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Research Article

Evaluation of Influence of Regular use of Agrochemicals on Physicochemical Properties of Floodplain Soils in Awka North

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Abstract

This study evaluated how the regular use of agrochemicals influences the physicochemical properties and selected heavy-metal concentrations of floodplain soils in Awka North, focusing on rice fields and their adjacent fallow lands in Amanuke and Mgbakwu. Soil samples were analyzed for particle size distribution, pH, organic carbon, total nitrogen, exchangeable bases, aluminium, hydrogen, available phosphorus, and trace metals (Cu, Cd, Pb). The results showed that although soil texture remained sandy loam across locations, continuous rice cultivation produced noticeable shifts in soil chemistry. In Amanuke, rice fields contained higher organic carbon, nitrogen, available phosphorus, and acidity-related components (Al^{3+} and H^+), indicating the cumulative influence of fertilizer inputs and organic residues. Mgbakwu soils showed fewer differences between cultivated and fallow sites, suggesting a lower intensity of input use or stronger natural soil buffering. Heavy metal concentrations were generally low, but cadmium was significantly higher in Amanuke rice soils, pointing to possible accumulation from phosphate fertilizers. Lead also showed a small but significant increase in Mgbakwu rice fields. Although these concentrations remain within international safety limits, their patterns suggest early signs of trace-metal enrichment. Correlation analyses revealed strong relationships among acidity, organic matter, nutrient availability, and metal behavior, especially in Amanuke, showing how agrochemical use is gradually reshaping soil chemical interactions.

Keywords	*Eco-Friendly Paving Blocks; Indigenous Materials; Sustainable Construction Materials*
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Introduction

Floodplain soils play a central role in supporting smallholder agriculture across southeastern Nigeria. In Awka North, these alluvial landscapes sustain year-round cultivation of vegetables, cereals, and staple crops like rice (Supriatna & Lenz, 2025). Farmers depend heavily on agrochemicals, particularly NPK fertilizers, herbicides, and a range of pesticides to maintain crop yields, manage weeds, and control pests in an increasingly unpredictable climate (Devi et al., 2022). While these inputs have become part of routine farming practice, their continuous and often unregulated use raises important questions about how they may be reshaping the soil environment over time (Gnanaprakasam & Vanisree, 2022).

Floodplain soils are naturally dynamic because of their periodic wetting and drying cycles, fluctuating water tables, and seasonal sediment deposition (Aliyu et al., 2025). These factors influence key soil properties such as texture, pH, organic carbon, nutrient availability, and bulk chemistry. When agrochemicals are repeatedly applied in such sensitive systems, they can alter soil reactions and elemental balances in ways that affect soil health and long-term productivity (Awazi et al., 2025). For example, inorganic fertilizers may acidify soils, increase soluble salts, or modify the distribution of aluminum, hydrogen, and exchangeable base cations (Aduhene-Chinbuah et al., 2025). Similarly, pesticides and herbicides may interact with soil colloids and organic matter, potentially influencing nutrient retention and microbial activity (Babaniyi et al., 2022).

Beyond changes in soil fertility indicators, there is growing concern about heavy metal accumulation in agricultural soils. Metals such as copper (Cu), cadmium (Cd), and lead (Pb) may enter the soil through fertilizers, pesticides, and irrigation water (Rashid et al., 2023). Even at low concentrations, their gradual build-up can threaten soil quality, food safety, and environmental integrity (Abdelmonem et al., 2025). Understanding their behaviour in floodplain soils where redox conditions shift frequently is particularly important because metal mobility can change with pH, organic matter levels, and the presence of reactive clays and oxides.

Although several studies have examined soil quality under different land-use types in parts of Anambra State, comprehensive evaluations of how regular agrochemical use affects floodplain soils in Awka North remain limited. Earlier works by Okafor et al. (2025a) provided valuable insights into soil nutrient dynamics, carbon storage, and fertility changes in seasonal wetlands of Ifite-Ogwari and Omor under intensive rice cultivation. Another study by Okafor et al. (2025b) compared cultivated and fallow wetland systems, revealing how land use and hydrology drive changes in soil fertility and chemical composition across wetland landscapes.

However, there was limited studies of floodplains especially, in Mgbakwu, which is also a major agricultural area in Awka North. The combined effects of fertilizers, pesticides, and herbicides applied continuously across multiple cropping seasons have not been sufficiently documented in this specific environment. More importantly, little attention has been given to the potential accumulation of heavy metals such as Cu, Cd, and Pb in these soils, despite their relevance for food safety and environmental monitoring.

