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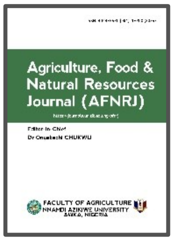

Original Article

Influence of industrial effluents on quality and fertility of guinea savanna alfisols at NOUN research farm, Kaduna, Nigeria

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ABSTRACT

Industrial wastewater is an increasing environmental concern in agricultural areas because of its effects on soil properties, nutrient dynamics, and long-term productivity. This study assessed the influence of industrial effluents on the chemical quality and fertility status of Guinea Savanna Alfisols at the NOUN Research Farm, Rigachikun, Kaduna State, Nigeria. A comparative sampling approach was used involving effluent-impacted and control plots, with soil collected at 0–15 cm and 15–30 cm depths. Laboratory analyses determined soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), available phosphorus (P), exchangeable bases (Ca, Mg, K, and Na), cation exchange capacity (CEC), and selected heavy metals (Zn, Cu, Pb, and Cd). Soil pH ranged from 6.72–7.05, indicating slightly acidic to neutral conditions. Electrical conductivity was higher in effluent-affected soils (0.72–0.96 dS m^{-1}) than in control soils (0.28–0.31 dS m^{-1}). Organic carbon ranged from 0.621.15%, while total nitrogen varied between 0.06–0.11%. Available phosphorus (7.8–15.4 mg kg^{-1}) was generally higher in effluent-impacted plots. Exchangeable sodium increased from 0.24–0.28 cmol kg^{-1} in control soils to 0.51–0.62 cmol kg^{-1} in affected soils, while CEC ranged from 6.5–9.8 cmol kg^{-1}. Heavy metal concentrations were also higher in impacted soils: Zn (1.202.84 mg kg^{-1}), Cu (0.70–1.36 mg kg^{-1}), Pb (15.7–42.5 mg kg^{-1}), and Cd (0.893.18 mg kg^{-1}), with Cd slightly above recommended limits in surface soils. Industrial effluents may improve nutrient availability in the short term but increase salinity and heavy metal accumulation, threatening long-term soil health and crop safety. Effluent treatment, regular soil monitoring, and appropriate fertility management are therefore recommended.

KEYWORDS: *Heavy metals, Soil chemical properties, Soil fertility, Wastewater irrigation*

INTRODUCTION

Soil quality and fertility are essential for sustainable agricultural production, particularly in the Guinea Savanna region of Nigeria where Alfisols are the dominant soil order. Alfisols are moderately weathered soils characterized by the presence of an argillic (clay-enriched) subsurface horizon, relatively high base saturation, and moderate natural fertility, making them suitable for crop production under proper management (Soil Survey Staff, 2014; Brady & Weil, 2017). These soils are generally well drained and productive; however, they can become vulnerable to degradation when exposed to improper land management, contamination, or continuous nutrient depletion. Industrial effluents, which often contain dissolved salts, organic matter, nutrients, and heavy metals, present a dual impact on soils. On one hand, they may temporarily enrich soils with nutrients that enhance plant growth; on the other hand, continuous or poorly managed discharge can degrade soil quality, disrupt nutrient balance, and introduce toxic contaminants that threaten food safety (Arora et al., 2008; Akinyemi et al., 2015; Sani et al., 2020).

In peri-urban agricultural areas, such as those surrounding the National Open University of Nigeria (NOUN) Research Farm in Rigachikun, Kaduna State, the potential for soil

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contamination from industrial discharges is particularly high (Binns et al., 2003; Abdulmumini et al., 2015). Wastewater generated from agro-processing, textile, and manufacturing industries may significantly influence several soil chemical properties, including soil reaction (pH), electrical conductivity (EC), cation exchange capacity (CEC), and the concentrations of essential nutrients and toxic elements (Dawaki & Jazuli, 2007; Pantami, 2019). Soil reaction (pH) determines nutrient availability and microbial activity, electrical conductivity (EC) reflects the concentration of soluble salts in soil, while cation exchange capacity (CEC) indicates the soil's ability to retain and exchange nutrient cations necessary for plant growth (Brady & Weil, 2017). Alterations in these properties due to effluent application can significantly influence soil fertility and crop performance.

