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Post-2022 Flood Impact on Soil Physicochemical Parameters and Nutrient Status Across Eight Agro-Ecological Communities in Isoko, Delta State, Southern Nigeria

AKPEZI Okiemute Edewor[1], UFUOMA Akpovwowo[2], & TOBECHUKWU Okwuokei[3]
Department of Geography and Environmental Sustainability,
Delta State University, Abraka
email: aoedewor@delsu.edu.ng
email: akpovwovwo@delsu.edu.ng
email: tokwuokei@delsu.edu.ng

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Abstract
Composite surface samples (0–20 cm) were collected from eight communities—Araya, Ofagbe, Oleh, Owhodokpoko, Ozoro, Igbide, Aviara, and Uzere—following flood recession. They were analysed for 17 parameters: texture, pH, exchangeable acidity, organic carbon (OC), total nitrogen (TN), available phosphorus, base cations, and electrical conductivity (EC). Ordinary least squares regression, one-way ANOVA with Tukey HSD post-hoc comparisons, and principal component analysis (PCA) with varimax rotation were employed. Organic carbon and total nitrogen exhibited near-perfect coupling ($R^2 = 0.971$, $p < 0.001$; C:N = 7.94 ± 1.94). Exchangeable H^+ constituted 96% of exchangeable acidity, deviating markedly from aluminium-dominated tropical soil norms. pH significantly predicted exchangeable acidity ($R^2 = 0.834$, $p = 0.002$). Five of seven pre-specified regressions were significant. Models for available phosphorus and cation exchange capacity were not. ANOVA confirmed pH class (Very Strongly Acidic vs. Strongly Acidic) as a significant stratifier for exchangeable acidity (+2.54 cmol/kg, $p = 0.029$) and EC (+22.4 µS/cm, $p = 0.029$). Meanwhile, organic carbon class significantly differentiated OC and TN only ($p = 0.005$ and $p = 0.020$, respectively). PCA extracted two components explaining 75.2% of cumulative variance. This revealed three functional site clusters: Acid-Saline (Araya), Fertile-Recovering (Aviara, Ozoro, Oleh, Owhodokpoko, Igbide), and Depleted (Uzere, Ofagbe). These findings provide the first empirical soil-physicochemical fertility, soil suitability and capability indeces for flood recovering communities.

Keywords: *2022 flood, Isoko communities, Delta State, soil acidity, exchangeable hydrogen, C:N ratio, principal component analysis, post-flood soil rehabilitation*

Introduction

The Isoko ethnolinguistic group occupies a lowland agrarian territory spanning Isoko North and Isoko South Local Government Areas in Delta State, southern Nigeria. Underlain by Coastal Plain Sand soils of the Benin Formation, this landscape supports cassava, yam, plantain, and maize as staple crops. The region's low elevation and Niger Delta distributary network render it chronically flood-prone. The 2022 event, however, exceeded all historical precedent, even exceeding the impact of the nearest 2012 flood.

Between September and November 2022, coordinated Lagdo Dam releases from Cameroon, superimposed on anomalous rainfall across the Niger–Benue basin, submerged Isoko farmlands for four to eight continuous weeks. Floodwaters reached one to three metres. Standing crops were destroyed. Several thousand residents were displaced to the Ozoro internally displaced persons camp. When waters finally receded, farmers confronted a pressing, unanswered question: what condition were their soils in?

Prolonged inundation reconfigures soil systems through physical scouring, sediment deposition, redox-driven chemical transformations, base-cation leaching, and disruption of organic matter dynamics. Edewor (2025) demonstrated that floodplain soils exhibit pronounced spatial heterogeneity in carbon pools and nutrient fluxes even within single reaches. Edewor & Atubi (2021) extended this finding by documenting strong lateral gradients in riparian soil physicochemical properties governed by microtopography, inundation duration, and distance from the channel. In tropical environments, these effects intensify: higher temperatures accelerate post-recession organic matter mineralization, and the kaolinitic clay mineralogy of these Coastal Plain sands provides minimal buffering against proton accumulation (Sanchez, 2019). The need for this study cannot be undermined on basis of the reasoning that justifies sustainable practices on the environment for proper environmental evaluation and monitoring.

Existing scholarship on the Niger Delta has addressed flood impacts on livelihoods and farmer adaptation (Ebhuoma et al., 2020; Ikehi et al., 2023). Broader reviews have linked climate-driven extreme weather to accelerating soil degradation across sub-Saharan Africa (Echendu, 2022). Yet post-disaster soil physicochemical assessments remain conspicuously scarce—precisely in regions where flood recurrence is intensifying under climate projections. No published study has conducted a systematic, multi-parameter soil characterization across Isoko communities following the 2022 floods. This gap denies agricultural extension services and Delta State agencies the site-specific evidence required to design differential, cost-effective rehabilitation interventions.

Pronounced inter-site heterogeneity compounds the problem. The eight communities sampled—Araya, Ofagbe, Oleh, Owhodokpoko, Ozoro, Igbide, Aviara, and Uzere, differ in micro-elevation, channel proximity, and pre-flood land-use history. Preliminary field observations indicated substantial variation in flood depth, flow velocity, and recession timing across these locations. Uniform rehabilitation prescriptions would therefore risk both under-treatment of severely degraded patches and wasteful over-application on less-affected terrain.

This study addresses three interlocking research questions. First, how did the 2022 flooding alter soil physicochemical properties—including texture, pH, exchangeable acidity, organic carbon, total nitrogen, available phosphorus, base cation concentrations, and electrical conductivity—across the eight sampling sites? Second, what inter-parameter relationships, revealed through correlation and regression analyses, explain post-flood nutrient status and inform mechanistic understanding of flood-induced soil change in this kaolinitic, sandy geo-environment? Third, can the sampling sites be grouped into functional clusters, through ANOVA and principal component analysis, that would permit differential, site-specific rehabilitation strategies rather than blanket recommendations? By answering these questions, the study provides the first empirical soil-physicochemical evidence base to guide post-2022 flood agricultural recovery in the Isoko region of Delta State.

Materials and Methods

Study Area

Eight agrarian communities—Araya, Ofagbe, Oleh, Owhodokpoko, Ozoro, Igbide, Aviara, and Uzere, across Isoko North and Isoko South Local Government Areas, Delta State, Nigeria (5°30′–5°45′ N, 6°00′–6°20′ E) constituted the study area. The region lies within the Benin Formation, comprising Miocene-to-Pleistocene continental sands with subordinate clays and lignite intercalations. Derived soils are deep, freely drained Typic Paleudults, correlating to Haplic Acrisols, characterised by sandy texture, low-activity kaolinitic clay, and pronounced base desaturation. The 2022 flood triggered by Lagdo Dam releases and extreme rainfall, inundated the Isoko lowlands for 4–8 weeks at depths of 1–3 m.

