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Heavy Metal Contamination of Wetland Soil and Water in the Jama'are River Basin, Nigeria: Implications for Livelihoods and Environmental Governance

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Abstract

The Jama'are River wetland in the Hadejia – Jama'are floodplain, northern Nigeria, is utilized for farming, fishing, and grazing by the riverine communities, but there is little information regarding the contamination of the wetland with metals. The study was conducted in the 2026 rainy season where the topsoils and surface water were sampled from three stations beside the maize farmland, sugarcane farmland and the waste dumping site, and analyzed with atomic absorption spectrophotometry to determine the levels of cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn). Zn and Pb dominated in both media (soil Zn 87.30 and Pb 40.60 mg/kg; water Pb 0.366 and Zn 0.280 mg/L). A guideline-normalized Pollution Load Index (PLI) was less than one for soil (0.133–0.224) and water (0.152–0.299), and soil metals were not greater than benchmarks. Water Cd was however 1.8–2.3 times higher than the limit set by the Food and Agriculture Organization (FAO) for irrigation water; Cd and Pb were 3.6–4.6 and 20.7–28.2 times higher than the Nigerian regulatory reference values, respectively; and there was a significant enrichment of Cd in soils because of the comparison of average shale values. The low composite index thus obscured risks pertinent to irrigation farmers and water users. The results suggest that regular monitoring of Cd and Pb concentrations, rein in open

dumping and agrochemicals use, and community understanding of water quality in irrigation water be implemented.

Keywords: Environmental governance, Hadejia–Jama'are basin, Heavy metals, Irrigation water, Livelihoods, Wetland contamination

INTRODUCTION

Nature contains metals including lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn); however, their presence in many soils and water bodies is high relative to their natural levels as a result of their release into the environment during waste disposal, fertilizers, pesticides, and in the process of mining (Alengebawy et al., 2021; Briffa et al., 2020). In contrast to organic pollutants, metals are not degradable and remain in the environment, partition between solid and dissolved phases, and can bioaccumulate in food chains, and have documented impacts on kidney function, neurodevelopment and cancer risk (Jaishankar et al., 2014; Tchounwou et al., 2012). A recent global synthesis of 796,084 soil measurements from 1493 regional studies estimated that 14-17% of the world's cropland is affected by toxic metal pollution and that 0.9-1.4 billion people live in regions of increased health and ecological risk (Hou et al., 2025). The sources and risks of soil metal contamination can also shift with rapid urbanization and intensification of agricultural activities, as evidenced for suburban farmland in southwest China (Huang et al., 2024).

The burden is particularly pronounced in wetlands. Wetlands occupy less than 6% of the earth's surface, but they provide more than 7.5% of the value of the global gross domestic product (GDP) in ecosystem services, while it is estimated that 22% of the world's wetlands have been lost since 1970, with some countries losing more than 30% (SCW, 2025; de Groot et al., 2012; Fluet-Chouinard et al., 2023). The characteristics which make wetlands useful for their hydrology and biogeochemistry also make them effective for the removal of particle-bound and sorbed metals (Mitsch & Gosselink, 2015). The impacts of metal levels in the wetland sediment and soil have been reported from India, where the mean concentrations of Pb, Cr, and Cu in 8 wetlands were found to be greater than the toxicity reference values (Panda & Mohanta, 2023), and from the Port Everglades region in Florida, where the concentrations of metals in the wetland sediments were reported to indicate moderate to high ecological risk (Giarikos et al., 2023).

Metal contamination has been reported around artisanal gold mining operations in the northwest and southwest of Nigeria (Adewumi & Laniyan 2020; Barde et al., 2024), in irrigated and wetland farmlands in the southwest with Cd having the highest pollution index and some metals highlighted for carcinogenic risk in the southwest (Taiwo et al., 2024), and in agrarian soils of the southeast (Afonne et al., 2022). In the Sahelian north where dry season irrigation is accessed from rivers and lakes, soils, irrigation water and vegetables were found to be contaminated with Pb, Zn, Ni, Cd and Cu in Wawan Rafi, Jigawa State (Sagagi et al., 2022). The contamination of irrigation water with similar metals (Pb, Cd and Ni) has been reported from vegetable growing sites in Anambra state (Nnaji & Arinze, 2022).

The Hadejia–Jama'are floodplain is one of the key wetland ecosystems in the Nigerian Sahel. Wet-season surveys suggest that the majority of inflow (i.e. 80%) to the downstream wetlands comes from the Jama'are River; and flooding, flood-recession agriculture, grazing and groundwater recharge services of the floodplain have been demonstrated to be economically valuable in comparison to upstream diversion schemes (Barbier, 2003). A pedogeochemical study of the Hadejia–Jama'are basin wetland soils identified the elements, most notably, as being Pb, Zn and Cr, and found that the soils were at high risk of contamination from these elements, with Pb and Zn being the most influential (Aliyu et al., 2022). A more recent study of the topsoils of the floodplain of the River Hadejia found that studies of metal contamination in the floodplain soils and waters were limited (Abdullahi & Saleh, 2026), and also noted that the soils of the floodplain were suitable for a pedogeochemical study. However, to the best of our knowledge, there were no published study that quantified the concentrations of the metals in the soil and surface water of the Jama'are wetland, calculated an integrated pollution index for the wetland and compared the result with Nigerian and international guideline values. This type of baseline information is a necessary precondition for a risk-based management of a floodplain where flood-recession agriculture and fisheries are practiced.

The contamination status of the Jama'are River wetland near Jama'are town, Bauchi State, Nigeria was therefore assessed in this study. The specific objectives were to (i) measure the levels of Cd, Cr, Cu, Ni, Pb and Zn in the surface water and soils of the wetland; (ii) calculate a guideline normalized Pollution Load Index (PLI); and (iii) compare measured levels with soil and irrigation water quality guidelines. Results were placed in a geochemical context by adding a supplementary screening to the average shale background values.