Some studies suggest that the controlled application of wastewater or industrial effluents may improve soil fertility by increasing organic matter and certain plant nutrients (Whalen & Chang, 2002; García-Delgado et al., 2012). However, other investigations warn that untreated or inadequately treated effluents often lead to the accumulation of soluble salts and heavy metals, resulting in soil salinization, structural deterioration, and reduced agricultural productivity (Balkhair, 2016; Magesan & Wang, 2003). Over time, these changes may compromise the long-term sustainability of agricultural systems.

The potential risk becomes more serious because heavy metals such as lead (Pb) and cadmium (Cd) are non-biodegradable and tend to accumulate in the soil–plant system. These metals can be absorbed by crops and subsequently enter the human food chain, posing serious health concerns (Arora et al., 2008). Even small concentrations can be harmful because the human body has limited capacity to eliminate these toxic elements. Consequently, understanding the balance between the short-term benefits of nutrient addition and the long-term environmental risks associated with industrial effluents is crucial for sustainable soil management.

Despite the increasing use of wastewater and the presence of industrial activities near agricultural lands, there remains limited information on the specific effects of industrial effluents on the soil quality and fertility status of Alfisols in the Guinea Savanna zone of Nigeria, particularly within the National Open University of Nigeria (NOUN) Research Farm in Rigachikun, Kaduna State. This knowledge gap raises concerns regarding the long-term productivity of the soils and the safety of crops produced in the area (Sani et al., 2020). Therefore, assessing the impact of industrial effluents on key soil fertility indicators is necessary to support informed land management and environmental protection strategies.

MATERIALS AND METHOD

Study Area Description

The research took place at the NOUN Research Farm, situated in Rigachikun, Igabi Local Government Area of Kaduna State, Nigeria. The farm is located within the Guinea Savanna agroecological zone and features Alfisol soils, which are moderately fertile and well-drained (Esu, 1991). The geographical coordinates are approximately latitude 10°37′N and longitude 7°28′E, with an elevation of around 645 m above sea level.

The climate is characterized as tropical wet-and-dry, with clear rainy and dry seasons. The rainy season lasts from May to October, with annual rainfall between 900 and 1,000 mm, while the dry season runs from November to April. The average annual temperature is about 27°C, with maximum temperatures reaching up to 38°C in March–April and minimum values around 15°C in December–January (Sharu et al., 2011). The natural vegetation consists of a blend of grasses and scattered trees, including *Vitellaria paradoxa, Parkia biglobosa, and Daniellia oliveri*. Traditionally, the land has been utilized for mixed cropping, mainly maize, sorghum, and legumes. The area is in proximity to light industrial activities, which may result in the discharge of untreated or partially treated effluents into nearby lands (Abdulmumini et al., 2015).

Soil Sampling

Two types of plots were chosen:

i. Effluent-affected plots – situated close to suspected industrial effluent discharge points.
ii. Control plots – positioned at least 200 m away from the effluent source, showing no visible impact from industrial wastewater.

Soil samples were gathered at two depths: 0 –15 cm (surface) and 15 –30 cm (subsurface) using a soil auger. For each depth and plot category, multiple cores were collected randomly and mixed to create a composite sample, thus minimizing microsite variability (Anderson & Ingram, 1993). Each category and depth combination was replicated sufficiently to facilitate statistical comparisons.

Representative samples of effluent were taken directly from the discharge point to evaluate pH, electrical conductivity (EC), key ions, and concentrations of heavy metals (FAO, 1993; FAO/WHO, 2007).

Laboratory Analyses

All soil samples were air-dried, carefully crushed, and passed through a 2 mm sieve prior to analysis. Soil reaction (pH) was measured in a 1:2.5 soil–water suspension using a pH meter (Anderson & Ingram, 1993), while electrical conductivity (EC) was determined using a conductivity meter (FAO, 1993). Soil organic carbon (OC) was determined using the Walkley–Black wet oxidation method (Nelson & Sommers, 1982). Total nitrogen (TN) was determined using the Kjeldahl digestion method, following standardized soil analytical procedures described in modern soil laboratory manuals (Burt, 2014; Sparks et al., 2020).

Available phosphorus (P) was determined using the Bray-1 extraction method, suitable for acidic to neutral soils (Bray & Kurtz, 1945). Exchangeable bases were extracted using 1 M ammonium acetate (NH_4OAc) at pH 7.0, with calcium (Ca) and magnesium (Mg) measured using atomic absorption spectrophotometry (AAS) and potassium (K) and sodium (Na) determined using a flame photometer (Hazelton & Murphy, 2016). The cation exchange capacity (CEC) was estimated as the sum of exchangeable base cations.