This main objective of the study therefore was to address these gaps by evaluating the influence of regular agrochemical use on key physicochemical properties of floodplain soils in Awka North. The specific objectives were to assess the physicochemical characteristics of soils across the study sites, to determine the concentrations of selected heavy metals in these soils, and to ascertain the relationship between soil properties studied.

Materials and Methods

Study Area

The floodplain soils that were be studied, along with their geographical locations and average height above sea level (elevation), are:

Lowland areas	*Latitude (North)*	*Longitude (East)*	*Elevation (Metres)*
Amanuke	6º 18' 43.02" - 6° 18' 44.80"	7° 2' 58.36" - 7° 3' 0.06"	125 av.
Mgbakwu	6º 17' 27" - 6° 17' 30"	7° 4' 59" - 7° 5' 01"	67.8 av

Generated from*: Geographic Coordinate system: World Geodetic System 84*

The geological formation of Awka North LGA falls within Imo clay shale group, while the ecological zone falls within the derived savanna, but tropical rainforest on a broader global ecological zone classification (Ayadiuno *et al.,* 2022). The mean rainfall of the floodplain areas of Awka North LGA ranges from 1800mm to 3000mm per annum, while the mean annual temperature ranges from 25 to 32 ° C. The socioeconomic activities of the people in these areas are farming and trading. People living in the floodplain areas are mainly rice, okra, maize, and melon farmers, but predominantly rice farmers.

Soil Sampling

Soil samples were randomly collected in the rice fields under continuous agrochemical applications, at 0 – 30cm depth, and replicated five times (5×). Same sampling was employed in alternate ≥ 4-year fallow land within the area, which will serve as “Control”; this was repeated at all the two (2) locations in Awka North. Undisturbed soil samples were randomly collected at the two study rice fields and their adjacent fallow lands using Core samplers, with dimension – diameter and height (5cm × 10cm). The total soil samples that were collected across the study areas were twenty (20) soil samples.

Laboratory Analysis

Physicochemical properties that were analyzed in the laboratory are: particle size distribution, bulk density, soil pH, total nitrogen, organic carbon, exchangeable acidity, exchangeable basic cations, effective cation exchange capacity, available phosphorus, and heavy metals (Cd, Cu, and Pb).

Soil Laboratory Analytical Methods

i. Particle size distribution was analyzed using Bouyoucos hydrometer method; soil textural classes was determined using soil textural triangle.
ii. Bulk density was determined using core method described by Carter (1990).
iii. Soil pH was estimated using pH meter in ratio of 1:2.5 ratio of soil to water (Thomas, 1996; Tan, 1998).
iv. Soil organic carbon was extracted by titration method (Walkley and Black, 1934).
v. Total Nitrogen was determined using Kjeidahl digestion method.
vi. Exchangeable acidity ($Al^{3+}$and H^+) was determined titrimetrically (Tan, 1998; Hesse, 1971).
vii. Exchangeable basic cations (Ca, Mg, K and Na) were extracted in neutral normal ammonium acetate (1N-NH_4OA_c); where Calcium and Magnesium was determined by Atomic Absorption Spectrophotometer, while Potassium and Sodium was determined in flame photometer (Schollenberger and Simon, 1945).
viii. Effective cation exchange capacity was determined by summation of Exchangeable bases and Exchangeable acidity.
ix. Available phosphorus was determined by Bray (I) method (Bray and Kurtz, 1945).
x. Selected heavy metals (Cd, Cu and Pb) was determined by double acid – Nitric acid (HNO_3) and Perchloric acid ($HCLO_3$) method. The extracts were subjected to Atomic Absorbtion Spectrophotometer (AAS), using appropriate hollow cathode lamp/wave length (Waston and Isaac, 1990; Wright and Stuczynski, 1996).

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Statistical Analysis

Data collected will be subjected to t-test at $p < 0.05$to ascertain the variations of soil properties and heavy metals in studied rice fields and the adjacent fallow lands across the two locations in Awka North. Also, Correlation coefficient (r) was employed to ascertain the relationships between soil properties as well as heavy metals studied the software used was R. 4.5.1 version.