MATERIALS AND METHODS

Study Area

The study was carried out on the floodplain of the Jama'are River in the Jama'are Local Government Area (LGA) of the NW of Bauchi State, Nigeria (Figure 1). The river is a tributary of Hadejia-Jama'are-Komadugu-Yobe system flowing to Lake Chad (Barbier, 2003). The LGA falls within the Sudan savanna region which is characterized by a single rainy season from May/June to September/October and long dry season. Land use includes rain-fed cereal farming on uplands and irrigated (fadama) rice, vegetable, maize and sugarcane farming, along with fishing, grazing and peri-urban settlement that generates waste and wastewater as its primary non-agricultural pressure on the wetland. Jama'are LGA had 117,482 inhabitants at the 2006 census, projected at about 209,800 in 2022 (Sulaiman et al., 2024).

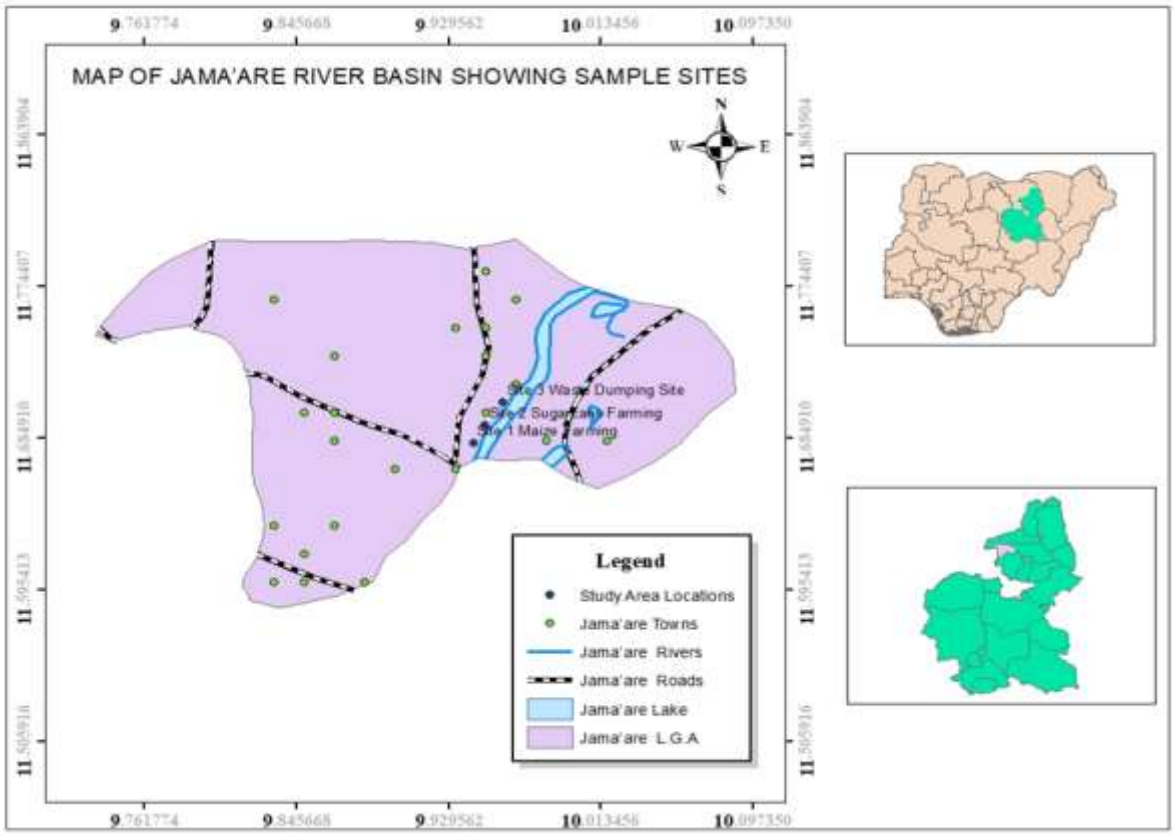


Figure 1. Map of the Jama'are River Basin Showing the Sampling Sites
Note. Site 1 = maize farming; Site 2 = sugarcane farming; Site 3 = waste-dumping site.

Sampling Design and Field Procedures

A reconnaissance survey was carried out and three stations A, B and C located in a section of approximately 150 m of the floodplain representing contrasting local land uses: Station A was located in maize farmland, Station B was located in sugarcane farmland and Station C was located at an open waste dumping site near a bridge (Table 1). Three soil samples and three surface water samples were taken at each station to account for six samples (three soil, three water) collected during the 2026 rainy season. The small sample size is due to the limited scope of the work and is considered a limitation, and the results are therefore presented as indicative of conditions at the sample points and not as statistically replicated means of the points.

Table 1: Sampling Stations on the Jama'are River Floodplain

Station	Code	Distance interval along reach	Dominant local land use
Site 1	A	0–50 m	Maize farming (upstream end)
Site 2	B	50–100 m	Sugarcane farming (middle)
Site 3	C	100–150 m	Waste-dumping site near bridge (downstream end)

Surface soil was raked to remove leaves, stones and visible debris and topsoil (0-15 cm) was sampled using a clean stainless-steel auger after the surface soil had been raked, and the soil was placed in labelled polyethylene bags and the auger was cleaned between sampling stations to prevent cross-contamination. Surface water was drawn into acid washed polyethylene bottles, rinsed in the field and filled without disturbing the bottom sediments. The samples were preserved in the field by adding concentrated nitric acid to lower the pH to < 2 as recommended by standard sample preservation procedures from APHA, (2017). The samples were all labeled by station, medium and date, put into cool boxes and carried to the Central Laboratory, Bayero University Kano for analysis.

Sample Preparation and Instrumental Analysis

The soil samples were air dried, homogenized and sieved of stones and plant materials. A one-gram sample was acid digested using the U.S. Environmental Protection Agency (USEPA) Method 3050B (acid digestion of sediments, sludges and soils), filtered and completed with 50 mL of distilled water. Samples of soil digests and acidified water samples were analyzed for the presence of Cd, Cr, Cu, Ni, Pb and Zn by atomic absorption spectrophotometry (AAS) using standard solutions before each analytical run. The concentrations in digest, in mg/L, were converted to the soil concentrations, in mg/kg, using the formula below:

$$C_{soil}\left(\frac{mg}{kg}\right) = C_{digest}\left(\frac{mg}{L}\right) \times V(L) \div m(kg) \ldots\ldots\ldots eqn.1$$

The final digest volume, V, is 0.050L and the mass of soil digested, m, is 0.001kg. Each batch was analysed along with a reagent blank to check for contamination. The water results are interpreted as total acid-recoverable concentrations since the water samples were preserved by the addition of acid and no attempt was made to distinguish between dissolved and particulate fractions.