Heavy metals were determined after wet acid digestion using nitric acid (HNO_3) and perchloric acid ($HClO_4$), and the digests were analyzed using atomic absorption spectrophotometry (AAS) following standard environmental soil analysis procedures (Akinyemi et al., 2015; Sparks et al., 2020).

Data Analysis

Descriptive statistics were generated for all parameters. ANOVA was employed to investigate variations between treatments and depths, applying LSD at $p < 0.05$ for mean differentiation. Pearson correlations were used to explore relationships between OC, TN, heavy metals, and other soil characteristics (Hao et al., 2004). Soil fertility classifications were based on Esu (1991), and heavy metal safety thresholds were referenced from FAO/WHO (2007).

RESULTS AND DISCUSSION

Soil pH

The pH values for soil influenced by effluent and control plots are displayed in Table 1. Soil pH ranged from slightly acidic to neutral (6.4–7.1) across various sampling depths. The plots affected by effluent showed marginally higher pH levels compared to the controls, although these differences were not statistically significant ($P > 0.05$). This slight increase in alkalinity may be attributed to the buffering capacity of exchangeable bases present in the industrial effluent, which can mitigate acidity (Sani et al., 2020). Soil pH is a vital factor that affects nutrient availability, microbial function, and the chemical form of elements (Esu, 1991). The nearly neutral pH observed is advantageous for the majority of crops; however, continued application of effluent could lead to gradual alkalinization, impacting nutrient dynamics. Similar trends were observed in savanna soils irrigated with wastewater by Dawaki and Jazuli (2007) and Sani et al. (2020).

Electrical Conductivity (EC)

Average electrical conductivity (EC) values ranged from 0.28 to 0.96 dS m^{-1} (Table 1), with effluent-affected plots showing significantly ($P < 0.05$) higher EC than the control plots at both soil depths. Electrical conductivity is an indicator of the concentration of soluble salts in the soil solution**,** and higher EC values generally reflect increased levels of dissolved ions such as Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}. In this study, the increased EC in the effluent-affected soils suggests salt accumulation derived from industrial wastewater inputs**.**

In soil science, elevated electrical conductivity refers to EC values higher than those normally observed in non-saline agricultural soils, indicating increased soluble salt concentration that may influence plant growth and soil processes**.** Although the EC values recorded in this study remained below the commonly accepted salinity threshold of 4 dS m^{-1} for most crops**,** the higher EC observed in effluent-affected soils indicates a progressive build-up of soluble salts**.** If effluent application continues without proper management, such accumulation may eventually lead to soil salinization. Elevated EC can adversely affect crop production by reducing seed germination, limiting plant water uptake due to osmotic stress, and disrupting nutrient balance within the soil–plant system**.**

Organic Carbon (OC) and Total Nitrogen (TN)

Topsoils influenced by effluent exhibited greater OC levels (1.15%) and TN levels (0.11%) when compared to control samples (0.82% and 0.08%, respectively) (Table 1), although these differences were not statistically significant ($P > 0.05$). The increase in surface soil nutrients is likely due to the organic components of the industrial effluent, which include plant remnants, dissolved organic matter, and suspended particles (Whalen & Chang, 2002; García-Delgado et al., 2012). Both OC and TN concentrations decreased with depth, indicating patterns of surface deposition and limited downward migration. The strong correlation ($r = 0.86$, $P < 0.01$) between OC and TN suggests that the nitrogen present is largely of organic origin (Hao et al., 2004). Nevertheless, despite this enrichment, the OC and TN levels are classified as low to moderate fertility based on Esu (1991) evaluations, indicating a need for further organic matter input to enhance crop yield.

Available Phosphorus (P)

The available P values ranged from 9.2 to 15.4 mg/kg across different treatments and depths (Table 1). Generally, higher levels were observed in plots affected by effluent, with the topsoil showing the most significant enrichment. The differences in P levels among plots may be attributed to variations in effluent composition, as industrial wastewater from specific processes might include phosphate-based detergents or residues from food processing (Toze, 2006). Although P concentrations in effluent-affected plots fell into the medium fertility category (10–20 mg/kg) according to Esu (1991), excessive accumulation of P could potentially result in runoff and eutrophication of adjacent water bodies (Rusan et al., 2007).

