International Journal of Innovative Environmental Studies Research 14(2):180-189, April-June, 2026

© SEAHI PUBLICATIONS, 2026 www.seahipublications.org ISSN: 2354-2918

DOI:10.5281/zenodo.20708032

Impact of Agricultural Practices on Soil Degradation, Contamination, and Water Quality in Monguno, Borno State, Nigeria

[1]A.A Malli,[2]S. Hassan, [3]U. Sanda, [4]U.W Wasaran [5]S.G Riskuwa.

[1]-[5]Department of General Studies, Federal Polytechnic Monguno, Borno State, Nigeria
*Corresponding Author: abdullahialhajimalli92@gmail.com | +234 706 837 3899

ABSTRACT

Across the semi-arid stretch of Northeastern Nigeria, soils are thinning, yields are declining, and water is carrying contaminants that should not be there yet almost no site-specific scientific evidence existed to quantify the problem, at least not in Monguno. This study fills that void. Working at the Federal Polytechnic Monguno (FPM) agricultural site in Borno State, composite soil and surface water (runoff) samples were collected during the active cropping season of May 2026 and subjected to a multi-analytical protocol encompassing pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Organic Carbon (TOC), phosphorus, and potassium determinations; Atomic Absorption Spectroscopy (AAS) for water-phase heavy metals; and Energy Dispersive X-Ray Fluorescence (ED-XRF) for full elemental soil profiling. The findings are alarming. Lead (Pb) in the runoff water registered at 0.061 ppm, six times above the WHO (2017) permissible limit of 0.010 ppm. Soil heavy metals far exceeded guideline thresholds: Copper (Cu) at 806.86 ppm, Chromium (Cr) at 1,005.78 ppm, Lead (Pb) at 631.26 ppm, and Nickel (Ni) at 220.02 ppm, with a combined Pollution Load Index (PLI) of 3.81, confirming significant multi-metal pollution. Soil Total Organic Carbon (TOC) was critically depleted at just 0.16%, and suspended solid loading in runoff exceeded the NESREA (2011) limit by more than fivefold. The principal drivers are continuous cropping without rest periods, unregulated agrochemical use, and bush burning, all operating on the geologically fragile Quaternary sandy sediments of the Chad Formation. This study establishes the first site-specific environmental baseline for Monguno and provides targeted, actionable recommendations for soil restoration, water protection, and sustainable agricultural policy.

Keywords: Agricultural Practices; Heavy Metal Contamination; Monguno Semi-Arid Zone; Pollution Load Index; Soil Degradation

1. INTRODUCTION

Soil is not merely dirt beneath our feet. It is the living foundation on which food security, ecosystem stability, and rural livelihoods all rest. Globally, soils support approximately 95% of all food production while performing functions carbon sequestration, water filtration, nutrient cycling that no engineered substitute has yet replicated (Montanarella et al., 2016; FAO, 2017). Despite this, the Food and Agriculture Organisation of the United Nations estimates that more than one-third of the world's soils are already degraded (FAO, 2021), and the pace of decline is fastest in the places least able to absorb it the smallholder farming systems of semi-arid sub-Saharan Africa.

In Northeastern Nigeria, the crisis is not approaching. It has arrived. Borno State lies within the Sahelian ecological zone, a landscape defined by low and erratic rainfall (400–600 mm annually), high ambient temperatures, and soils of inherently coarse sandy texture with low organic matter and poor structural stability (Akinbola et al., 2020; Yakubu, 2017). These soils were fragile long before the first plough broke

the surface. Decades of continuous cropping without meaningful fallow periods, widespread bush burning for land clearance, excessive tillage, and the indiscriminate application of synthetic fertilisers, pesticides, and herbicides have compounded their natural vulnerability, driving progressive nutrient depletion, structural breakdown, erosion, salinisation, and the accumulation of toxic heavy metals in both soil and water (Lal, 2015; Bationo et al., 2018).

Heavy metals are among the most insidious of these contaminants. Unlike organic pollutants, they do not break down. Once incorporated into the soil through agrochemical application, atmospheric deposition, or irrigation with mineralized water, lead (Pb), copper (Cu), chromium (Cr), and nickel (Ni) persist for decades available for uptake into food crops, leachable into shallow groundwater, and ingestible by the farming families who work the land and the children who play near it. Lead, in particular, has no safe exposure threshold: even at trace concentrations, it causes irreversible neurological damage in children (WHO, 2017; Alloway, 2013).

