM): Sampling location variance = 0.02

3.5 Overall Soil Response to Perennial Flooding

The combined chemical and physical results indicate that perennial flooding produced only limited changes in the soil quality indicators of the Geriyo floodplain. The slight reductions in exchangeable nutrients, saturated hydraulic conductivity and wet aggregate stability represent normal responses to seasonal inundation rather than evidence of soil degradation. Similar responses have been reported in floodplain ecosystems where periodic flooding causes temporary modifications to soil chemical and physical properties without substantially compromising long-term soil quality or agricultural productivity [9, 10, 21]. The stability of soil texture, pH, particle density and dry aggregate stability, together with favourable fertility indices, demonstrates the resilience of the floodplain soils. Soil resilience in floodplain environments is largely attributed to the buffering capacity of alluvial soils, the maintenance of soil exchange properties and the periodic replenishment of sediments and nutrients during inundation [21, 38, 46]. These processes help sustain soil fertility and structural stability despite repeated seasonal flooding [10, 48]. Under the prevailing flood regime, inundation therefore functions primarily as a soil-renewing process rather than a degrading mechanism. The absence of significant deterioration in the measured soil quality indicators suggests that the current flooding regime contributes to the maintenance of productive soil conditions through natural sediment deposition and nutrient renewal [9, 10, 48]. However, continued monitoring remains necessary because long-term changes in flood frequency, duration and sediment characteristics associated with climate variability and catchment land-use change may alter future soil behaviour and ecosystem functioning [5, 10].

4 CONCLUSIONS

Perennial flooding within the Lake Geriyo Reclamation Irrigation Project produced only limited changes in soil quality indicators over the two-year study period. The soils maintained favourable chemical fertility conditions, characterized by stable pH, low salinity status, high base saturation, moderate nutrient retention capacity and negligible sodium hazards. Although flooding resulted in slight reductions in organic carbon, total nitrogen, some exchangeable cations, saturated hydraulic conductivity and wet aggregate stability, these changes were relatively small and did not compromise soil productivity. Soil texture, particle density and dry aggregate stability remained unchanged, indicating preservation of the fundamental physical characteristics of the floodplain soils. The findings demonstrate that the Geriyo floodplain soils possess considerable resilience to recurrent flooding. Rather than causing soil degradation, seasonal inundation appears to support soil fertility through continued alluvial sediment deposition while producing only minor and reversible structural modifications. The continued productivity of the irrigation system under the current flood regime is therefore supported. Nevertheless, long-term monitoring is recommended to assess potential cumulative effects of changes in flood intensity, duration and sediment characteristics associated with future environmental variability.

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