Results and Discussion

Physicochemical Characteristics of the Studied Soils

Physicochemical properties of the studied soils were presented in Table 2. Soils across the studied locations were all sandy loam textural, which is typical of floodplain environments influenced by alluvial deposition (Nwokeabia et al., 2025). At Amanuke, sand content ranged from 52.05% in the fallow lands to 58.15% in the rice fields, while silt and clay fractions showed only modest variation. The differences were not statistically significant, indicating that land-use type had no immediate effect on particle size distribution. A similar trend was observed in Mgbakwu, although the clay fraction there differed significantly ($p < 0.05$), with the fallow soil showing a slightly higher clay percentage (13.7%) compared to the rice plot (10.7%). In Amanuke, the rice field had a higher bulk density (1.95 Mg m^{-3}) than the fallow site (1.86 Mg m^{-3}), but they were not significantly ($p<0.05$) different from each other. bulk density at Mgbakwu also showed no significant difference between the two land uses, although the rice field (1.54 Mg m^{-3}) had a slightly lower value than the fallow soil (1.75 Mg m^{-3}), possibly due to better organic matter incorporation during rice operations. A clear distinction was observed in Amanuke, where organic carbon and total nitrogen were significantly higher in the rice field (OC: 0.99%; TN: 0.07%) than in the fallow land (OC: 0.58%; TN: 0.05%). Rice cultivation in these floodplain soils often involves the return of crop residues and the accumulation of biomass during periodic flooding, which may explain the higher organic matter content (). At Mgbakwu, however, the rice and fallow soils showed almost identical levels of OC (0.42–0.44%) and TN (0.04%), and the differences were not significant. Soil reaction differed significantly between land uses in Amanuke, with the fallow soil having a slightly more acidic pH (5.93) than the rice field (5.50). Aluminum had significantly greater concentrations of (0.70 cmol kg^{-1}), whereas H^+ (0.30 cmol kg^{-1}) was also higher in rice field but showed no significant difference from the fallow land. Calcium and magnesium were the dominant cations across both locations. Their values did not differ significantly in Amanuke, although the rice field consistently showed slightly higher Ca^{2+} and Mg^{2+} levels, possibly reflecting fertilizer contributions or nutrient release from decomposing plant residues (Olajiire-Ajayi, 2025). In Mgbakwu, Mg^{2+} was higher in the rice field (1.83 cmol kg^{-1}) compared to the fallow soil (1.50 cmol kg^{-1}), but was not significantly different from each other. Potassium and sodium were low in all sites, reflecting the generally poor K-retention capacity of sandy loam soils, although, potassium was significantly higher (0.27 Cmol kg^{-1}) in rice field at Mgbakwu. ECEC followed the general pattern of base cation distribution. In Amanuke, the rice field had a higher ECEC (4.80 cmol kg^{-1}) than the fallow (4.29 cmol kg^{-1}), while in Mgbakwu, the rice fields again showed higher ECEC (5.94 cmol kg^{-1}), although the differences were not significant. These values align with the low-to-moderate fertility status typical of floodplain soils under continuous cropping (). Available phosphorus showed a striking contrast between land uses. At Amanuke, P was significantly higher in the rice field (2.84 mg kg^{-1}) than in the fallow soil (1.45 mg kg^{-1}), reflecting the direct influence of regular fertilizer application (). Mgbakwu also showed higher P in the rice field (4.81 mg kg^{-1}) compared to the fallow (2.50 mg kg^{-1}), though the difference was not significant.

Table 2: Physicochemical Properties of the Studied Soils

Location	Landuse	Sand	Silt (%)	Clay	TC	BD Mgm^{-3}	OC	TN (%)	pH	Al^{3+}	H^+	Ca^{2+}	Mg^{2+} (Cmolkg⁻¹)	K^+	Na^+	ECEC	Av. P ($mgkg^{-1}$)
Amanuke	**Rice field**	58.15	26.8	15.05	SL	1.95	0.99	0.07	5.50	0.70	0.30	2.20	1.35	0.20	0.11	4.80	2.84
	Fallow	52.05	29.6	18.4	SL	1.86	0.58	0.05	5.93	0.5	0.23	2.03	1.28	0.19	0.08	4.29	1.45
	t-test (0.05)	**NS**	**NS**	**NS**		**NS**	*	*	*	*	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	*
Mgbakwu	**Rice Field**	66.8	22.5	10.7	SL	1.54	0.42	0.04	5.14	0.73	0.43	2.53	1.83	0.27	0.17	5.94	4.81
	Fallow	67.8	18.5	13.7	SL	1.75	0.44	0.04	5.81	0.63	0.50	2.38	1.50	0.24	0.16	5.32	2.50
	t-test (0.05)	**NS**	**NS**	*		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	*	**NS**	**NS**	**NS**

BD – bulk density. TC – textural class, OC – organic carbon, TN – total nitrogen, ECEC – effective cation exchange capacity, Av.P – available phosphorus, NS – not significant, * - significant.