Sampling Protocol

Sampling followed a systematic protocol in January–February 2023, four weeks post-recession using the soil auger tool. At each community, composite surface samples (0–20 cm) were obtained via radial design: five subsamples at cardinal and intercardinal points (10 m from a central geo-referenced point) were homogenized to yield ~1.5 kg of composite material. Visible debris, roots, and coarse fragments (>2 mm) were removed by hand-picking. Samples were air-dried (72 h), crushed, passed through a 2 mm sieve, and stored in sealed polythene bags, integrating microtopographic variability while preserving site-level representativeness.

Laboratory Analyses

Seventeen physicochemical parameters were determined. Particle-size distribution employed the Bouyoucos hydrometer method with sodium hexametaphosphate. Soil pH was measured potentiometrically in deionised water (1:2.5). Available phosphorus was extracted by Bray-1 (0.03 M NH_4F in 0.025 M HCl) and quantified colourimetrically at 882 nm. Exchangeable acidity (H^+, Al^{3+}) was determined by titration of 1 M KCl extracts with 0.05 M NaOH. Exchangeable bases, Ca^{2+}, Mg^{2+}, K^+, Na^+, were extracted with neutral 1 M ammonium acetate; Ca^{2+} and Mg^{2+} by atomic absorption spectrophotometry, K^+ and Na^+ by flame emission photometry. Organic carbon used Walkley-Black wet oxidation; total nitrogen used macro-Kjeldahl digestion–distillation. Electrical conductivity was measured in 1:2.5 soil–water suspension. Quality assurance comprised analytical duplicates, procedural blanks, and certified reference materials (NIST SRM 2710a, 2711a) at one blank and one reference per eight-sample batch, achieving ±5% RSD and 92–105% recovery.

Statistical Analysis

Statistical analyses were conducted in R v4.3.1. Seven pre-specified ordinary least squares regressions tested: organic carbon versus total nitrogen, pH versus exchangeable acidity, exchangeable H^+ versus pH, electrical conductivity regressed on Na^+ and exchangeable acidity, clay versus sand, available phosphorus predicted by pH and organic carbon, and effective cation exchange capacity as a function of clay and organic carbon. One-way ANOVA stratified sites by pH class (Very Strongly Acidic: pH < 5.0; Strongly Acidic: pH 5.0–5.5) and organic carbon class (Low: <1%; Medium: 1–2%; High: >2%), with Tukey HSD post-hoc comparisons at $\alpha = 0.05$. Principal Component Analysis with varimax rotation was applied to all 15 continuous variables. Shapiro-Wilk tests confirmed residual normality for all significant regressions ($W = 0.87–0.98$; $p = 0.14–0.95$). Effect sizes (R^2, η^2) supplemented significance testing given the limited sample ($n = 8$).

Results

Descriptive Statistics

Descriptive statistics for all 17 parameters across eight sites are presented in Table 1. Soils were uniformly sandy loam (sand: 80.0 ± 2.4%; clay: 8.0 ± 2.4%), strongly acidic (pH 4.57–5.30; mean 4.95 ± 0.25), and characterized by low effective cation exchange capacity (CEC: 4.10 ± 2.02 cmol/kg; range 2.19–8.16). Exchangeable acidity exhibited the highest variability (CV = 58.0%), driven by exchangeable H^+ (2.88 ± 1.75 cmol/kg), which constituted ~96% of total acidity, with Al^{3+} negligible (0.11 ± 0.06 cmol/kg). Organic carbon (OC) ranged from 0.21% to 2.95% (mean 1.69 ± 0.86%; CV = 51.1%) and total nitrogen (TN) from 0.06% to 0.36% (mean 0.20 ± 0.09%; CV = 45.7%). Electrical conductivity (EC) averaged 57.0 ± 15.3 µS/cm; available phosphorus ranged from 11.92 to 17.48 mg/kg. Base saturation was uniformly low (30.1 ± 10.0%).

Table 1. Descriptive statistics of post-2022 flood soil properties across eight Isoko communities.

Parameter	Mean ± SD	Range	CV (%)	Agronomic Status
Sand (%)	80.0 ± 2.4	75–83	3.1	Uniform sandy loam
Clay (%)	8.0 ± 2.4	5–13	29.9	Low clay
pH (H_2O)	4.95 ± 0.25	4.57–5.30	5.0	100% below threshold (pH 5.5)
Avail. P (mg/kg)	14.0 ± 2.1	11.9–17.5	14.9	Moderate
Exch. Acidity (cmol/kg)	2.99 ± 1.73	1.30–6.20	58.0	High variability
Exch. H^+ (cmol/kg)	2.88 ± 1.75	1.15–6.15	60.9	Dominant acid source (96%)
Exch. Al^{3+} (cmol/kg)	0.11 ± 0.06	0.05–0.20	53.0	Negligible (4%)
Org. Carbon (%)	1.69 ± 0.86	0.21–2.95	51.1	Low–moderate; 14-fold range
Total N (%)	0.20 ± 0.09	0.06–0.36	45.7	Low–moderate
Ca^{2+} (cmol/kg)	0.54 ± 0.24	0.30–1.08	44.5	Very low
EC (µS/cm)	57.0 ± 15.3	34–83	26.8	Low salinity
CEC_eff (cmol/kg)	4.10 ± 2.02	2.19–8.16	49.3	Low–moderate
Base Saturation (%)	30.1 ± 10.0	20.6–44.2	33.2	Very low (<50%)