Monguno Local Government Area (LGA), located approximately 140 km northeast of Maiduguri in the Lake Chad basin, is home to one of the most agriculturally dependent communities in Nigeria. Smallholder farming of millet, sorghum, maize, vegetables, and legumes under both rainfed and fadama (irrigated lowland) systems is the primary livelihood and food source for most of the rural population. Despite the evident environmental pressures on this landscape, the scientific literature contains not a single site-specific study of soil quality, heavy metal contamination, or water chemistry for Monguno LGA. This absence of baseline data is not merely an academic shortcoming it is a barrier to action, preventing farmers, extension officers, regulators, and policymakers from making the informed decisions needed to protect the land and the people who depend on it.

This study was designed precisely to fill that void. By conducting a rigorous, multi-analytical assessment of agricultural soil and surface water at the Federal Polytechnic Monguno (FPN) site, it generates the first published environmental baseline for Monguno LGA. The specific objectives were to: (i) evaluate the physicochemical properties of soil and runoff water against WHO (2017), NESREA (2011), and SON (2015) regulatory standards; (ii) determine concentrations of key heavy metals in soil and water; (iii) quantify contamination severity using established pollution indices; (iv) identify the principal agricultural and geological drivers of deterioration; and (v) provide science-based recommendations for sustainable land and water management.

1.2 Statement of the Problem

Agricultural productivity in Monguno and its surrounding communities is increasingly threatened by declining soil quality resulting from unsustainable land-use and farming practices that have persisted over several decades. Continuous cropping without adequate rest periods, inappropriate and excessive tillage, land clearance through bush burning, and indiscriminate application of agrochemicals have collectively contributed to progressive soil degradation manifesting as nutrient depletion, structural breakdown, erosion, salinization, and chemical contamination (Lal, 2015; Bationo et al., 2018).

The semi-arid environment of Northeastern Nigeria further exacerbates these challenges. Soils in this region are inherently low in organic matter, have coarse sandy textures with poor water retention capacity, and are highly susceptible to wind and water erosion (Akinbola et al., 2020). The combination of ecological fragility and intensifying agricultural pressure accelerates degradation processes and heightens the risk of contaminant accumulation in both soil and water resources.

Of particular concern is the potential contamination of agricultural soils by heavy metals and agrochemical residues derived from repeated application of synthetic inputs, use of untreated irrigation water, and atmospheric deposition. These contaminants are persistent, toxic at elevated concentrations, and capable of entering the human food chain through crop uptake or infiltrating shallow groundwater systems used for drinking and domestic purposes (Alloway, 2013; Rattan et al., 2005). Existing studies from Northern Nigeria broadly indicate elevated heavy metal levels in agricultural soils near areas of intensive farming and agrochemical use (Abdu et al., 2016; Suleiman et al., 2018), yet site-specific data for Monguno remain absent.

This critical data gap limits the ability of relevant stakeholders to adequately assess environmental risks, design targeted soil restoration interventions, or develop evidence-based policies for sustainable agricultural management in the region. Without such information, soil degradation is likely to continue unchecked, leading to reduced crop yields, increased food insecurity, and potential long-term risks to human health and environmental sustainability in Monguno and its environs.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at an agricultural site within the Federal Polytechnic Monguno (FPN) environs, Monguno LGA, Borno State, Nigeria (approx. 13°36′N, 13°37′E; ~320 m a.s.l.). The area lies within the semi-arid Sudan Savannah zone with annual rainfall of 400–600 mm (June–September). The underlying Quaternary Chad Formation sediments produce predominantly sandy to sandy-loam soils of inherently low organic matter and limited nutrient-holding capacity. Dominant farming practices include continuous cropping, over-tillage, bush burning, and application of NPK fertilisers, urea, and agrochemicals.

2.2 Sample Collection

One composite soil sample was collected from the 0–30 cm topsoil layer using a stainless-steel auger at five sub-sampling points along a diagonal transect. Sub-samples were homogenised by quartering, transferred to sealed polyethylene bags, and air-dried, disaggregated, and sieved at 2 mm prior to analysis. One surface water (runoff) sample was collected in pre-cleaned 1-litre HDPE bottles from pooled agricultural runoff at the field margin. Water for metal analysis was acidified to pH < 2 with HNO_3 (Analar grade); physicochemical samples were stored at 4°C and analysed within 48 hours (APHA, 2017).