Contamination Factor and Pollution Load Index

The contamination factor (CF) for each metal at each station was obtained by dividing the measured concentration by a concentration that was considered representative (Equation 2); the Pollution Load Index (PLI) was calculated as the geometric mean of the CFs for the n metals at each station (Equation 3) based on the already established formula by Tomlinson et al. (1980):

$$CF_i = \frac{C_i}{B_i} \ldots\ldots\ldots eqn.2$$

$$PLI = \frac{(CF_1 \times CF_2 \times CF_3 \times \ldots\ldots \times CF_n)1}{n} \ldots\ldots\ldots eqn.3$$

where C_i is the measured concentration of metal *i* and B_i is its reference value. The adoption of no verified pre-contamination geochemical baseline for the Jama'are Basin led to the use of an approach based on guidelines the NESREA-referenced soil values and the FAO long-term

irrigation-water limits for water (Table 2). The PLI is considered to be above the reference level when the combined metal load is >1, and at or below the reference level when the combined metal load is ≤1 (Tomlinson et al., 1980). Guideline-normalized values are not a measurement of enrichment above natural background levels; they are a geometric mean a single metal that exceeds the guideline value can be offset by several metals that do not exceed the guideline value (Caeiro et al., 2005).

Benchmarks for Comparison

The measured concentrations were compared with the reference concentrations given in Table 2. The primary reference was the maximum concentrations for long term use (Ayers & Westcot, 1985) which were recommended by the Food and Agriculture Organization (FAO), and were compared with NESREA-referenced water quality values as a secondary reference. NESREA referenced values and FAO type agricultural soil limits were employed for soil. The drinking-water guideline values (WHO, 2022) are health-based values for drinking water and do not constitute water irrigation standards; they are given as a point of reference only to protect the health of the water users, i.e. the communities along the rivers from which water may be collected for domestic use. Comparisons are shown for the percent of the benchmark (soil) and/or measured-to-benchmark ratio (water).

Table 2: Reference Values used for Contamination Factors and Benchmark Comparison

Metal	Soil: NESREA-referenced (mg/kg)	Soil: FAO-type limit (mg/kg)	Soil: average shale (mg/kg)	Water: FAO long-term (mg/L)	Water: NESREA-referenced (mg/L)	Water: WHO drinking (mg/L)
Cd	3	3	0.3	0.01	0.005	0.003
Cr	100	400	90	0.10	0.10	0.05
Cu	100	80	45	0.20	—	2.0
Ni	70	50	68	0.20	—	0.07
Pb	164	300	20	5.0	0.015	0.01
Zn	421	200	95	2.0	—	—

Supplementary Background-Referenced Screening

In order to put the soil data into a geochemical context, a supplementary screening CF was calculated for soil based on the average shale concentrations according to Turekian & Wedepohl (1961). Table 2 contains the shale data as Bi for soil calculations. The grading of Håkanson (1980) was used to classify CF values as low (< 1), moderate (1–3), considerable (3–6) or very high (≥ 6). This screening has been applied to soil only, not water; and global average shale is not a local baseline.

Data Analysis

The mean, mean ± sample standard deviation and range of the three values of each metal in each medium were calculated. Inferential tests were not used, as there was only one sample per station and medium. The calculations and figures were done in python (matplotlib), and the CF and PLI values were verified by re-calculating from the raw laboratory concentrations independently.

RESULTS

Metal Concentrations in Wetland Soil

All three soil samples contained all six metals as presented in Table 3. The mean concentrations followed the order Zn (87.30 mg/kg) > Pb (40.60 mg/kg) > Cr (15.35 mg/kg) > Ni (8.78 mg/kg) > Cu (8.03 mg/kg) > Cd (1.62 mg/kg). The combined contribution of Zn and Pb made up the metal burden (Figure 2a). Station A (close to the maize farmland) had the highest concentration of all five metals (Zn 93.90 mg/kg, Pb 46.40 mg/kg, Cr 23.50 mg/kg, Cu 10.35 mg/kg and Ni 11.20 mg/kg), while Station C (the dumping site) had the lowest concentrations of all the five metals. There was the greatest spatial variation (CV 53%) for Cr, followed by Cu (CV 37%) and Ni (CV 33%) from Station A to Station C. However, Cd was almost constant along the reach (range 1.55–1.70 mg/kg; CV 4.7%) and the maximum concentration was found at Station C (Figure 2b).

Table 3: Metal Concentrations in Wetland Soil Samples (mg/kg)

Metal	Site A	Site B	Site C	Mean ± SD	Range
Cd	1.55	1.60	1.70	1.62 ± 0.08	1.55–1.70
Cr	23.50	15.40	7.15	15.35 ± 8.18	7.15–23.50
Cu	10.35	9.05	4.70	8.03 ± 2.96	4.70–10.35
Ni	11.20	9.55	5.60	8.78 ± 2.88	5.60–11.20
Pb	46.40	42.30	33.10	40.60 ± 6.81	33.10–46.40
Zn	93.90	91.45	76.55	87.30 ± 9.39	76.55–93.90