Source: Author's fieldwork

Correlation Structure,

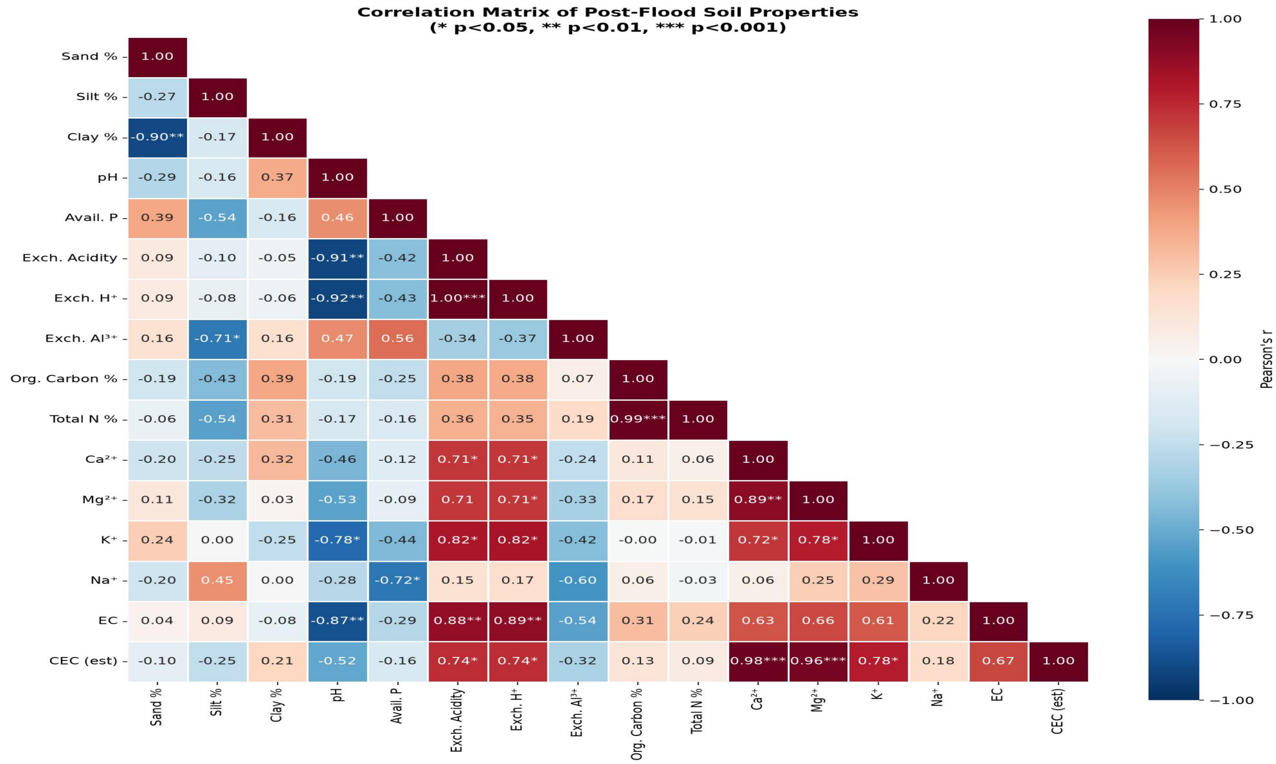

Figure 1. Pearson correlation heatmap of 16 soil physicochemical parameters across eight post-2022 flood Isoko sampling sites.

The Pearson correlation heatmap (Fig. 1) revealed 27 of 136 pairwise correlations as significant ($p < 0.05$). The strongest associations were OC–TN ($r = +0.985$, $p < 0.001$), exchangeable acidity–H^+ ($r = +1.000$, $p < 0.001$), pH–exchangeable acidity ($r = -0.913$, $p = 0.002$), and sand–clay ($r = -0.903$, $p = 0.002$). Critically, CEC correlated almost exclusively with exchangeable acidity ($r = +0.992$) rather than with clay ($r = +0.277$) or OC ($r = +0.097$), indicating proton-dominated exchange complexes post-flood.

Three dominant correlation axes emerged:

- **Acidity–Ionic Strength:** Exch. Acidity ↔ H^+ ($r = +1.000$), Exch. Acidity ↔ CEC ($r = +0.992$), pH ↔ H^+ ($r = -0.918$), EC ↔ H^+ ($r = +0.889$)
- **Organic Matter Coupling:** OC ↔ TN ($r = +0.985$)
- **Texture–Base Cations:** Sand ↔ Clay ($r = -0.903$), Ca^{2+} ↔ Mg^{2+} ($r = +0.891$)

Regression Analyses

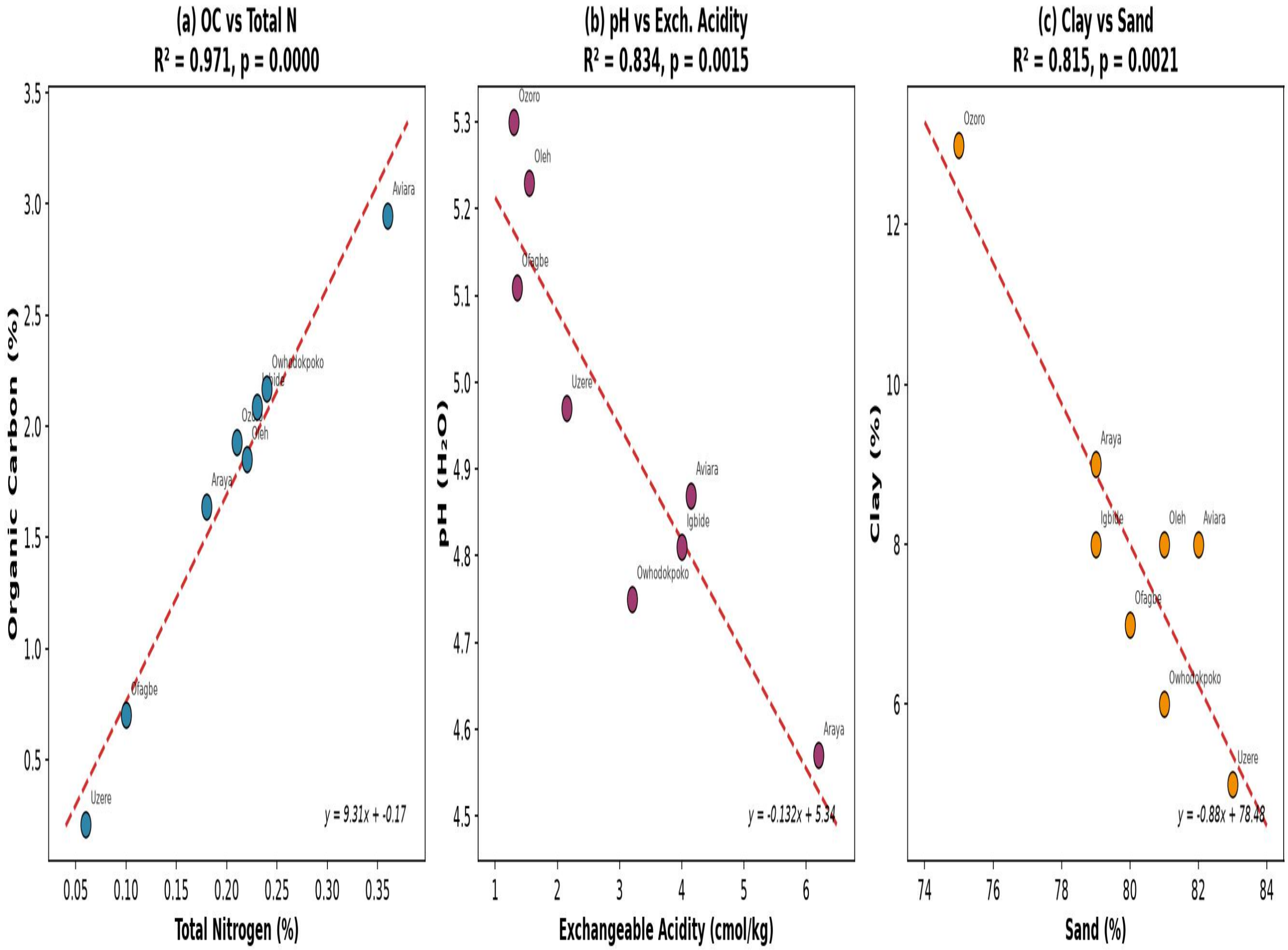

Figure 2. Four-panel regression scatterplots for key soil relationships across eight Isoko communities.

Five of seven linear regression models were significant (Fig. 2, Table 2).

Table 2. Summary of seven regression models.

