

Spatial Variation and Sources of Heavy Metals in Soils Near Waste Disposal Points on University Farms in Rivers State, Nigeria

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Abstract

The study assessed the spatial variation and sources of heavy metal in soils around waste disposal points on university farms in Rivers State University. Each university farm in Rivers State, Nigeria, the study adopted quasi experimental design. Forty-eight composite topsoil samples 0–20 cm was collected from April to June 2026 at four farms, from stations within 10 m ST1 and 150–200 m ST2 of each waste disposal point. Lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), cobalt (Co), zinc (Zn), potassium (K) and magnesium (Mg) were measured by atomic absorption spectrophotometry, compared with Nigerian soil target values, and analysed by three-factor ANOVA, correlation and principal component analysis (PCA). Zn, Pb, As, Cr and Co were far below their target values, but Cd mean of 0.72 mg/kg approached its 0.8 mg/kg target, which 18 of 48 samples exceeded, 15 of them at ST1. All eight elements were significantly higher at ST1 than at ST2 $p \leq 0.001$ and varied between months $p \leq 0.027$, with most lowly in May. PC1 (45.6% of variance) loaded on all eight elements and separated ST1 from ST2 samples. Waste disposal points are therefore localised hotspots of joint metal enrichment where Cd already exceeds the national target, and soil levels change within a single season. The study recommends waste segregation at source, relocation of disposal points away from cultivated beds, and seasonal monitoring of Cd near disposal points.

Keywords: heavy metals; waste disposal; spatial variation; principal component analysis; cadmium; agricultural soil; university farms; Niger Delta

Introduction

Heavy metals are among the most persistent contaminants of agricultural soil. They do not degrade, they accumulate in soil over years of input, and they can pass from soil into crops and then into people (Alengebawy et al., 2021; Rashid et al., 2023). On farmland, they come from phosphate fertilisers, manures, sewage sludge, waste-derived soil amendments, agrochemicals and uncontrolled waste disposal (Akhter et al., 2022; Taghavi et al., 2024; Wan et al., 2024). Of these, waste disposal is the source most easily controlled by farm management, yet it is often the least documented. Studies of waste-affected soils show that metal levels rise close to waste. In Nigeria, cadmium contributed 98–99% of the potential ecological risk in soils of a municipal waste dump in Uyo (Ihedioha et al., 2017). Soils around the Gosa dumpsite in Abuja

were moderately polluted with Pb, Zn and Cd (Omada et al., 2024), and an abandoned dumpsite in Enugu that had been converted to farmland remained strongly enriched in Zn and Cd (Ekere et al., 2020). In Khulna, Bangladesh, cropland next to a waste disposal site held about seven times more Pb, more than three times more Cd and about three times more Zn than cropland further away (Jolly et al., 2025). These studies dealt with large municipal dumps, however. Far less is known about the small, mainly organic waste heaps found on farms themselves, where crop residues, plastics, fertiliser bags and agrochemical containers are dumped beside the beds. Metal levels in soil are also not fixed in time. In the humid tropics, rainfall, surface runoff and leaching move metals through and across the soil, and farm inputs change from month to month (Wan et al., 2024). A single round of sampling may therefore give a misleading picture, especially in the Niger Delta, where annual rainfall exceeds 2,000 mm. Multivariate methods such as principal component analysis (PCA) can help separate elements that share a source from those that do not, and are widely used for this purpose in farm soils (Tong et al., 2025; Zhao et al., 2022). University farms in Rivers State combine teaching, research and food production, and are worked daily by students, staff and farm hands. Iyama et al. (2022) found Cd above World Health Organization/Food and Agriculture Organization (WHO/FAO) and United States Environmental Protection Agency (USEPA) limits in soils and plants of three university farms in Port Harcourt. That study did not, however, relate metal levels to on-farm waste disposal points, compare soils near and far from them, or examine how levels changed over time. No later study in the literature reviewed has done so.

The present study therefore aimed to assess the spatial variation of heavy metals in soils of four university farms in Rivers State in relation to their waste disposal points. The objectives were (i) determine the concentrations of Pb, Cd, As, Cr, Co and Zn, and of the macro elements K and Mg, and compare them with soil guideline values adopted in Nigeria; (ii) assess the concentrations of soils between stations near and far from the waste disposal points and across three months of the rainy season; and (iii) identify groups of elements that share likely sources using correlation analysis and PCA.