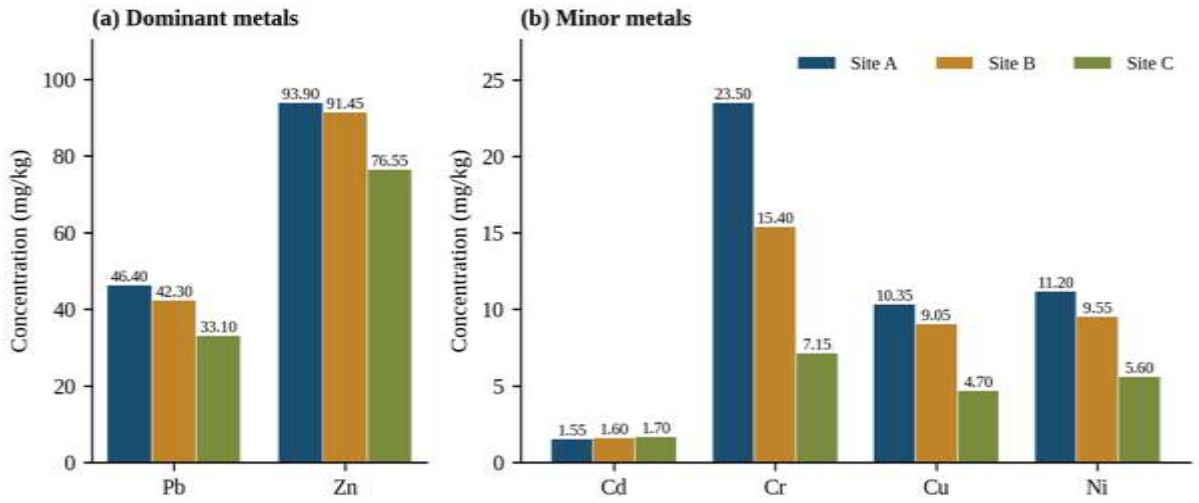


Figure 2. Concentrations of Metals in Wetland Soil at the Three Sampling Stations

Metal Concentrations in Wetland Water

Table 4 shows that all six metals were also found in all three water samples. Pb had the highest mean concentration (0.366 mg/L), followed by Zn (0.280 mg/L), Cr (0.034 mg/L), Cu (0.029 mg/L), Ni (0.021 mg/L), and Cd (0.021 mg/L), the last two being practically equal (Figure 3). The water concentrations of the two major metals increased downstream while the concentrations in soil remained constant, with the Pb concentration increasing from 0.310 mg/L at Station A to 0.364 and 0.423 mg/L at Stations B and C (a 36% increase), and the Zn concentration increasing from 0.219 mg/L at Station A to 0.300 and 0.321 mg/L at Stations B and C (a 47% increase). Station C also recorded the highest Cr (0.071 mg/L, 6.5 times the Station B value), Cu (0.043 mg/L), and Ni (0.033 mg/L). The concentration of Cd did not change significantly (0.018 to 0.023 mg/L), with the highest concentration recorded at Station B.

Table 4: Metal Concentrations in Wetland Water Samples (mg/L)

Metal	Site A	Site B	Site C	Mean ± SD	Range
Cd	0.018	0.023	0.021	0.021 ± 0.003	0.018–0.023
Cr	0.019	0.011	0.071	0.034 ± 0.033	0.011–0.071
Cu	0.030	0.013	0.043	0.029 ± 0.015	0.013–0.043
Ni	0.017	0.014	0.033	0.021 ± 0.010	0.014–0.033
Pb	0.310	0.364	0.423	0.366 ± 0.057	0.310–0.423
Zn	0.219	0.300	0.321	0.280 ± 0.054	0.219–0.321

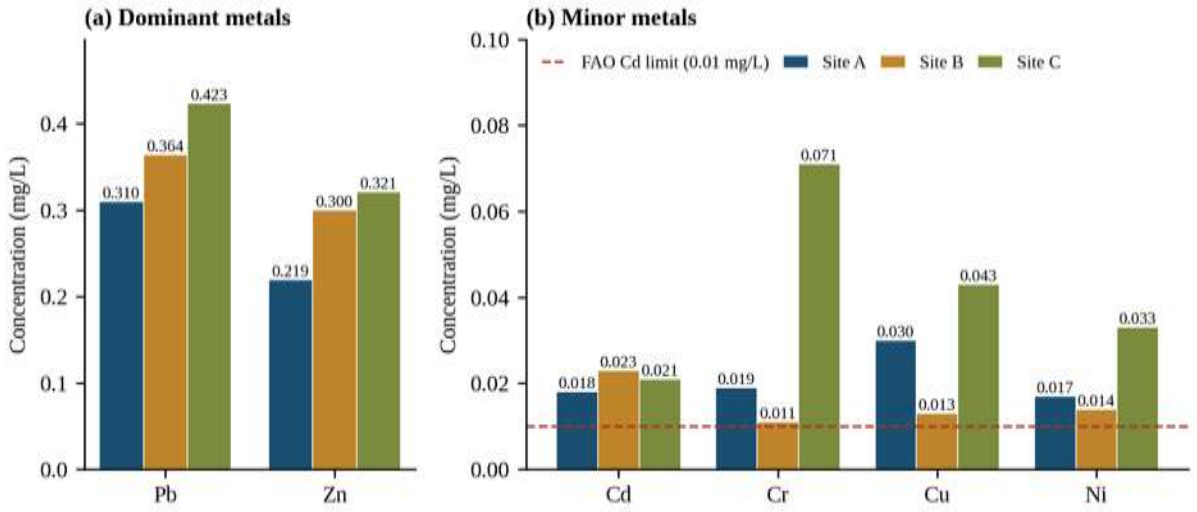


Figure 3: Concentrations of Metals in Wetland Water at the Three Sampling Stations

Contamination Factors and Pollution Load Index

Soil: All contamination factors at the three stations were below 1 when compared to the NESREA referenced soil values (Table 5; Figure 4a), and the Station A, B and C PCLs were 0.224, 0.196 and 0.133 respectively (Figure 5). The PLI also decreased in the downstream direction, in line with the other metal reductions (Cr, Cu, Ni, Pb and Zn). Cd had the highest individual CF at all three stations (0.517, 0.533 and 0.567) and it was the only metal that showed higher CF from A to C, meaning that it was not a zero input of metal that was being reported through the low PLI.

Table 5: Contamination Factors and Guideline-Normalized PLI for Soil

Metal	NESREA-referenced value (mg/kg)	CF Site A	CF Site B	CF Site C
Cd	3	0.517	0.533	0.567
Cr	100	0.235	0.154	0.072
Cu	100	0.104	0.091	0.047
Ni	70	0.160	0.136	0.080
Pb	164	0.283	0.258	0.202
Zn	421	0.223	0.217	0.182
PLI	—	**0.224**	**0.196**	**0.133**

Water: The PLI ranged from < 0.1 to 0.3, all below 1, at Stations A, B and C (Table 6; Figure 5) with the highest PLI values at Station C, where the highest concentrations of Cr, Cu, Ni, Pb, and Zn were recorded. At all three stations, however, the CF for Cd was greater than 1 (1.80, 2.30 and 2.10) while the CFs for all other metals were less than 1 (Figure 4b). Cr at Station C (CF = 0.71) was the next closest to the limit.