#	Model	R^2	Adj. R^2	F	p	Sig.
M1	Org. Carbon ~ Total Nitrogen	0.971	0.966	197.53	<0.001	***
M2	pH ~ Exch. Acidity	0.834	0.806	30.13	0.002	**
M3	Exch. H^+ ~ pH	0.843	0.816	32.14	0.001	**
M4	EC ~ Na^+ + Exch. Acidity	0.784	0.697	9.05	0.022	*
M5	Clay ~ Sand	0.815	0.784	26.41	0.002	**
M6	Avail. P ~ pH + Org C	0.241	−0.063	0.79	0.503	ns
M7	CEC_eff ~ Clay + Org C	0.046	−0.336	0.12	0.889	ns

The OC–TN relationship yielded the highest explanatory power:

Org. Carbon (%) = −0.170 + 9.311 × Total Nitrogen (%) — $R^2 = 0.971$, $p < 0.001$

pH was strongly predicted by exchangeable acidity:

pH = 5.345 − 0.132 × Exch. Acidity — $R^2 = 0.834$, $p = 0.002$

Exchangeable H^+ was strongly predicted by pH:

Exch. H^+ = 34.77 − 6.44 × pH — $R^2 = 0.843$, $p = 0.001$

In the two-predictor model (pH ~ H^+ + Al^{3+}), only H^+ was significant ($\beta = -0.123$, $p = 0.005$), while Al^{3+} was not ($\beta = +0.688$, $p = 0.423$). H^+ constituted 96% of total acidity — a striking departure from aluminium-dominated tropical soil norms.

EC was jointly predicted by exchangeable acidity and Na^+ ($R^2 = 0.784$, $p = 0.022$), though only acidity was individually significant ($\beta = +7.64$, $p = 0.009$). Textural complementarity was confirmed (Clay vs. Sand: $R^2 = 0.815$, $p = 0.002$).

Two models were non-significant: available P ~ pH + OC ($R^2 = 0.241$, $p = 0.503$) and CEC ~ Clay + OC ($R^2 = 0.046$, $p = 0.889$). These null results are mechanistically important — phosphorus is likely controlled by Fe/Al oxide sorption equilibria, and CEC is H^+-dominated rather than mineral/OM-driven.

ANOVA — Group Comparisons

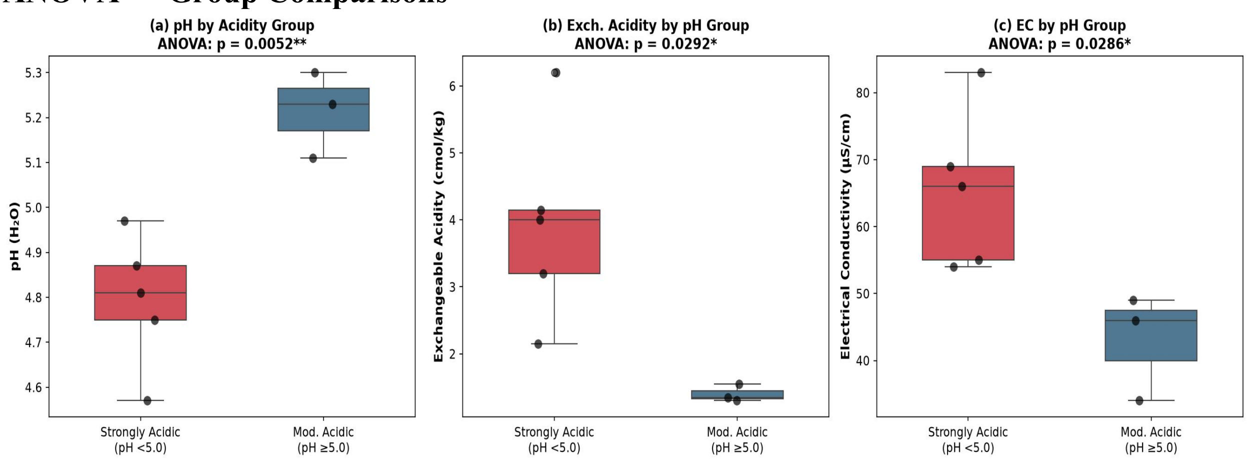

Figure 3. Boxplots of soil properties by pH acidity class across Isoko communities.

One-way ANOVA by pH class (Very Strongly Acidic, n = 5 vs. Strongly Acidic, n = 3) revealed significantly elevated exchangeable acidity (+2.54 cmol/kg; $F_{1,6} = 8.12$, $p = 0.029$) and EC

(+22.4 μS/cm; $F_{1,6} = 8.21$, $p = 0.029$) in more acidic sites (Fig. 3). Base saturation, Ca^{2+}, Mg^{2+}, and K^{+} also differed ($p = 0.003–0.043$). Tukey HSD confirmed these differences (Table 3).

Table 3. One-way ANOVA: Very Strongly Acidic (pH < 5.0) vs. Strongly Acidic (pH 5.0–5.5).

Variable	VSA Mean	SA Mean	F(1,6)	p	Tukey Δ	p-adj
pH	4.79	5.21	18.39	0.005	−0.42	0.005
Exch. Acidity	3.94	1.40	8.12	0.029	−2.54	0.029
EC	65.4	43.0	8.21	0.029	−22.4	0.029
CEC_eff	5.11	2.40	5.60	0.056	−2.71	0.056
Avail. P	13.89	14.28	0.06	0.819	—	ns
Org. Carbon	1.81	1.49	0.23	0.651	—	ns