2.3 Laboratory Analysis

All analyses were conducted at Spectral Laboratory Services, Kaduna, Nigeria (10 June 2026). Physicochemical parameters (pH, TDS, TSS, TOC, P, K) were determined using a Hanna HI 83099 Multiparameter Photometer and Hanna HI 9813-6 TDS meter. Heavy metals (Cu, Zn, Pb) in water were quantified by AAS in air/acetylene flame mode with method-specific calibration curves ($R^2 \geq 0.894$). Soil elemental composition was determined by ED-XRF using a CrossRoads Scientific XRS-FP spectrometer (20 kV, 30 µA, Rh target, SDD detector, 60 s, air; Fundamental Parameter method). All analyses were in triplicate; QA/QC included reagent blanks, calibration verification, and use of analytical-grade reagents.

2.4 Contamination Indices

The Geo-accumulation Index ($Igeo = \log_2[Cn / 1.5 \times Bn]$), Contamination Factor ($CF = Cn/Bn$), and Pollution Load Index ($PLI = \sqrt[n]{(\prod CFn)}$) were calculated using geochemical background values for average shale (Taylor & McLennan, 1985). Igeo classes range from 0 (unpolluted) to 6 (extremely polluted) per Müller (1969). PLI > 1 indicates contamination above background.

3. RESULTS

3.1 Physicochemical Parameters

Table 1. Physicochemical parameters of surface water (runoff) and FPN soil compared with regulatory limits.

Sample	pH	P (mg/kg)	K (mg/kg)	TDS (mg/kg)	TSS (mg/kg)	TOC (mg/kg)	Temp (°C)
Water (Runoff)	6.8	96.32	235.69	121.67	164.65	19.65	29
FPN Soil	6.3	69.10	134.16	4,550.95	5,915.11	1,618.93	29
WHO (2017)	6.5–8.5	—	—	500	—	—	—
NESREA (2011)	6.0–9.0	—	—	1,000	30	—	—
SON (2015)	6.5–8.5	—	—	500	—	—	—

TDS = Total Dissolved Solids; TSS = Total Suspended Solids; TOC = Total Organic Carbon; — = no standard specified. Temperature at sampling: 29°C.

Soil pH (6.3) and water pH (6.8) were slightly acidic. Water TDS (121.67 mg/kg) was within all limits; soil TDS (4,550.95 mg/kg) was markedly elevated, indicating salt accumulation. Water TSS (164.65 mg/kg) exceeded the NESREA (2011) limit of 30 mg/L by more than fivefold. Soil TOC (0.16%) was critically low. Phosphorus and potassium were higher in runoff water than in soil, indicating active nutrient wash-off. Figure 1 illustrates the physicochemical profile for both matrices.

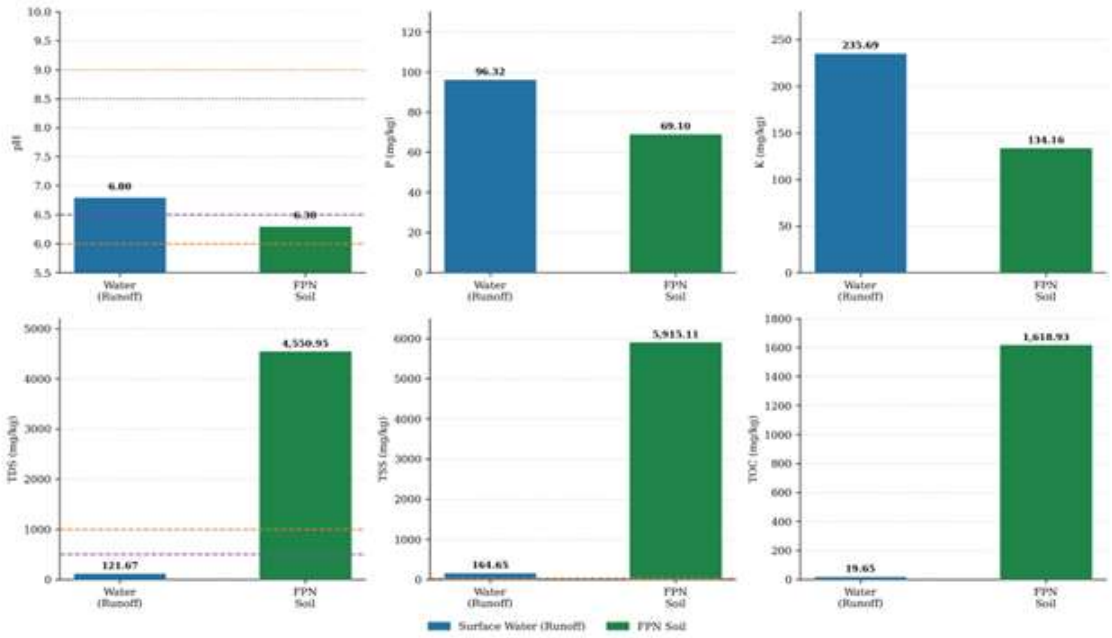

Figure 1. Physicochemical parameters of surface water (runoff) and FPN soil compared with WHO (2017), NESREA (2011), and SON (2015) regulatory limits