Table 6: Contamination Factors and Guideline-Normalized PLI for Water

Metal	FAO limit (mg/L)	CF Site A	CF Site B	CF Site C
Cd	0.01	1.800	2.300	2.100
Cr	0.10	0.190	0.110	0.710
Cu	0.20	0.150	0.065	0.215
Ni	0.20	0.085	0.070	0.165
Pb	5.0	0.062	0.073	0.085
Zn	2.0	0.110	0.150	0.161
PLI	—	**0.176**	**0.152**	**0.299**

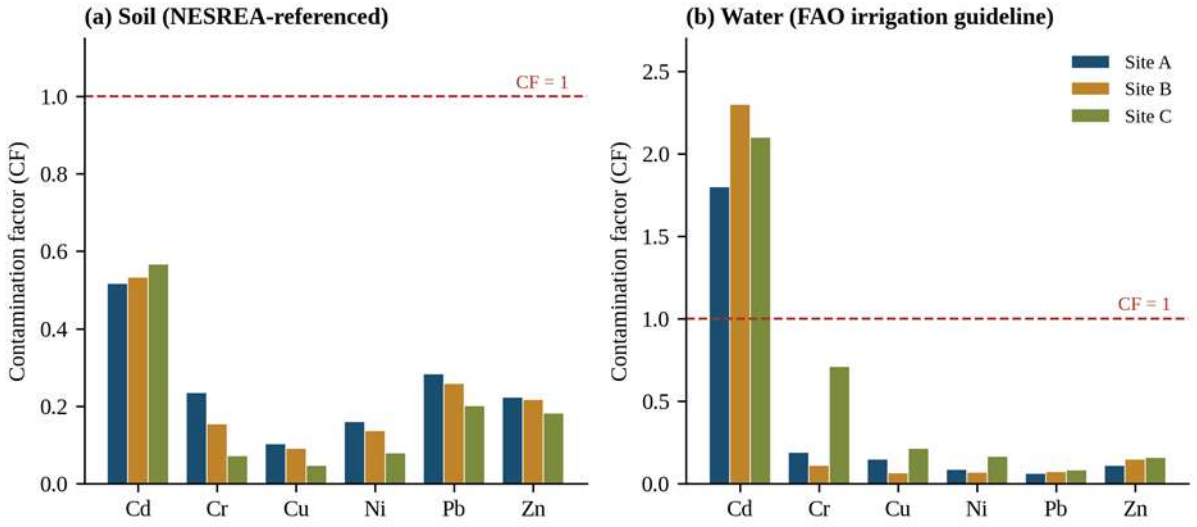


Figure 4. Guideline-Normalized Contamination Factors for Soil and Water

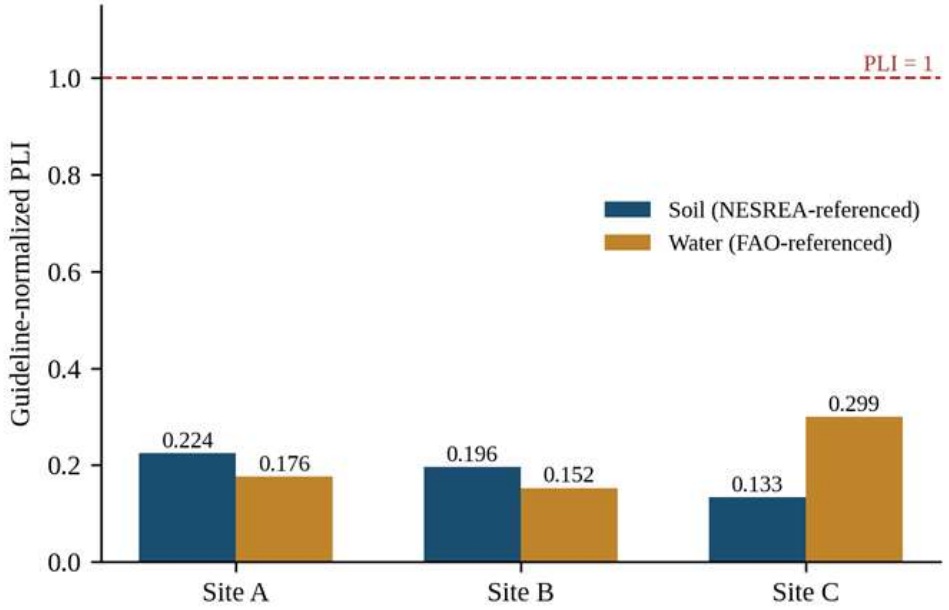


Figure 5. Guideline-Normalized Pollution Load Index for Soil and Water

Comparison With Benchmarks

Soil: At all stations, no metal met both soil criteria (Table 7). Relative to the NESREA-referenced values, Cd was highest at 51.7–56.7% of the limit, followed by Pb (20.2–28.3%), Zn (18.2–22.3%), Cr (7.2–23.5%), Ni (8.0–16.0%), and Cu (4.7–10.4%). Relative to the FAO-type limits, Cd again reached 51.7–56.7%, Zn 38.3–47.0%, Ni 11.2–22.4%, Pb 11.0–15.5%, Cu 5.9–12.9%, and Cr 1.8–5.9%. Percentages for Cu, Ni and Zn are dependent on the benchmark as these metal limits defined by FAO are less than the NESREA-referenced limits, and some are pH dependent.