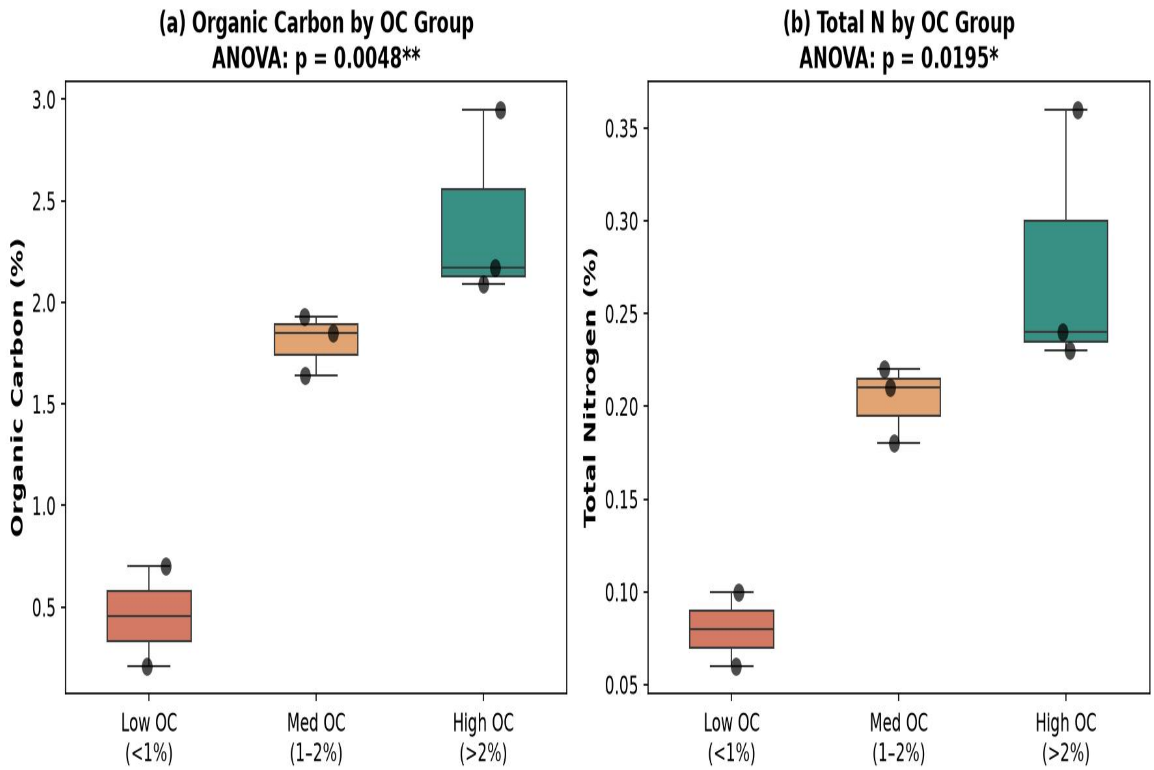

Figure 4. Boxplots of soil properties by organic carbon class across Isoko communities.

When stratified by OC class (Low/Medium/High), only OC ($F_{2,5} = 18.73$, $p = 0.005$) and TN ($F_{2,5} = 9.57$, $p = 0.020$) differed significantly (Fig. 4, Table 4).

Table 4. One-way ANOVA: Low (<1%), Medium (1–2%), and High (>2%) organic carbon.

Variable	Low OC	Med OC	High OC	F(2,5)	p	Significant Pairs
Org. Carbon	0.46	1.81	2.40	18.73	0.005	High > Low**
Total Nitrogen	0.08	0.20	0.28	9.57	0.020	High > Low*
C:N Ratio	5.25	8.73	8.47	6.91	0.036	High, Med > Low*

Critically, no other soil property differed across OC classes — not pH, exchangeable acidity, available phosphorus, or CEC. This indicates organic matter was decoupled from mineral chemistry: the flood redistributed organic matter independently of the mineral soil matrix.

Site-by-Site Comparative Analysis

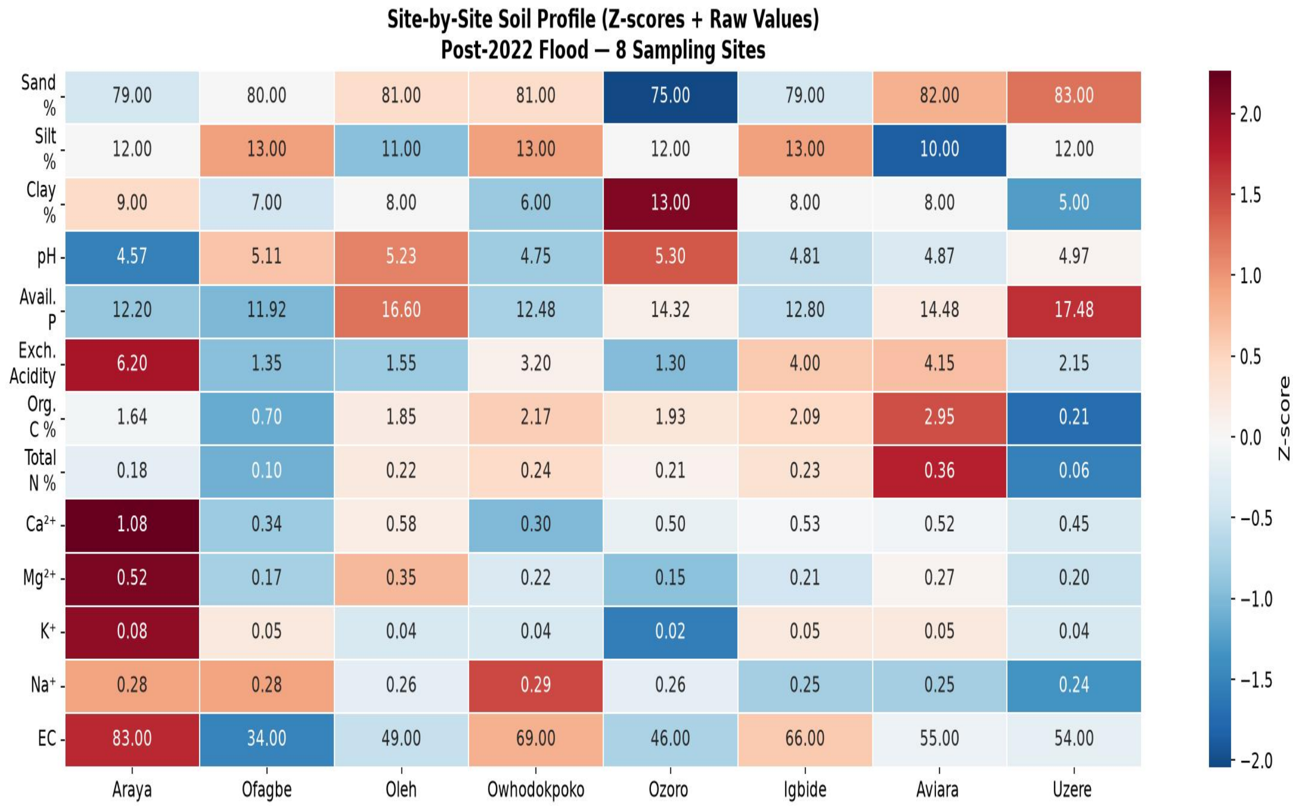

Figure 5. Site-by-parameter heatmap for eight Isoko communities.

The site-by-parameter heatmap (Fig. 5) identified three extremes:

Table:5. Parameter Concern and Evidence of Flood Debris Accumulation Zone

Site	Primary Concern	Evidence
Araya	Extreme acidity & salinity	pH 4.57, Exch. Acidity 6.20 cmol/kg, EC 83 µS/cm — all maxima
Uzere	Severe OM & nutrient depletion	OC 0.21%, TN 0.06%, C:N 3.5 — all minima
Ofagbe	Borderline OM, low base cations	OC 0.70%, lowest CEC (2.19 cmol/kg), Ca^{2+} 0.34 cmol/kg

Conversely, **Aviara** represents the best-preserved site: highest organic carbon (2.95%), highest total nitrogen (0.36%), and moderate acidity, likely a flood debris accumulation zone.