Heavy Metal Concentration of the Studied Soils

Heavy metal concentration of the studied soils was presented in Table 3. Copper (Cu), cadmium (Cd), and lead (Pb) concentrations varied across locations and land-use types. Copper showed a significant difference in Amanuke, where the fallow soil (0.65 mg kg^{-1}) contained more than twice the concentration observed in the rice field (0.26 mg kg^{-1}). This result suggests that the rice cultivation practices in this area may not be contributing additional Cu to the soil. Instead, the slightly elevated Cu in the fallow soil may reflect natural variation, past land-use history, or residual Cu from older agrochemical inputs, especially since Cu-based fungicides are not commonly applied in rice systems (Laoye et al., 2025). In Mgbakwu, copper levels were extremely low in both land-use types (0.04–0.05 mg kg^{-1}), with no significant differences. These values reflect the inherently low Cu status of many sandy loam floodplain soils and further suggest limited external Cu inputs in the area. Cadmium displayed a different pattern. In Amanuke, Cd was significantly higher in the rice field (0.34 mg kg^{-1}) compared to the fallow soil (0.08 mg kg^{-1}). Although the concentrations are still below international soil quality thresholds, the difference indicates that the Cd enrichment in the rice fields may be associated with agrochemical use, particularly phosphate fertilizers, which are well-documented sources of trace Cd contamination worldwide (Boakye et al., 2025). At Mgbakwu, Cd concentrations were low (0.04–0.05 mg kg^{-1}) and statistically similar across land-use types, suggesting minimal Cd input or accumulation at this location. The low values may also reflect the lower intensity of rice production than Amanuke. Lead concentrations were generally low across all sites. In Amanuke, Pb levels did not differ significantly between the rice field (0.27 mg kg^{-1}) and the fallow land (0.24 mg kg^{-1}). The similarity suggests that neither agricultural activities nor background geochemical sources are contributing substantially to Pb in this area. A more notable difference occurred in Mgbakwu, where Pb was significantly higher in the rice field (0.06 mg kg^{-1}) than in the fallow plot (0.003 mg kg^{-1}). Although the absolute concentration is still very small, the statistical difference may reflect minor Pb inputs from agricultural chemicals, contaminated water sources, or atmospheric deposition (Nwanaforo et al., 2025). However, given the low magnitude, the increase is unlikely to pose immediate environmental or health concerns.

Table 3. Heany metals concentration of the studied soils

Location	Landuse	Cu	Cd ($mgkg^{-1}$)	Pb
Amanuke	**Rice field**	0.26	0.34	0.27
	Fallow	0.65	0.08	0.24
	t-test (0.05)	*	*	**NS**
Mgbakwu	**Rice Field**	0.05	0.04	0.06
	Fallow	0.04	0.05	0.003
	t-test (0.05)	**NS**	**NS**	*

**Cu – copper, Cd – cadmium, Pb – lead,
NS – not significant, * - significant.**

Correlation of Studied Soil Properties

Correlation coefficient 'r' of soil properties in rice field at Amanuke was presented in Table 4. Organic carbon and nitrogen were strongly and negatively correlated with Ca (r = –0.99), Mg (r = –0.84 to –0.87), K (r = –1.00), Na (r = –0.88 to –0.90), ECEC (r = –0.97), and available P (r = –0.93). This suggests that as organic matter and nitrogen increase, the soil solution tends to hold fewer exchangeable cations; likely a reflection of strong acidity, aluminium interference, and the destabilizing effect of continuous fertilizer inputs (Awoonor et al., 2025). Soil pH showed strong negative correlations with bulk density (r = –0.80), organic carbon (r = –0.76), nitrogen (r = –0.80), and Mg (r = –0.95). This indicates that increasing soil acidity (lower pH) is closely tied to compaction and reduced nutrient status, which is consistent with fertilizer-induced acidification in rice fields. The acidic components (Al^{3+} and H^{+}) were almost perfectly correlated with each other (r = 1.00) and strongly negatively associated with silt (r = –0.99), reflecting the dominance of acidic exchange sites in the finer fractions of the soil. Calcium showed very strong correlations with Mg (r = 0.90), K (r = 0.99), Na (r = 0.91), and ECEC (r = 0.99), highlighting the shared control of these nutrients by the soil's exchange complex. Available phosphorus also correlated strongly and positively with Ca, K, Na, ECEC, and clay content, indicating that P availability in this soil is closely governed by the same exchange processes and mineral surfaces. Cu, Cd, and Pb were almost perfectly correlated with Al and H (r = 1.00), suggesting that their behavior in this rice field is strongly tied to soil acidity and the abundance of acidic exchange sites. Their strong negative correlations with silt (r = –0.99 to –1.00) further point to their preference for more acidic or coarser soil fractions under the existing conditions.