Table 7: Soil Metal Concentrations Expressed as a Percentage of Reference Values

Metal	NESREA-referenced value (mg/kg)	% of NESREA-referenced value (A, B, C)	FAO-type limit (mg/kg)	% of FAO-type limit (A, B, C)
Cd	3	51.7, 53.3, 56.7	3	51.7, 53.3, 56.7
Cr	100	23.5, 15.4, 7.2	400	5.9, 3.9, 1.8
Cu	100	10.4, 9.1, 4.7	80	12.9, 11.3, 5.9
Ni	70	16.0, 13.6, 8.0	50	22.4, 19.1, 11.2
Pb	164	28.3, 25.8, 20.2	300	15.5, 14.1, 11.0
Zn	421	22.3, 21.7, 18.2	200	47.0, 45.7, 38.3

Water: The results showed that of all the metals, Cd exceeded the FAO irrigation limit at Stations A, B and C at 1.8, 2.3, and 2.1 times the limit, respectively, while the others were within the limit (Table 8; Figure 6). Cd (3.6-4.6 times the value of 0.005 mg/L) and Pb (20.7-28.2 times the value of 0.015 mg/L) were found to be greater than the benchmark at each and every station, while the presence of Cr was found to be less than 0.10 mg/L. The discrepancy between FAO and NESREA outcomes for Pb is due to the difference in the long term irrigation limits, FAO = 5 mg/L while NESREA = 0.016 mg/L. Compared to the WHO drinking water guideline of 5 micrograms per litre (µg/L) for Cd, the same concentrations were 6.0-7.7 times higher for the whole water sample, and Cr at Station C (0.071 mg/L) was 1.4 times higher than the 5 µg/L guideline, while Cu and Ni were lower.

Table 8: Ratio of Measured Water Concentrations to Reference Values

Metal	FAO (A, B, C)	NESREA-referenced (A, B, C)	WHO drinking water (A, B, C)
Cd	1.80, 2.30, 2.10	3.6, 4.6, 4.2	6.0, 7.7, 7.0
Cr	0.19, 0.11, 0.71	0.19, 0.11, 0.71	0.38, 0.22, 1.42
Cu	0.15, 0.07, 0.22	—	0.01, 0.01, 0.02
Ni	0.09, 0.07, 0.17	—	0.24, 0.20, 0.47
Pb	0.06, 0.07, 0.08	20.7, 24.3, 28.2	31.0, 36.4, 42.3
Zn	0.11, 0.15, 0.16	—	—

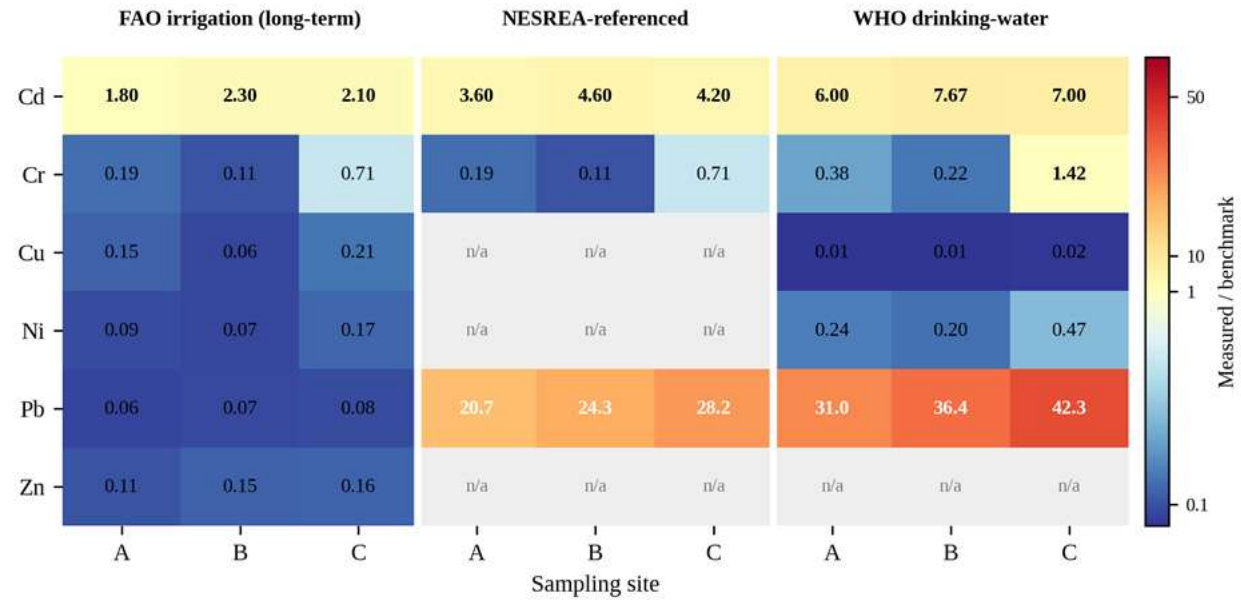


Figure 6. Ratio of Measured Water Concentrations to Three Sets of Reference Values

Supplementary Background-Referenced Screening of Soil

When average shale was used as the reference (Table 9; Figure 7), Cd had a CF of 5.17–5.67 (considerable), Pb a CF of 1.66–2.32 (moderate), and Zn a CF of 0.81–0.99; Cr, Cu, and Ni were well below 1. Therefore, the metal with the largest number of values above 1 was Cd with 0.700 and 0.612 for Stations A and B respectively, and with 0.416 for Station C. Pb was the only other metal for which more than one value exceeded 1.

Table 9: Supplementary Shale-Referenced Contamination Factors and PLI for Soil

Metal	Shale value (mg/kg)	CF Site A	CF Site B	CF Site C
Cd	0.3	5.17	5.33	5.67
Cr	90	0.26	0.17	0.08
Cu	45	0.23	0.20	0.10
Ni	68	0.16	0.14	0.08
Pb	20	2.32	2.11	1.66
Zn	95	0.99	0.96	0.81
PLI	—	**0.700**	**0.612**	**0.416**