3.6 Residual Diagnostics

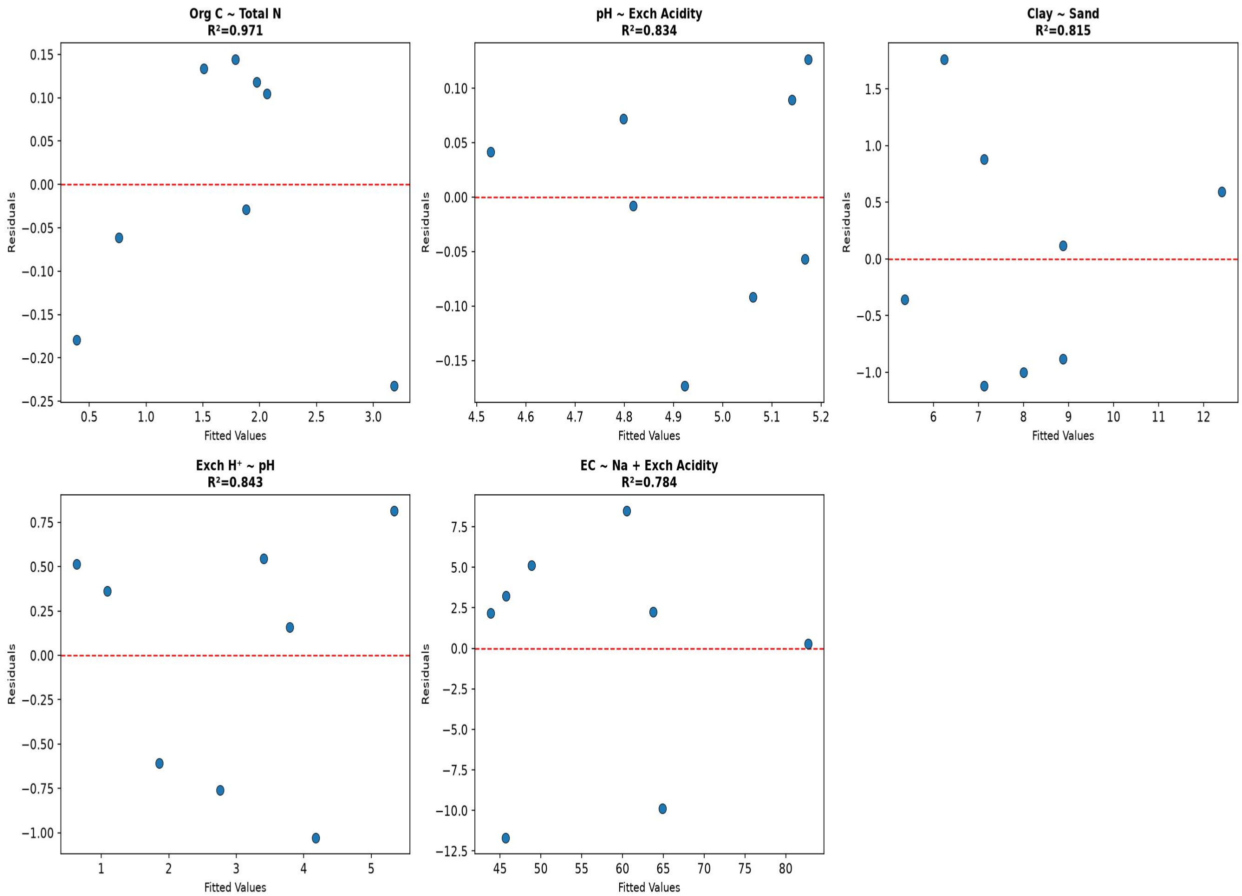

Figure 6. Residual diagnostic plots for five regression models.

All significant regression residuals passed Shapiro-Wilk normality tests ($W = 0.87–0.98$; $p = 0.14–0.95$; Fig. 6). No site exceeded ±2 standardized residuals, confirming that even the extreme communities (Araya, Uzere) are legitimate data points within the dataset structure.

3.7 Principal Component Analysis

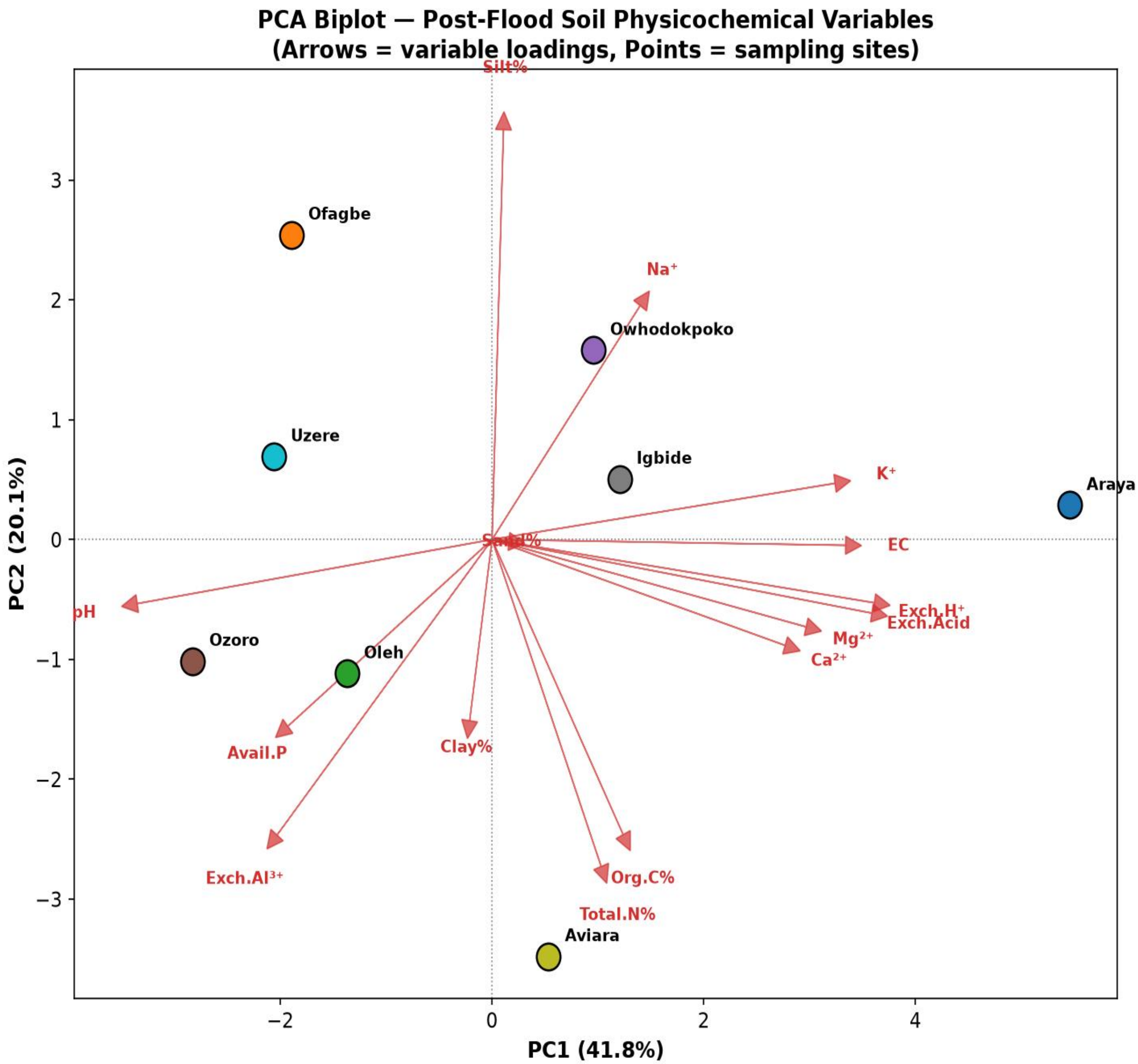

Figure 7. PCA biplot of 15 soil variables across eight Isoko communities.