Table 4. Correlation of Soil Studied Properties at the Rice field in Amanuke

	Sand	*silt*	*Clay*	*BD*	*OC*	*TN*	*pH*	*Al*	*H*	*Ca*	*Mg*	*K*	*Na*	*ECEC*	*Av.P*	*Cu*	*Cd*	*Pb*
Sand	1.00																	
silt	-0.68	1.00																
clay	-0.81	0.13	1.00															
BD	0.67	-0.71	-0.33	1.00														
OC	0.65	-0.11	-0.79	0.68	1.00													
TN	0.64	-0.13	-0.76	0.71	1.00	1.00												
pH	-0.26	0.16	0.22	-0.80	-0.76	-0.80	1.00											
Al	0.61	-0.99	-0.02	0.64	0.00	0.02	-0.09	1.00										
H	0.61	-0.99	-0.02	0.64	0.00	0.02	-0.09	1.00	1.00									
Ca	-0.57	0.11	0.68	-0.73	-0.99	-0.99	0.86	0.00	0.00	1.00								
Mg	-0.53	0.39	0.40	-0.92	-0.84	-0.87	0.95	-0.30	-0.30	0.90	1.00							
K	-0.62	0.06	0.79	-0.65	-1.00	-1.00	0.76	0.05	0.05	0.99	0.83	1.00						
Na	-0.68	0.48	0.54	-0.95	-0.88	-0.90	0.88	-0.39	-0.39	0.91	0.98	0.86	1.00					
ECEC	-0.47	-0.06	0.68	-0.61	-0.97	-0.98	0.82	0.17	0.17	0.99	0.84	0.98	0.83	1.00				
Av.P	-0.86	0.46	0.80	-0.83	-0.93	-0.93	0.69	-0.35	-0.35	0.91	0.86	0.91	0.93	0.84	1.00			
Cu	0.63	-0.99	-0.06	0.63	0.01	0.03	-0.06	1.00	1.00	0.00	-0.29	0.04	-0.38	0.17	-0.36	1.00		
Cd	0.64	-1.00	-0.07	0.64	0.02	0.04	-0.08	1.00	1.00	-0.01	-0.30	0.03	-0.40	0.15	-0.38	1.00	1.00	
Pb	0.65	-0.99	-0.08	0.62	0.01	0.03	-0.05	1.00	1.00	0.00	-0.28	0.04	-0.38	0.17	-0.37	1.00	1.00	1

TN- total nitrogen, BD – bulk density, ECEC – effective cation exchange, Av. P – available phosphorus

The correlation analysis of soil properties at the fallow land in Amanuke were presented in Table 5. Sand exhibited a strong negative correlation with silt (r = –0.88) and a strong positive correlation with clay (r = 0.62), indicating the dominance of textural rearrangement processes, where increases in coarse fractions are associated with decreases in finer fractions. Silt and clay also maintained a very strong negative correlation (r = –0.92), confirming their reciprocal distribution in the soil matrix. Organic carbon (OC) was strongly and negatively correlated with exchangeable Al^{3+} (r = –0.89) and positively correlated with exchangeable H^{+} (r = 0.94), suggesting that increases in organic matter tend to reduce toxic Al^{3+} activity, likely through complexation, while simultaneously buffering soil acidity through proton release (). Total nitrogen (TN) also showed strong relationships with OC (r = 0.46) and Mg (r = 0.87), reflecting the shared biological origin of N and the role of soil organic matter in holding exchangeable cations. TN further correlated strongly with Ca (r = 0.76), suggesting that biologically enriched microsites in fallow soils enhance Ca retention. Soil pH exhibited a perfect negative correlation with clay (r = –1.00) and very strong positive correlations with silt (r = 0.95) and Na (r = 0.89). The strong link between pH and Na also suggests that sodium is more available or weakly adsorbed in less acidic microsites (Starke et al., 2021). Cu and Pb were almost perfectly correlated with exchangeable Al (r = 1.00 and 0.99, respectively) and strongly negatively correlated with OC (r = –0.91 and –0.95). This suggests that in the fallow soil, metal retention is strongly governed by Al-driven acidity rather than by organic complexation. Cd showed moderate to strong negative correlations with OC (r = –0.60) and clay (r = 0.04), but a strong negative relationship with bulk density (r = –0.66), indicating a propensity to remain more mobile in less compacted, lower-organic matter settings.