3.2 Heavy Metals in Surface Water (AAS)

Table 2. Heavy metal concentrations in surface water by AAS and regulatory limits.

Metal	Method	λ (nm)	R^2	Conc. (ppm)	WHO Limit (ppm)	NESREA Limit (ppm)
Copper (Cu)	Cu-D2-324.7	324.7	0.994	0.033	2.000	1.000
Zinc (Zn)	Zn-D2-213.9	213.9	0.894	1.434	3.000	3.000
Lead (Pb)*	Pb-D2-283.2	283.2	0.987	0.061	0.010	0.010

** Lead exceeds WHO (2017) and NESREA (2011) limits. λ = analytical wavelength; R^2 = calibration curve correlation coefficient. All values in ppm (mg/L).*

Lead was detected at 0.061 ppm, exceeding both the WHO and NESREA limit of 0.010 ppm by a factor of six. Zinc (1.434 ppm) and Copper (0.033 ppm) remained within regulatory limits but were elevated above natural background. Figure 2 presents a visual comparison of measured concentrations against regulatory thresholds.

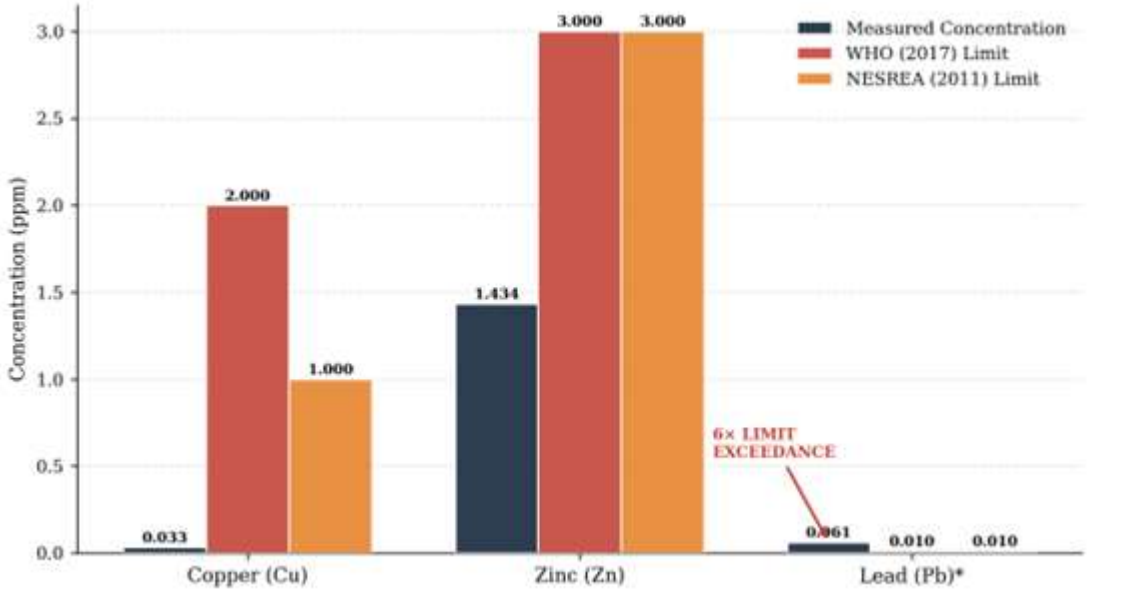

Figure 2. Heavy metal concentrations in surface water (runoff) by AAS compared with WHO (2017) and NESREA (2011) permissible limits. Lead significantly exceeds both limits.

3.3 Soil Elemental Composition (ED-XRF)

3.3.1 Major Constituents

Table 3. Major elemental oxide composition of FPN soil by ED-XRF (≥1.0 wt.%).