Exchangeable Bases and Cation Exchange Capacity (CEC)

Soils impacted by effluent showed increased concentrations of Na^+, and to a lesser extent, Ca^{2+} and Mg^{2+}, compared to control soils (Table 1). The rise in Na^+ raises concerns regarding potential sodicity risks, as excessive Na^+ can replace Ca^{2+} and Mg^{2+} on the exchange complex, resulting in soil aggregate dispersion and decreased permeability (Bauder et al., 2011; Sani et al., 2020). CEC values ranged from 6.2 to 9.8 cmol/kg, with significantly ($P < 0.05$) higher values observed in effluent-affected topsoils. This increase may be due to the influx of soluble cations from the effluent and a slight increase in soil organic matter (Hao et al., 2004). However, the overall CEC classification remains in the low to moderate range for Alfisols, reflecting their naturally low clay content and organic matter (Esu, 1991).

Table 1: Physicochemical properties and fertility indicators of effluent-affected and control Alfisols at the NOUN Research Farm

Parameter	*Depth (cm)*	*Effluent-Affected Mean ± SD*	*Control Mean ± SD*	*LSD (0.05)*	*Rating**
pH (H_2O)	*0–15*	*7.05 ± 0.06*	*6.84 ± 0.07*	*ns*	*Neutral*
	15–30	*6.92 ± 0.04*	*6.72 ± 0.06*	*ns*	*Neutral*
EC (dS/m)	*0–15*	*0.96 ± 0.08*	*0.31 ± 0.04*	*0.12*	*Below threshold*
	15–30	*0.72 ± 0.06*	*0.28 ± 0.03*	*0.10*	*Below threshold*
Organic Carbon (%)	*0–15*	*1.15 ± 0.09*	*0.82 ± 0.07*	*ns*	*Low –Moderate*
	15–30	*0.84 ± 0.07*	*0.62 ± 0.05*	*ns*	*Low*
Total Nitrogen (%)	*0–15*	*0.11 ± 0.01*	*0.08 ± 0.01*	*ns*	*Low*
	15–30	*0.09 ± 0.01*	*0.06 ± 0.01*	*ns*	*Low*
Available P (mg/kg)	*0–15*	*15.4 ± 1.2*	*9.2 ± 0.8*	*ns*	*Medium/Low*
	15–30	*12.1 ± 1.0*	*7.8 ± 0.7*	*ns*	*Low*
Exch. Ca^{2+} (cmol/kg)	*0–15*	*3.8 ± 0.22*	*3.2 ± 0.19*	*ns*	*Medium*
	15–30	*3.2 ± 0.18*	*2.8 ± 0.16*	*ns*	*Medium*
Exch. Mg^{2+} (cmol/kg)	*0–15*	*2.4 ± 0.15*	*2.0 ± 0.13*	*ns*	*Medium*
	15–30	*2.0 ± 0.12*	*1.8 ± 0.10*	*ns*	*Medium*
Exch. K^+ (cmol/kg)	*0–15*	*0.31 ± 0.03*	*0.29 ± 0.02*	*ns*	*Medium*
	15–30	*0.28 ± 0.02*	*0.25 ± 0.02*	*ns*	*Medium*
Exch. Na^+ (cmol/kg)	*0–15*	*0.62 ± 0.05*	*0.28 ± 0.04*	*0.08*	*Slight hazard*
	15–30	*0.51 ± 0.04*	*0.24 ± 0.03*	*0.06*	*Slight hazard*
CEC (cmol/kg)	*0–15*	*9.8 ± 0.62*	*7.2 ± 0.50*	*0.84*	*Low–Moderate*
	15–30	*8.6 ± 0.55*	*6.5 ± 0.47*	*0.78*	*Low–Moderate*

**Ratings according to Esu (1991). ns = not significant.*

Heavy Metal Concentrations

Zn, Cu, Pb, and Cd levels were found to be greater in soils influenced by effluent compared to controls, with the highest concentrations occurring in the surface layer (0–15 cm) (Table 2). Pb and Cd levels in some effluent-affected topsoils surpassed the maximum permissible limits established by FAO/WHO (2007) for agricultural soils. This pattern of surface accumulation indicates limited vertical mobility but highlights the potential for long-term accumulation with ongoing effluent application.