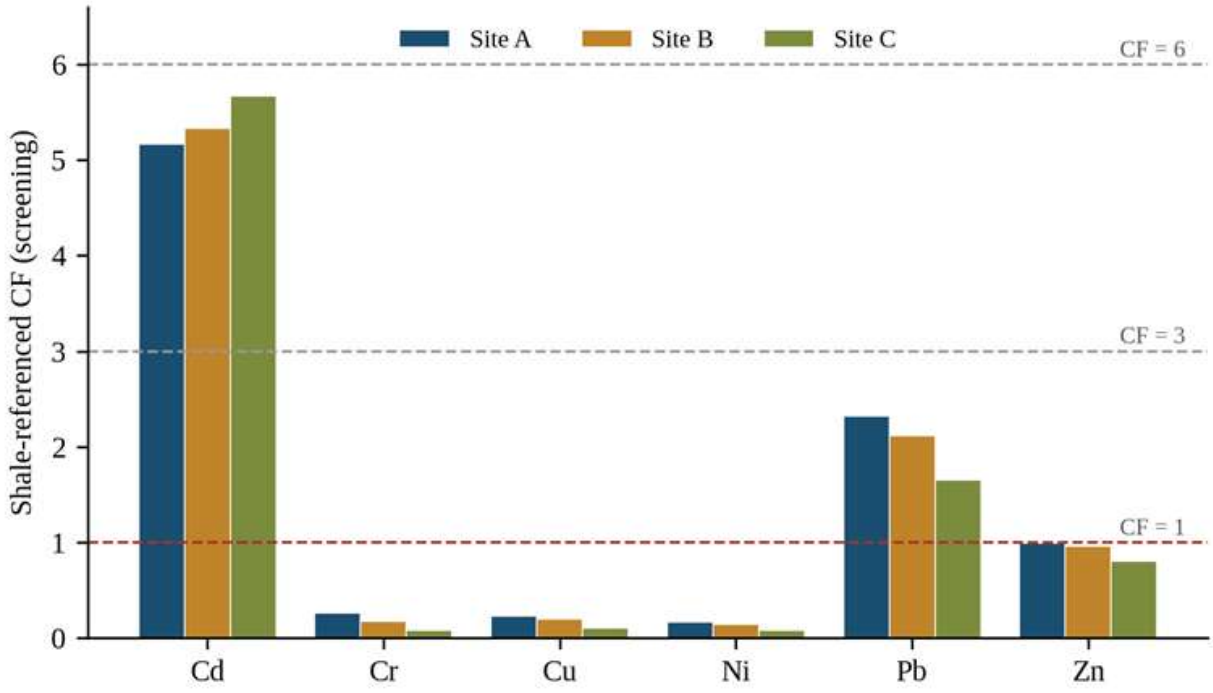


Figure 7. Shale-Referenced Contamination Factors for Soil (Screening)

DISCUSSION

Metal Levels in Context

The two metals that dominated the soil burden were Zn and Pb, while for the water burden they were also Pb and Zn. This is in alignment with the identification of Pb and Zn (along with Cr) as the most influential metals in wetland soils of the entire Hadejia–Jama'are basin (Aliyu et al., 2022), as well as the high levels of these (Pb and Zn) among the metals found in soil, irrigation water and vegetables at Wawan Rafi, Jigawa State (Sagagi et al., 2022). The same, in agreement with the importance we find for Cd, has been reported for irrigable wetland soils in southwestern Nigeria, where the soil profile was also Zn rich (second only to Fe). The soil concentration results in the present study have been compared with the NESREA-referenced and FAO-type concentrations and it was revealed that the present soil concentration is relatively lower than the concentration of the soils affected by the mining operation (Adewumi & Laniyan, 2020; Barde et al., 2024; Kyowe et al., 2024), although there is a limit in making direct numerical comparison across the studies because there is a difference in digestion method, depth and benchmark used.

Contrasting Soil and Water Patterns Along the Reach

It is interesting to note that the concentrations of Cr, Cu, Ni, Pb and Zn decreased in the soil moving from Station A to Station C, while they increased (or peaked at Station C) in the water (Figure 7). Source apportionment and soil properties (pH, organic matter, texture, cation exchange capacity) were not measured and so the causes can only be discussed as hypotheses. The increased levels in the soil at the maize-farm station may be a consequence of cumulative agrochemical and fertilizer applications to the soils, a known source of metals in agricultural soils (Alengebawy et al., 2021). Secondly, metals are often bound tightly to soil under certain conditions and can be released or bound under others, and seasonally saturated soils can bind or release metals as a result of changes in soil pH, redox, and/or organic matter status (Violante et al., 2010); for example, a disturbed, coarse-textured waste-dump soil may bind metals poorly, while a water-logged, fine-textured farm soil may bind metals well. Third, during the rainy season, metals may be added to the water column and suspended particles may increase in total concentration at Station C, from direct discharge at the dumping site and from leachate and runoff from the site and bridge. The near uniformity of Cd over a 150 m reach suggests a diffuse rather than point-source source, but requires confirmation by multivariate or isotopic source apportionment.