Symbol	Element	Oxide Form	Conc. (wt.%)	Error (±wt.%)	Mole (%)
Si	Silicon	SiO_2	79.707	2.862	84.999
Fe	Iron	Fe_2O_3	4.206	0.080	1.688
K	Potassium	K_2O	4.023	0.204	2.737
Ca	Calcium	CaO	3.286	0.165	3.755
Al	Aluminium	Al_2O_3	3.204	5.221	2.013
Ti	Titanium	TiO_2	1.414	0.077	1.134
S	Sulphur	SO_3	1.133	0.257	0.907
Cl	Chlorine	Cl	1.084	0.124	1.959

Instrument: CrossRoads Scientific XRS-FP; 20 kV, 30 µA, Rh target, SDD detector, Air, 60 s; 8 June 2026. Fundamental Parameter (FP) method.

SiO_2 dominated at 79.71 wt.% (84.99 mole %), confirming sandy, quartz-rich parent material of the Quaternary Chad Formation. Fe_2O_3 (4.21 wt.%), K_2O (4.02 wt.%), CaO (3.29 wt.%), and Al_2O_3 (3.20 wt.%) were next. Elevated SO_3 (1.13 wt.%) and Cl (1.08 wt.%) indicate sulphate and chloride salt accumulation consistent with progressive salinisation.

3.3.2 Trace Elements

Table 4. Trace elemental concentrations in FPN soil by ED-XRF (ppm, mg/kg).

Symbol	Element	Conc. (ppm)	Error (±ppm)	WHO Soil Guideline (ppm)
Nb	Niobium	2174.02	5836.99	—
Ba	Barium	2776.53	1818.18	—
Cr	Chromium	1005.78	177.89	100
Cu	Copper	806.86	135.81	100
Mn	Manganese	844.16	154.89	—
Pb	Lead	631.26	603.41	85
Ni	Nickel	220.02	133.59	35
V	Vanadium	532.16	207.26	—
Zn	Zinc	40.17	104.44	200
Zr	Zirconium	1843.46	1406.66	—
Ta	Tantalum	1596.99	573.28	—
P	Phosphorus	685.19	3770.72	—
Rb	Rubidium	429.77	320.04	—
Sr	Strontium	118.38	405.89	—
W	Tungsten	340.98	570.94	—
Cs	Caesium	594.23	2065.66	—

Concentrations converted from oxide wt.% using: ppm = wt.% × 10,000 × ($n \times MW_{el}/MW_{ox}$). WHO (2006) soil screening values used where available; — = no standard.

Chromium (1,005.78 ppm), Copper (806.86 ppm), Manganese (844.16 ppm), Lead (631.26 ppm), and Nickel (220.02 ppm) all exceeded their respective WHO (2006) soil guideline values of 100, 100, —, 85, and 35 ppm. Zinc (40.17 ppm) and Vanadium (52.62 ppm) remained below guideline thresholds. Figure 3 shows all trace element concentrations against applicable guideline values.