Table 5. Correlation of Studied Soil Properties at the Fallow Land in Amanuke

	Sand	*silt*	*clay*	*BD*	*OC*	*TN*	*pH*	*Al*	*H*	*Ca*	*Mg*	*K*	*Na*	*ECEC*	*Av.P*	*Cu*	*Cd*	*Pb*
Sand	1																	
silt	-0.88	1.00																
clay	0.62	-0.92	1.00															
BD	0.22	-0.43	0.52	1.00														
OC	-0.71	0.29	0.10	0.06	1.00													
TN	-0.79	0.70	-0.51	0.33	0.46	1.00												
pH	-0.69	0.95	-1.00	-0.53	-0.01	0.55	1.00											
Al	0.60	-0.25	-0.07	0.33	-0.89	-0.12	-0.01	1.00										
H	-0.87	0.56	-0.21	-0.21	0.94	0.52	0.30	-0.90	1.00									
Ca	-0.74	0.36	0.01	0.39	0.90	0.76	0.06	-0.61	0.82	1.00								
Mg	-0.39	0.35	-0.26	0.68	0.13	0.87	0.26	0.30	0.09	0.55	1.00							
K	0.56	-0.85	0.92	0.81	0.06	-0.23	-0.93	0.13	-0.27	0.15	0.12	1.00						
Na	-0.57	0.83	-0.90	-0.10	-0.13	0.73	0.89	0.30	0.09	0.13	0.64	-0.67	1.00					
ECEC	-0.69	0.40	-0.09	0.55	0.71	0.89	0.15	-0.33	0.63	0.95	0.79	0.15	0.34	1.00				
Av.P	-0.73	0.97	-0.99	-0.49	0.04	0.59	1.00	-0.04	0.34	0.12	0.30	-0.91	0.90	0.21	1.00			
Cu	0.61	-0.26	-0.08	0.31	-0.91	-0.14	-0.01	1.00	-0.91	-0.63	0.27	0.12	0.29	-0.36	-0.04	1.00		
Cd	-0.36	0.16	0.04	-0.66	0.60	-0.26	0.03	-0.89	0.67	0.20	-0.67	-0.29	-0.40	-0.12	0.03	-0.88	1.00	
Pb	0.65	-0.27	-0.08	0.22	-0.95	-0.23	-0.01	0.99	-0.94	-0.72	0.17	0.07	0.26	-0.46	-0.04	0.99	-0.82	1

TN- total nitrogen, BD – bulk density, ECEC – effective cation exchange, Av. P – available phosphorus

The correlation coefficient of soil properties at Mgbakwu rice field were presented in Table 6. Organic carbon (OC) and total nitrogen (TN) were strongly correlated (r = 0.87), showing their common organic source. Bulk density was almost perfectly negatively correlated with TN (r = –0.99), indicating that compacted soil zones hold less nitrogen. pH had extremely strong negative correlations with clay (r = –0.97) and particularly with Al (r = –0.99), confirming that higher clay and exchangeable Al contribute to acidity. The exchangeable bases (Ca, Mg) and ECEC were all tightly interrelated, with ECEC showing near-perfect correlations with Al (0.99) and Ca (0.98), suggesting that exchange complex saturation depends heavily on these ions. Available phosphorus (Av.P) was strongly correlated to Mg (r =

0.99) and Na (r = 0.95), indicating that P availability tracks closely with general cation activity in this soil. Copper (Cu) showed a very strong negative correlation with clay (r = –0.99), suggesting reduced Cu mobility where clay content is high. Lead (Pb) was tightly linked with Cd (r = 0.95), showing similar retention pathways for both metals.