PCA (Fig. 7) extracted two components explaining 75.2% of total variance:

Component	Eigenvalue	Variance	Cumulative	Primary Loadings (|loading| > 0.30)
PC1	7.56	**50.4%**	50.4%	+Exch. H^+, +Exch. Acidity, +EC, +Ca^{2+}, +Mg^{2+}, +K^+, +CEC; −pH
PC2	3.72	**24.8%**	75.2%	+Silt, +Na^+; −Total N, −Org. C, −Exch. Al^{3+}

Three functional groups emerged from the ordination:

1. **Acid-Saline (Araya alone)**- PC1 score +5.46 (extreme outlier), driven by maximum exchangeable acidity, CEC, and EC
2. **Fertile-Recovering (Aviara, Ozoro, Oleh, Owhodokpoko, Igbide)** — moderate PC1, variable PC2, moderate to high OM

3. **Depleted (Uzere, Ofagbe)** — low PC1, characterized by critically low organic carbon and nitrogen

Discussion

Proton-Dominant Acidity: A Post-Flood Signature

The analytical results challenge canonical pedological assumptions about tropical acid soils while demanding differential management across Isoko's eight flood-affected communities. Exchangeable H^+ accounted for 96% of total exchangeable acidity (mean 2.88 vs. 0.11 cmol/kg for Al^{3+}), departing sharply from the aluminium-dominated acidity typical of weathered tropical soils, where Al^{3+} typically accounts for 60–90% of exchangeable acidity (Thomas, 1996).

Prolonged flood inundation, 1–3 m depth for 4–8 weeks, likely leached exchangeable Al^{3+} from the coarse-textured Coastal Plain Sand matrix. Sandy loam soils (75–83% sand) offer limited reactive surface area for aluminium retention; reducing conditions during flooding would have solubilized Al-hydroxy interlayers, enabling downward translocation as waters receded. Comparable flood-induced cation redistribution has been documented in channelized floodplain systems where altered hydrological connectivity produces complex leaching patterns (Baldwin & Mitchell, 2000).

This finding has important management implications for Isoko farmers: liming requirements can be calculated directly from exchangeable acidity (H^+) without needing to account for Al^{3+} buffering, simplifying and reducing the cost of lime recommendations. Aluminium toxicity, normally the primary constraint to crop root growth in acid tropical soils, is negligible post-flood, leaving hydrogen ion toxicity and low base saturation (<45%) as the chief chemical constraints.

Organic Matter: Conserved Stoichiometry, Redistributed Mass

The near-perfect organic carbon–nitrogen coupling ($R^2 = 0.971$, $p < 0.001$, C:N ≈ 9:1) demonstrates that flood disturbance preserved fundamental organic matter stoichiometry. This is consistent with Chohan et al. (2023), who reported stoichiometrically conservative flood-induced OM changes in Pakistan. Flood-deposited organic inputs, rather than selective stripping of nitrogen-rich fractions, govern post-flood organic matter distribution.

The significantly lower C:N ratio in low-OC communities, Uzere (C:N 3.5) and Ofagbe (C:N 7.0) compared to high-OC communities (Aviara: C:N 8.2; Owhodokpoko: C:N 9.0) suggests preferential carbon loss via physical scouring of particulate organic matter (the light fraction with higher C:N) while mineral-associated organic nitrogen remained bound to soil particles. This differential OM stripping has been documented in flood-affected soils elsewhere (Baldwin & Mitchell, 2000; Qadir et al., 2009).

For Isoko farmers, communities like Uzere and Ofagbe have not simply lost topsoil, they have lost the most biologically active, nutrient-rich fraction of organic matter critical for nitrogen supply to crops. Simple replacement of total organic carbon via compost must be accompanied by nitrogen fertilization to correct the depleted C:N ratio.

The CEC Paradox

The failure of clay and organic carbon to predict effective cation exchange capacity ($R^2 = 0.046$, $p = 0.889$) constitutes the most instructive null result. CEC is governed overwhelmingly by exchangeable acidity ($r = +0.992$) rather than by permanent charge on clay minerals or pH-dependent charge on organic matter. This paradox resolves through Benin Formation mineralogy: the clay fraction is dominated by low-activity kaolinite and sesquioxides with negligible permanent charge, while organic matter (mean 1.69% OC) is too low to influence CEC meaningfully. H^+ saturation of the limited exchange complex, a direct legacy of base-cation leaching during flooding masks intrinsic charge sites.

This "H^+-CEC paradox" has been observed in acid sulfate soils subjected to tidal inundation (Bautista et al., 2023; Johnston et al., 2009) but is rarely documented in inland floodplain soils. Its occurrence across Isoko communities suggests the 2022 flood produced base-cation stripping severe enough to convert these soils into a proton-dominated exchange system, a condition that, if uncorrected, will perpetuate acidity and low fertility regardless of organic matter additions.

Phosphorus Unpredictability

Available phosphorus eluded prediction by any combination of measured variables (best model $R^2 = 0.241$, $p = 0.503$). Uniformly moderate Bray-1 P (11.9–17.5 mg/kg) across sites with divergent acidity and organic matter indicates phosphorus dynamics are governed by iron and aluminium oxide sorption–desorption equilibria, processes sensitive to redox oscillations of flood-drain cycles, rather than by bulk pH or organic carbon (Sanchez, 2019). The moderate values may also reflect fertilizer legacies from previous cassava and yam cropping that survived flood leaching.

PCA-Derived Rehabilitation Framework

PCA resolved three functional site groups demanding different rehabilitation strategies. This differential approach recognizes that Isoko communities were not uniformly affected by the 2022 flood:

Table 6. Community Constraints and Recommended Interventions

Group	Communities	Primary Constraint	Recommended Intervention
Acid-Saline	Araya	H^+ toxicity, high EC (83 µS/cm)	Lime @ 4–6 t/ha $CaCO_3$ + gypsum @ 2 t/ha
Depleted	Uzere, Ofagbe	Severe OM loss (OC < 1%)	Biochar-compost @ 15 t/ha + Mucuna pruriens / Calopogonium mucunoides + N @ 60 kg/ha
Fertile-Recovering	Aviara, Igbide, Owhodokpoko	Incipient base cation depletion	Conservation agriculture: minimum tillage, residue retention, balanced NPK
Intermediate	Ozoro, Oleh	Moderate across parameters	Maintenance liming @ 2 t/ha; routine soil testing

Araya, with extreme acidity and the highest EC, likely represents a flood-water stagnation zone where solutes concentrated as waters receded and evaporated. Uzere and Ofagbe, with critically low organic carbon, were likely in the path of high-velocity floodwater flow that scoured topsoil. Ozoro, which hosted the government IDP camp, shows moderate soil properties, likely reflecting its slightly elevated position that escaped the most severe flood impacts.