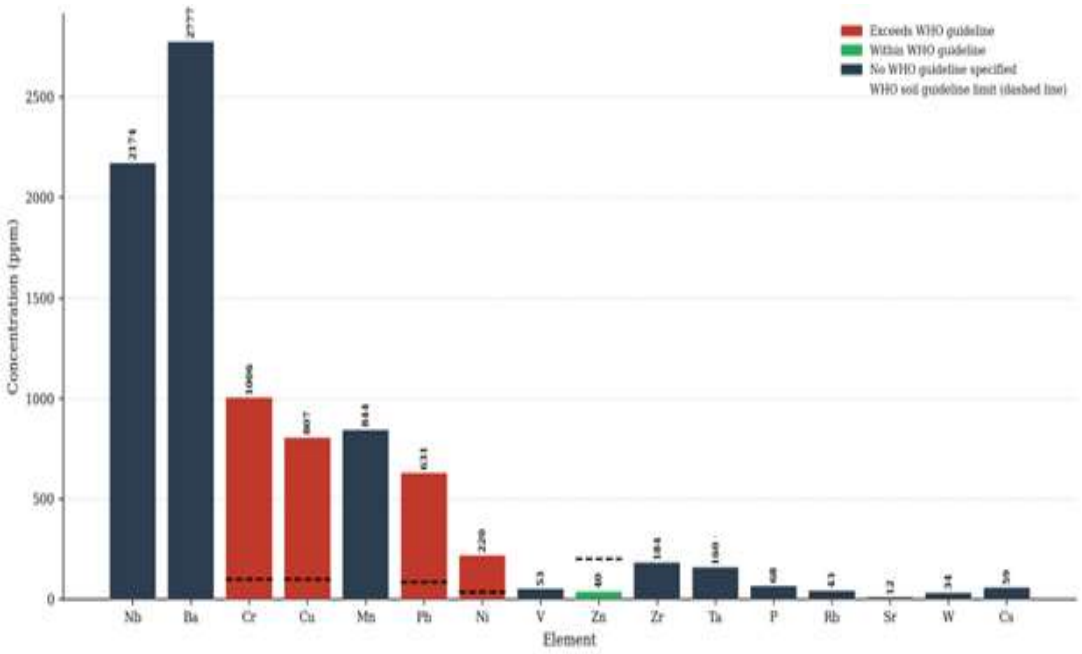

Figure 3. Trace elemental concentrations (ppm) in FPN soil by ED-XRF. Dashed markers indicate WHO (2006) soil guideline values. Red bars = exceedance; green = within guideline; dark = no guideline specified.

3.4 Contamination Indices

Table 5. Geo-accumulation Index (Igeo), Contamination Factor (CF), and Pollution Load Index (PLI) for selected heavy metals in FPN soil.

Metal	Measured (ppm)	Bg (ppm)	CF	Igeo	Igeo Class	PLI
Copper (Cu)	806.86	45	17.93	3.58	4 – Strongly	**3.81**
Chromium (Cr)	1005.78	90	11.18	2.90	3 – Mod.–Strong	—
Lead (Pb)	631.26	20	31.56	4.40	5 – Strong.–Ext.	—
Nickel (Ni)	220.02	58	3.79	1.34	2 – Moderately	—
Manganese (Mn)	844.16	850	0.99	-0.59	0 – Unpolluted	—
Zinc (Zn)	40.17	95	0.42	-1.83	0 – Unpolluted	—

Background (Bg) values after Taylor & McLennan (1985). PLI = $\sqrt[n]{(CF_1 \times CF_2 \times \ldots \times CFn)}$ for all six metals combined; PLI > 1 = contamination. Igeo classes after Müller (1969).

The combined PLI of 3.81 confirms significant multi-metal contamination above geochemical background. Lead and Copper show the highest Igeo values (strongly to extremely polluted). Chromium and Nickel fall in the moderately to strongly polluted class. Manganese is unpolluted to moderately polluted, suggesting primarily geogenic input. Zinc remains unpolluted relative to background. Figure 4 illustrates the Igeo and CF values for all analysed metals.

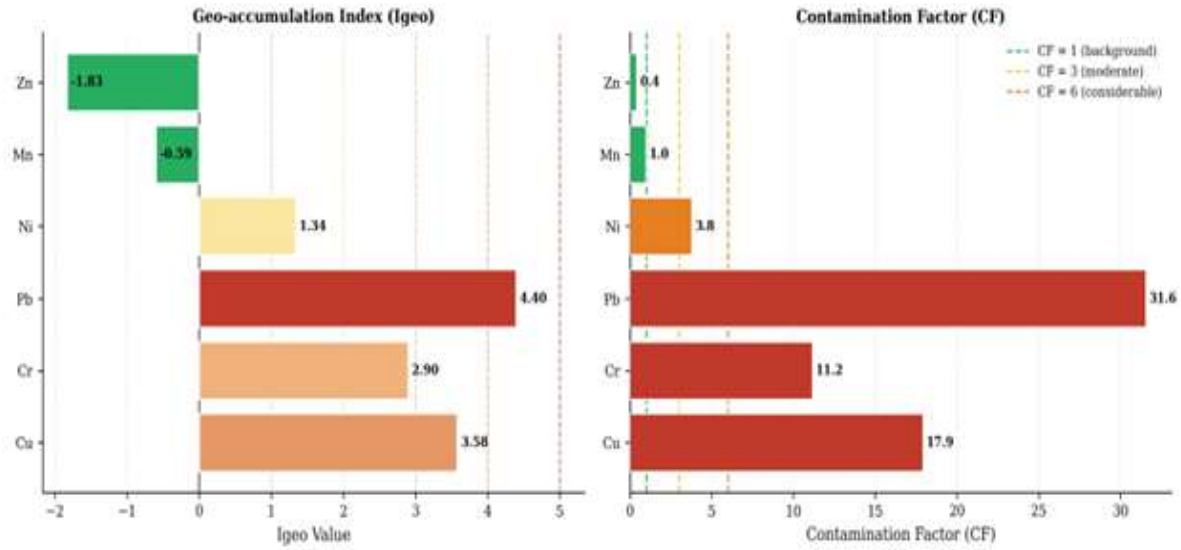

Figure 4. Geo-accumulation Index (Igeo) and Contamination Factor (CF) for selected heavy metals in FPN soil. Combined Pollution Load Index (PLI) = 3.81, confirming significant multi-metal contamination.