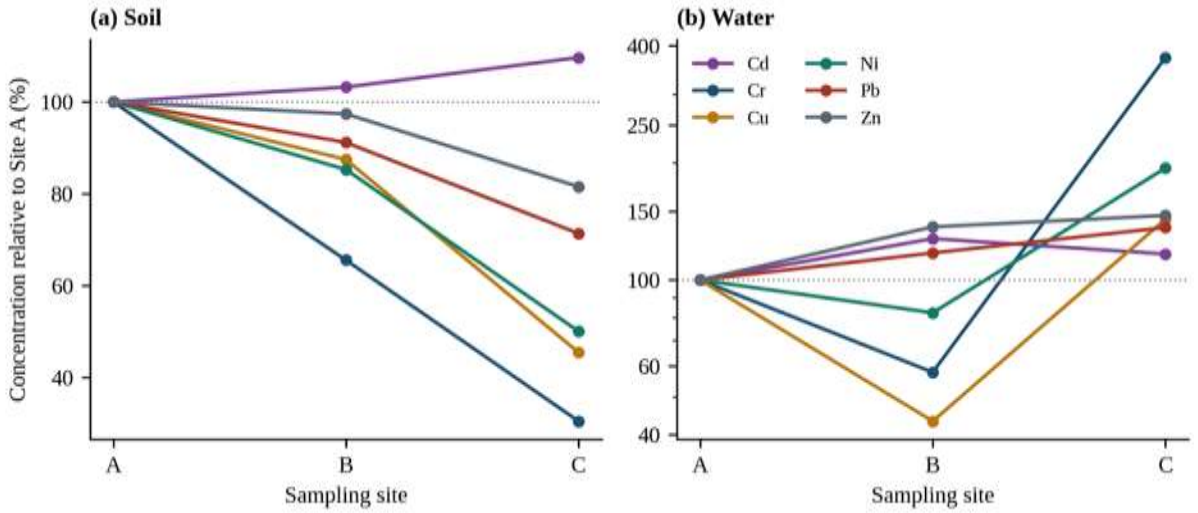


Figure 8. Spatial Trends of Soil and Water Metal Concentrations Relative to Site

Why a Low PLI Can Coexist with Metals of Concern

The PLI values for both of the guideline-normalized series were less than 1; however Cd was above the FAO limit in all water samples, and Cd and Pb was above the NESREA-referenced water values. This is a built-in characteristic of the index: in a geometric mean, the PLI is weighted by the several metals with low CFs, and if the reference is a guideline, the PLI is not a measurement of enrichment above natural background, but rather of proximity to a policy threshold (Caeiro et al., 2005; Tomlinson et al., 1980). The screening is illustrated for soil in the supplementary. There is measurable enrichment of Cd and Pb in soil, although no guideline is surpassed, with soil Cd being 52-57% of the guideline value but being 5-6 times the average shale value; and Pb being 1.7-2.3 times the average shale value. The results obtained from both of these reference systems are thus complementary, and both systems indicate that Cd is the metal of greatest relative concern for both media. It is important to note that shale is not a background and a local baseline (e.g., from uncultivated reference soils or deep soil horizons) is required to validate the level of enrichment.

Cadmium and Lead in Wetland Water: Implications

All three stations had concentrations of Cd above the FAO limit of 0.01 mg/L. The FAO limit is conservative since Cd may be accumulated in the soil and crops, and repetitive irrigation with water containing Cd can lead to a gradual increase of soil Cd (Ayers & Westcot, 1985). The existing soil Cd concentration was already 52-57% of the benchmark and the continued irrigation with water of higher concentration than the limit, especially to the fadama farmlands that rely on the river could close the gap even more. Cd is a known cause of kidney damage and cancer, and a long biological half-life, and the transfer of Cd from soil to food chains is well documented as a human exposure pathway near a contaminated site (Surenbaatar et al., 2023).

The Pb scores are dependent on the benchmark. The level of Pb was low but 21–28 times higher than the NESREA referred value and 31–42 times higher than the WHO drinking water guideline. The more protective benchmarks are the relevant ones wherever the water is used for drinking, bathing or livestock, since Pb is toxic to the developing nervous system at very low exposure levels (ATSDR, 2020).

Implications for Livelihoods, Public Health, and Environmental Governance

The results validate four practical priorities viz: Firstly, the environmental regulator and water-resource authorities should incorporate the regular monitoring of Cd and Pb in the water of the wetland, preferably in the wet and dry seasons, into the planning and management of the wetland. Second, farmers should be discouraged from using water that is regularly used for too long that may be above irrigation thresholds, and they should keep track of soil and crop Cd. Third, the open dumping and uncontrolled discharge of waste water at the river bank should be reduced as the highest concentrations of most of the metals were measured at the station at the river bank where waste water is dumped. Fourth, the use of agrochemicals, especially phosphate fertilizers and pesticides, should be controlled, considering the presence of metal content (Alengebawy et al., 2021). These priorities are in line with general evidence which shows that pollution of soils by metals is a common problem for agricultural land and human health (Hou et al., 2025) and that the Jama'are–Hadejia floodplain is an economically valuable asset that needs to be protected (Barbier, 2003). These priorities are institutional and technical. Households living in the riverine areas who farm, fish and raise livestock on the floodplain are exposed, while local government, the state environmental agencies, and the federal regulator share responsibility for collecting waste, controlling agrochemicals and monitoring water quality. Simple and regular water quality monitoring in local government environmental health services, and providing the results in terms farmers and fishing communities can use in their livelihood decisions, would transform data silos into information. The environmental management decisions made in Jama'are also have impacts on the surrounding floodplain economies (Barbier, 2003) and, therefore, impacts beyond the town.

Limitations and Future Work

There are a few things that should be kept in mind: (a) There was not enough information to measure within station variability or measurement uncertainty and no statistical tests were performed because only a single soil and water sample was analyzed at each station. (b) The three stations are within approximately 150 m of each other, and spatial conclusions are therefore based on local variation, rather than the basin as a whole. (c) One rainy season was sampled, but dry season conditions, which have different concentrations of metals in water and irrigation, were not measured. Retention and mobility are not interpretable for (d) Soil pH, Organic matter, Texture and Cation exchange capacity were not measured. (e) Analytical quality assurance was only carried out for calibration and reagent blanks; certified reference materials, recovery and detection limit data should be reported in future work. (f) Water: Total acid-recoverable concentration. The guideline normalised value of PLI is dependent on the guideline used and should be compared to the main regulations if used to check for compliance with the regulations, as the NESREA-referenced and FAO-type values are dependent on the guideline

used. No source apportionment or biological sampling (crops, fish) was done. Replication of sampling over longer reach, seasonal sampling, measurement of soil properties, dissolved and particulate fractionation, background concentrations derived locally, source apportionment tools, and human health risk assessment should be used in future work, as would be additional indices as the geo-accumulation index and the potential ecological risk index.

CONCLUSION

This study presents for the first time site-specific data for the metals in soil and surface water of wetland in the Jama'are River area, around the town of Jama'are. All six (6) metals were detected in both media, the most abundant being Zn and Pb. The guideline-normalized PLI values were below 1 for soil (0.133–0.224), and water (0.152–0.299), and the soil concentrations were below guideline-referenced (NESREA) and FAO-type limits at all stations. However, the water concentration of Cd was found to be higher than the FAO irrigation limit at all stations (1.8–2.3 times) Cd and Pb concentrations were also higher than the NESREA-referenced water concentration (3.6–4.6 times and 20.7–28.2 times, respectively) and a supplementary shale-referenced screening showed high concentrations of both Cd and Pb in soil. A low integrated index does not mean that the wetland is not of concern with metals. The conclusions are preliminary and should be considered a baseline and early warning, as a small sample size and limited seasonality (one season) are given. Further seasonal monitoring of Cd and Pb, better management of waste and agrochemicals along the flood plain, and a follow-up study with source apportionment and health risk assessment with more replication are recommended.

Declarations

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this article.

Data availability

All data generated or analyzed during this study are included in this article. The underlying laboratory report is available from the corresponding author on reasonable request.

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