Spatial and Depth Variability

Statistical evaluations indicated significant ($P < 0.05$) variations in electrical conductivity (EC), sodium ions (Na^+), zinc (Zn), lead (Pb), and cadmium (Cd) between plots affected by effluent and control plots, as well as between layers of topsoil and subsoil. Organic carbon, nitrogen, and phosphorus exhibited notable but statistically insignificant differences across treatments. Spatially, the plots nearest to the effluent discharge sites showed the highest concentrations of salts and heavy metals, suggesting that the intensity of contamination diminishes with increasing distance from the source (Binns et al., 2003; Sani et al., 2020).

Implications for Soil Fertility and Management

The findings suggest that the application of industrial effluents may lead to short-term enhancements in specific fertility indicators such as phosphorus (P), organic carbon (OC), and cation exchange capacity (CEC), but also poses risks of salinity and heavy metal contamination. The observed positive relationship between OC and total nitrogen (TN) underscores the contribution of organic inputs from effluents, while the higher levels of Na^+ and heavy metals indicate potential structural decline and contamination risks. Sustainable management strategies including pre-treatment of effluents, dilution with fresh water, routine soil testing, and the addition of organic amendments are crucial for sustaining productivity and safeguarding environmental quality (Abdulmumini et al., 2015; Sani et al., 2020).

Table 2: Heavy metal concentrations (mg/kg) in effluent-affected and control Alfisols at the NOUN Research Farm

Heavy Metal	**Depth (cm)**	**Effluent-Affected Mean ± SD**	**Control Mean ± SD**	**LSD (0.05)**	**FAO/WHO Limit***	**Remarks**
Zn	0–15	2.84 ± 0.18	1.52 ± 0.10	0.22	100	Safe
	15–30	2.10 ± 0.15	1.20 ± 0.08	0.18	100	Safe
Cu	0–15	1.36 ± 0.10	0.85 ± 0.07	0.12	36	Safe
	15–30	1.02 ± 0.09	0.70 ± 0.05	0.10	36	Safe
Pb	0–15	42.5 ± 3.8	18.4 ± 2.1	4.6	50	Borderline risk
	15–30	35.2 ± 3.1	15.7 ± 1.9	3.9	50	Safe
Cd	0–15	3.18 ± 0.25	1.02 ± 0.12	0.28	3	Slightly above limit
	15–30	2.52 ± 0.21	0.89 ± 0.10	0.26	3	Safe

**FAO/WHO (2007) maximum allowable limits for agricultural soils.*

CONCLUSION AND RECOMMENDATIONS

This study revealed that industrial effluents significantly modify the chemical properties of Guinea Savanna Alfisols at the National Open University of Nigeria (NOUN) Research Farm, Rigachikun, Kaduna State. The results showed that effluent-affected soils recorded higher electrical conductivity (EC), certain exchangeable bases, and increased concentrations of selected heavy metals compared with control plots. Although the application of industrial effluents may provide short-term improvements in soil fertility through slight increases in organic carbon (OC), total nitrogen (TN), and available phosphorus (P), the accompanying risks of salt accumulation and heavy metal build-up pose potential threats to long-term soil health and sustainable crop production.

The findings therefore indicate that continued and uncontrolled discharge of industrial effluents into agricultural lands may gradually degrade soil quality and reduce productivity if appropriate management practices are not implemented. To minimize these risks and sustain soil fertility in the study area, industrial wastewater should be properly treated before discharge into the environment. In addition, regular monitoring of key soil quality indicators such as EC, OC, TN, P, exchangeable bases, and heavy metals should be established to detect early signs of soil degradation.

Sustainable soil management practices should also be encouraged through the adoption of Integrated Soil Fertility Management (ISFM) strategies, including the use of organic amendments such as compost, farmyard manure, and green manure to enhance soil structure, nutrient balance, and resilience against contamination stress. Furthermore, agricultural activities should be restricted in areas where heavy metal concentrations exceed permissible limits, while appropriate remediation measures such as the use of tolerant crop species or phytoremediation approaches may be considered for the rehabilitation of contaminated soils.

Overall, effective regulation of industrial wastewater discharge, combined with continuous soil monitoring and improved soil fertility management practices, is essential for maintaining the productivity and environmental sustainability of Guinea Savanna Alfisols in the Rigachikun area.

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Authors' Contributions

AM conducted all experiments and wrote the manuscript.

Ethical Statement

Not applicable

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