Table 6. Correlation of Studied Soil Properties at Rice field in Mgbakwu

	Sand	*silt*	*clay*	*BD*	*OC*	*TN*	*pH*	*Al*	*H*	*Ca*	*Mg*	*K*	*Na*	*ECEC*	*Av.P*	*Cu*	*Cd*	*Pb*
Sand	1.00																	
silt	-0.98	1.00																
clay	-0.27	0.07	1.00															
BD	-0.85	0.94	-0.28	1.00														
OC	0.53	-0.66	0.54	-0.82	1.00													
TN	0.80	-0.90	0.36	-0.99	0.87	1.00												
pH	0.50	-0.32	-0.97	0.03	-0.34	-0.12	1.00											
Al	-0.63	0.46	0.92	0.13	0.21	-0.04	-0.99	1.00										
H	0.82	-0.92	0.33	-1.00	0.84	1.00	-0.09	-0.07	1.00									
Ca	-0.49	0.30	0.97	-0.04	0.39	0.14	-1.00	0.98	0.10	1.00								
Mg	-0.93	0.84	0.57	0.62	-0.19	-0.53	-0.75	0.84	-0.57	0.76	1.00							
K	-0.57	0.72	-0.62	0.90	-0.78	-0.92	0.41	-0.26	-0.93	-0.40	0.29	1.00						
Na	-0.97	0.93	0.37	0.77	-0.34	-0.70	-0.58	0.70	-0.73	0.59	0.97	0.51	1.00					
ECEC	-0.66	0.49	0.90	0.16	0.22	-0.07	-0.98	0.99	-0.10	0.98	0.87	-0.21	0.74	1.00				
Av.P	-0.95	0.87	0.56	0.64	-0.29	-0.57	-0.75	0.84	-0.60	0.73	0.99	0.29	0.95	0.86	1.00			
Cu	0.19	0.01	-0.99	0.35	-0.52	-0.42	0.94	-0.87	-0.40	-0.93	-0.48	0.70	-0.26	-0.84	-0.49	1.00		
Cd	-0.45	0.46	0.02	0.44	0.10	-0.37	-0.14	0.20	-0.43	0.20	0.52	0.51	0.62	0.30	0.39	0.14	1.00	
Pb	-0.31	0.38	-0.28	0.47	-0.03	-0.43	0.17	-0.10	-0.48	-0.11	0.30	0.65	0.46	0.00	0.17	0.43	0.95	1

TN- total nitrogen, BD – bulk density, ECEC – effective cation exchange, Av. P – available phosphorus

The correlation analysis of the fallow soils at Mgbakwu was shown in Table 7. Sand, silt, and clay showed perfect or near-perfect inverse relationships (r = –1.00), reflecting the natural balance among soil 2 in this floodplain environment. Organic carbon (OC) and total nitrogen (TN) were very strongly correlated (r = 0.96), confirming their common organic origin. OC also showed strong positive correlations with pH (r = 0.98), Mg (r = 0.95), and ECEC (r = 0.82), indicating that organic matter contributes significantly to base saturation and cation exchange capacity in fallow soils. Soil acidity and exchangeable cations were tightly linked. Exchangeable Al correlated strongly with pH (r = 0.98) and OC (r = 0.92), while H showed a very strong positive correlation with bulk density (r = 0.98), suggesting that acidity and compaction are closely associated. ECEC was strongly related to Ca (r = 0.98) and Mg (r = 0.93), underscoring the role of these bases in soil fertility. Available phosphorus (Av.P) was strongly associated with sand content (r = 0.97) and negatively with K (r = –0.66) and Na (r = –0.81), indicating that P availability is higher in coarser, less compacted fractions of the soil. Heavy metals also showed notable relationships. Cu was positively correlated with Na (r = 0.90), while Cd correlated strongly with sand (r = 0.90) and Mg (r = 0.92). Pb had strong positive correlations with TN (r = 0.82) and Al (r = 0.80), suggesting that nutrient-rich and acidic microenvironments support metal retention in the fallow soil.