Implications for Isoko Food Security

The eight communities lie within Isoko's cassava–yam–plantain cropping system. All sites fall below pH 5.5; Uzere and Ofagbe dip beneath the 1% organic carbon threshold where structural integrity and nutrient supply collapse in sandy soils. Cassava suffers yield depression below 30% base saturation; yam requires structured soils for tuber expansion; plantain is sensitive to potassium deficiency and moisture stress on coarse substrates. The Delta State government and agricultural extension services should replace blanket fertilizer distribution with community-specific packages based on the three-tier PCA classification. Climate change is projected to intensify extreme weather frequency across West Africa (Echendu, 2022), making flood-responsive, site-specific soil management protocols a priority extending beyond Delta State to floodplain communities throughout the Niger Delta.

Conclusion and Recommendations

This study set out to answer a question that thousands of Isoko farmers confronted when the 2022 floodwaters finally receded: what condition were their soils in? Through systematic sampling across eight communities and analysis of seventeen physicochemical parameters, we have provided the first empirical answer. The picture that emerges is one of a landscape reshaped not uniformly but in a sharply differentiated pattern that demands an equally differentiated response.

Five interconnected findings anchor that answer. First, the near-perfect coupling of organic carbon and total nitrogen ($R^2 = 0.971$, $p < 0.001$; C:N ≈ 9:1) across a fourteen-fold range of organic carbon demonstrates that flood disturbance conserved fundamental organic matter stoichiometry. Carbon and nitrogen were redistributed together, in proportion, rather than selectively stripped. Communities such as Uzere (OC = 0.21%) and Ofagbe (OC = 0.70%) have not simply lost topsoil; they have lost the most biologically active, nitrogen-rich fraction of organic matter that sustains crop growth in these sandy soils.

Second, and possibly perhaps most strikingly, soil acidity across the Isoko floodplain is overwhelmingly proton-driven rather than aluminium-driven. Exchangeable hydrogen constituted 96% of total exchangeable acidity, with aluminium contributing a negligible 4%. This departs sharply from the canonical model of tropical acid soils, where aluminium typically accounts for 60 to 90% of exchangeable acidity. The prolonged inundation at depths of one to three metres for four to eight weeks appears to have leached exchangeable aluminium from the coarse-textured Coastal Plain Sand matrix, leaving hydrogen ions as the dominant acid source. For agricultural extension services, this has a practical consequence: liming requirements can be calculated directly from exchangeable acidity without the complication of aluminium buffering, simplifying and reducing the cost of rehabilitation.

Third, the analyses confirmed what we term an acid-saline syndrome. The communities classified as Very Strongly Acidic (pH below 5.0) exhibited significantly elevated exchangeable acidity (+2.54 cmol/kg, $p = 0.029$) and electrical conductivity (+22.4 µS/cm, $p = 0.029$) relative to those in the Strongly Acidic range. This co-occurrence is consistent with evaporative concentration of solutes in flood stagnation zones, where water ponded longest and receded slowest.

Fourth, organic matter was established to be functionally decoupled from mineral chemistry. Effective cation exchange capacity was governed overwhelmingly by exchangeable acidity ($r = +0.992$) rather than by clay content or organic carbon, both of which failed as predictors ($R^2 = 0.046$, $p = 0.889$). The kaolinitic mineralogy of Benin Formation soils, with its low permanent charge and limited reactive surface area, resolves this paradox: proton saturation of the limited exchange complex masks intrinsic charge sites. Unless corrected, this condition will perpetuate acidity and low fertility regardless of organic matter additions.

Fifth, principal component analysis which extracted two components, explaining 75.2% of cumulative variance and resolved the eight communities into three functional groups: an Acid-Saline cluster represented by Araya alone, characterised by extreme acidity (pH 4.57), maximum exchangeable acidity (6.20 cmol/kg), and the highest electrical conductivity (83 µS/cm); a Fertile-Recovering cluster comprising Aviara, Ozoro, Oleh, Owhodokpoko, and Igbide, where moderate organic matter and base cation levels suggest some buffering against the flood's worst effects; and a Depleted cluster encompassing Uzere and Ofagbe, where critically low organic carbon and nitrogen indicate severe topsoil scouring by high-velocity floodwater. Aviara, with the highest organic carbon (2.95%) and total nitrogen (0.36%), likely represents a flood debris accumulation zone and serves as a benchmark for what recovery might achieve elsewhere.

These three groups demand three distinct rehabilitation pathways. Araya requires aggressive lime application at four to six tonnes per hectare of calcium carbonate equivalent, supplemented with gypsum at two tonnes per hectare to address the elevated electrical conductivity, alongside drainage improvements to prevent future stagnation. Uzere and Ofagbe require organic matter reconstruction through biochar-compost blends at fifteen tonnes per hectare, nitrogen fertilisation at sixty kilograms per hectare, and leguminous cover crops such as *Mucuna pruriens* or *Calopogonium mucunoides* to rebuild the depleted carbon and nitrogen pools. The Fertile-Recovering communities can be maintained through conservation agriculture, minimum tillage, residue retention, balanced NPK fertilisation, and maintenance liming at two tonnes per hectare with periodic soil testing to monitor trends.

At the policy level, these findings carry clear implications for Delta State. Blanket fertilizer distribution, the prevailing practice, should be replaced with community-specific soil rehabilitation packages keyed to the three-tier classification derived from this study. A lime-gypsum subsidy scheme is essential, given that all eight sites fall below the pH 5.5 threshold for most arable crops. Biochar-compost production hubs established at Ozoro and Oleh could service the depleted communities with organic amendments at scale. Mandatory post-flood soil testing should be incorporated into the State Emergency Management Agency protocol for all future flood events, so that the next disaster does not again leave farmers and extension agents without the evidence needed to act. Finally, rehabilitation should be budgeted across three to five growing seasons, recognizing that soil recovery is a gradual process, and geographic coverage should be extended to neighbouring flood-prone local government areas including Ndokwa East, Patani, and Bomadi.

The 2022 flood was not an isolated event. Climate projections indicate that extreme weather frequency will intensify across West Africa in the coming decades. The Niger Delta, with its low elevation, dense distributary network, and vulnerable agrarian economy, will bear repeated impacts. The framework developed here provides a systematic multi-parameter assessment, regression-driven mechanistic understanding, and PCA-derived differential management zones is not merely a post-hoc diagnostic for one flood event. It is a replicable protocol for flood-responsive soil management throughout the region, and a step toward ensuring that when the waters rise again, Isoko farmers will not be left without answers.

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