4. DISCUSSION

The results describe an agricultural system under severe chemical stress, with mutually reinforcing degradation processes operating across the soil–water–crop pathway. The slightly acidic pH in both matrices (soil: 6.3; water: 6.8) is consistent with continuous cultivation under ammonium-based fertiliser regimes without lime correction, a pattern documented across Northern Nigeria by Suleiman et al. (2018) and Akinbola et al. (2020). Under acidic conditions, heavy metals including Pb, Cu, Cr, and Ni exist in more soluble, bioavailable, and water-mobile ionic forms (Alloway, 2013), amplifying both crop phytotoxicity and groundwater contamination risks.

Soil TOC at 0.16% is severely below the 1% threshold for adequate biological activity and structural stability (Doran & Zeiss, 2000). Organic matter depletion from continuous cultivation without organic amendments is widely documented across the West African Sahel (Bationo et al., 2018; Mohammed et al., 2019) and is the proximate cause of the poor soil structure, high erodibility, and reduced metal-buffering capacity observed here. The fivefold exceedance of the NESREA TSS limit in runoff water (164.65 vs. 30 mg/L) is a direct consequence: each rainfall event strips metal-laden topsoil from the cultivated surface and deposits it in receiving water bodies a contaminant transfer mechanism confirmed by Yakubu (2017) and Akinbola et al. (2020) for similar Sahelian settings.

The sixfold exceedance of WHO and NESREA Pb limits in runoff water (0.061 vs. 0.010 ppm) is the most critical water quality finding. Lead is neurotoxic at any level, with children disproportionately vulnerable (WHO, 2017). Soil Pb at 631.26 ppm — 7.4 times the WHO guideline of 85 ppm — confirms an active contamination source. Repeated phosphate fertiliser application and lead-containing pesticide use, common in small-scale Northern Nigerian farming (Abdu et al., 2016), combined with atmospheric Pb deposition from bush burning (Rattan et al., 2005), are the most probable drivers. These findings align with Suleiman et al. (2018), who reported Pb exceedances in intensively farmed Northern Nigerian soils under comparable management regimes.

Soil Cr at 1,005.78 ppm exceeds its WHO guideline tenfold. Chromium contamination in agricultural soils is associated with phosphate fertiliser impurities and pesticide residues (Wuana & Okieimen, 2011). The potential presence of hexavalent Cr(VI) — carcinogenic and highly mobile at near-neutral pH — warrants urgent speciation analysis. Copper at 806.86 ppm, over eight times the guideline, most likely reflects cumulative input from copper-based fungicides (Alloway, 2013; Abdu et al., 2016). Nickel at

220.02 ppm, exceeding its guideline sixfold, is consistent with phosphate-fertiliser-associated Ni inputs documented across Northern Nigeria. The PLI of 3.81 places this site among the more contaminated agricultural soils in the Nigerian literature, comparable to values ≥2.5 reported by Abdu et al. (2016) and Suleiman et al. (2018) for intensively farmed soils in Kano and Kaduna.

Elevated soil TDS (4,550.95 mg/kg) and TSS (5,915.11 mg/kg) indicate advanced physicochemical degradation with a large dissolved and particulate contaminant pool available for mobilisation during rainfall. Active nutrient losses in runoff (P: 96.32 mg/kg; K: 235.69 mg/kg, exceeding respective soil values) confirm that applied fertiliser nutrients are washing off before plant uptake, simultaneously reducing agronomic efficiency and increasing eutrophication risks in receiving water bodies (Bationo et al., 2018; Manyong et al., 2005). Overall, this study demonstrates that current agricultural practices in Monguno are driving measurable, interconnected, and worsening soil and water quality degradation with direct implications for food safety, public health, and long-term agricultural sustainability.