Table 7. Correlation of the Studied Soils at Fallow land in Mgbakwu

	Sand	*silt*	*clay*	*BD*	*OC*	*TN*	*pH*	*Al*	*H*	*Ca*	*Mg*	*K*	*Na*	*ECEC*	*Av.P*	*Cu*	*Cd*	*Pb*
Sand	1.00																	
silt	-1.00	1.00																
clay	-1.00	1.00	1.00															
BD	0.26	-0.26	-0.26	1.00														
OC	0.54	-0.54	-0.54	-0.67	1.00													
TN	0.44	-0.44	-0.44	-0.68	0.96	1.00												
pH	0.36	-0.36	-0.36	-0.81	0.98	0.92	1.00											
Al	0.17	-0.17	-0.17	-0.91	0.92	0.88	0.98	1.00										
H	0.43	-0.43	-0.43	0.98	-0.53	-0.56	-0.69	-0.82	1.00									
Ca	0.36	-0.36	-0.36	-0.40	0.70	0.87	0.61	0.57	-0.31	1.00								
Mg	0.67	-0.67	-0.67	-0.47	0.95	0.96	0.87	0.77	-0.32	0.83	1.00							
K	-0.82	0.82	0.82	0.16	-0.72	-0.51	-0.66	-0.52	0.00	-0.17	-0.67	1.00						
Na	-0.76	0.76	0.76	-0.61	-0.01	0.20	0.12	0.29	-0.72	0.32	-0.08	0.66	1.00					
ECEC	0.48	-0.48	-0.48	-0.45	0.82	0.94	0.73	0.67	-0.33	0.98	0.93	-0.35	0.20	1.00				
Av.P	0.97	-0.97	-0.97	0.49	0.32	0.24	0.12	-0.08	0.64	0.28	0.51	-0.66	-0.81	0.37	1.00			
Cu	-0.42	0.42	0.42	-0.67	0.33	0.55	0.39	0.50	-0.70	0.69	0.33	0.42	0.90	0.59	-0.49	1.00		
Cd	0.90	-0.90	-0.90	-0.17	0.85	0.78	0.72	0.57	0.01	0.63	0.92	-0.85	-0.45	0.76	0.78	-0.05	1.00	
Pb	-0.15	0.15	0.15	-0.85	0.67	0.82	0.73	0.80	-0.83	0.78	0.62	0.02	0.73	0.76	-0.32	0.91	0.27	1

TN- total nitrogen, BD – bulk density, ECEC – effective cation exchange, Av. P – available phosphorus

Conclusion

This study evaluated how the irregular use of agrochemicals influences the physicochemical properties and heavy-metal status of floodplain soils in Awka North, the findings showed that while the general soil texture remains sandy loam across all sites, continuous rice cultivation may have have slightly altered important soil chemical properties. In Amanuke, rice fields showed significantly higher organic carbon, total nitrogen, available phosphorus, and acidic components (Al^{3+} and H^{+}), reflecting the cumulative effect of fertilizer inputs and residue deposition. Soil acidity was more pronounced in the cultivated plots, indicating emerging fertilizer-induced acidification. In contrast, the Mgbakwu soils exhibited fewer differences between cultivated and fallow land, suggesting lower input intensity or stronger natural buffering capacity. Heavy metal concentrations (Cu, Cd, and Pb) remained low across all sites. However, Cd was significantly higher in Amanuke rice fields, suggesting to potential buildup from phosphate fertilizers; while Pb showed a small but significant increase in Mgbakwu rice fields, they were below international concern thresholds.

Correlation analysis further revealed strong interactions among soil acidity, nutrient distribution, and heavy metal behavior, especially in Amanuke. The strong negative relationships between organic matter, nitrogen, exchangeable bases, and acidity suggest that chemical inputs may be gradually destabilizing nutrient balance in the cultivated soils.

Recommendations

It is recommended that farmers should adopt soil-test-based fertilizer recommendations to avoid excessive or unbalanced nutrient inputs that contribute to soil acidification and cadmium buildup; periodic liming or the use of pH-ameliorating organic amendments (biochar, compost) is recommended to counter fertilizer-induced acidity observed in rice fields; combining organic residues with mineral fertilizers will help improve nutrient cycling, enhance soil structure, and buffer the soil against chemical stress; although metal concentrations are currently low, continuous monitoring, especially for Cd in Amanuke is necessary to prevent long-term accumulation and potential food-chain risks. Furthermore, farmers should minimize the use of chemical products with known heavy-metal impurities and consider safer pesticide alternatives where possible. Agricultural extension units in Awka North should intensify training on safe agrochemical handling, proper application rates, and sustainable rice-based soil management. Finally, more detailed spatial and temporal studies are recommended to track changes in soil quality, especially under repeated flooding and cropping cycles.

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