5. CONCLUSIONS

This study delivers the first quantitative environmental baseline for agricultural soil and water in Monguno, Borno State. The key conclusions are:

1. Soil (pH 6.3) and water (pH 6.8) are slightly acidic, increasing heavy metal mobility along the soil–water–crop pathway.
2. Water TSS (164.65 mg/kg) exceeds the NESREA limit fivefold, driven by active topsoil erosion from structurally degraded, low-organic-matter soil (TOC: 0.16%).
3. Lead in runoff water (0.061 ppm) exceeds WHO and NESREA limits by a factor of six, posing direct public health risks to farming communities and children.
4. Soil Cr (1,005.78 ppm), Cu (806.86 ppm), Pb (631.26 ppm), and Ni (220.02 ppm) far exceed WHO guideline values, driven by continuous agrochemical inputs and bush burning.
5. The combined PLI of 3.81 classifies the FPN soil as significantly polluted by multiple heavy metals, consistent with findings from intensively farmed soils elsewhere in Northern Nigeria.

Immediate responses should include eliminating lead-containing agrochemicals, introducing organic amendments, adopting conservation agriculture, and establishing regulatory water and soil quality monitoring in Monguno. Future research priorities include multi-site spatial surveys, heavy metal speciation analysis, crop tissue sampling for dietary exposure assessment, and GIS-based contamination mapping across Monguno LGA.

ACKNOWLEDGEMENTS

The authors thank Spectral Laboratory Services, Kaduna, for conducting the physicochemical, AAS, and ED-XRF analyses, and the management of Federal Polytechnic Monguno for institutional support. The authors declare no conflict of interest. This research received no specific external funding.

REFERENCES

Abdu, N., Abdullahi, A. A., & Abdulkadir, A. (2016). Heavy metals and soil microbial biomass carbon and nitrogen mineralization in contaminated soils of Northern Nigeria. Environmental Monitoring and Assessment, 188(3), 1–12. https://doi.org/10.1007/s10661-016-5170-1

Akinbola, G. E., Salami, A. T., & Ojo, O. M. (2020). Assessment of soil degradation in semi-arid regions of Northern Nigeria using geospatial techniques. Journal of Environmental Management, 263, 110365. https://doi.org/10.1016/j.jenvman.2020.110365

Alloway, B. J. (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability (3rd ed.). Springer.

APHA. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.

Bationo, A., Waswa, B., Okeyo, J. M., Maina, F., & Kihara, J. (2018). Sustainable intensification of crop production systems in the drylands of sub-Saharan Africa. Springer.

Doran, J. W., & Zeiss, M. R. (2000). Soil health and sustainability: Managing the biotic component of soil quality. Applied Soil Ecology, 15(1), 3–11.

Food and Agriculture Organization (FAO). (2021). Soil pollution: A hidden reality. FAO.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875–5895.

Manyong, V. M., Smith, J., Weber, G. K., Jagtap, S., & Oyewole, B. (2005). Assessment of the constraints to agricultural production in Northern Nigeria. IITA.

McLaughlin, M. J., Parker, D. R., & Clarke, J. M. (1999). Metals and micronutrients — food safety issues. Field Crops Research, 60(1–2), 143–163.

Mohammed, A. S., Abubakar, A., & Zakari, I. (2019). Soil fertility decline in continuously cultivated fields of Borno and Yobe states, Northeastern Nigeria. Journal of Soil Science and Environmental Management, 10(3), 44–53.

Müller, G. (1969). Index of geo-accumulation in sediments of the Rhine River. GeoJournal, 2(3), 108–118.

NESREA. (2011). National environmental (surface and groundwater quality) regulations. Federal Republic of Nigeria Official Gazette, 98(63).

Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K., & Singh, A. K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops, and groundwater. Agriculture, Ecosystems & Environment, 109(3–4), 310–322.

Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from polluted areas. Journal of Environmental Monitoring, 12(4), 773–781.

Standards Organisation of Nigeria (SON). (2015). Nigerian standard for drinking water quality (NIS 554:2015). SON.

Suleiman, M. S., Abdullahi, M. S., & Yusuf, A. A. (2018). Assessment of heavy metal contamination in agricultural soils of Northern Nigeria. Nigerian Journal of Environmental Sciences and Technology, 2(1), 45–56.

Taylor, S. R., & McLennan, S. M. (1985). The continental crust: Its composition and evolution. Blackwell Scientific.

WHO. (2006). WHO guidelines for the safe use of wastewater, excreta and greywater: Vol. 2. World Health Organization.

WHO. (2017). Guidelines for drinking-water quality (4th ed., incorporating the 1st addendum). World Health Organization.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology, 2011, 1–20.

Yakubu, O. H. (2017). Environmental degradation and land use dynamics in semi-arid Northeastern Nigeria. Environmental Science and Pollution Research, 24(30), 23077–23090.