Materials and Methods

Study area

The study covered four university farms in Rivers State, Nigeria (Figure 1): the RSU Research Farm, Etche 5.0728° N, 7.0133° E; the RSU Farm, Emohua Campus 4.9816° N, 6.7556° E; the IAUE Farm, Ndele Campus 4.9818° N, 6.7554° E; and the UNIPORT Farm, Choba (4.8937° N, 6.9106° E). The Emohua and Ndele farms lie on neighbouring campuses but are managed separately. All four lie in the humid tropical rainforest zone of the Niger Delta, where annual rainfall exceeds 2,000 mm, mean temperatures are 26–30 °C and soils are mostly sandy loam to loam. Each farm has one main waste disposal point, where crop residues, plastics, nylon, fertiliser bags and agrochemical containers are dumped in open heaps.

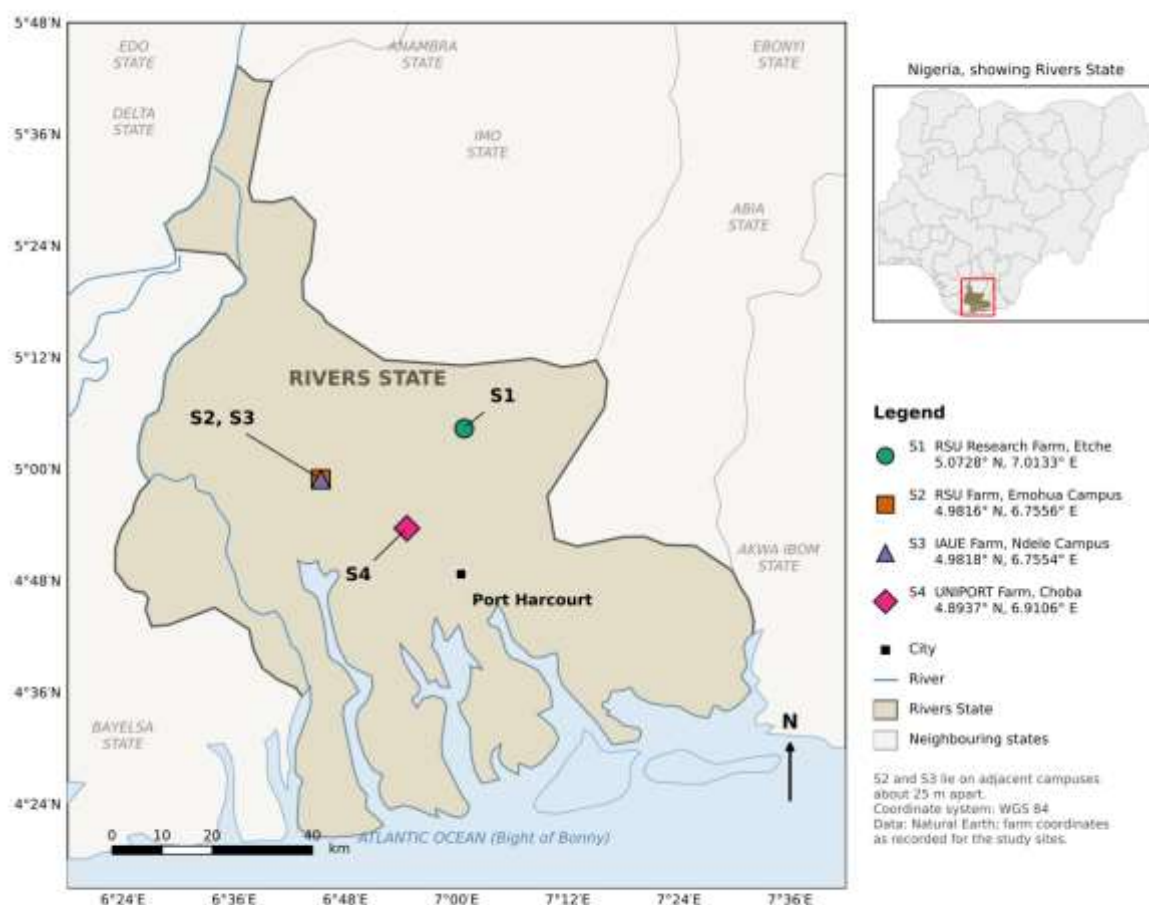


Figure 1. Map of Rivers State, Nigeria, showing the locations of the four university farms studied (S1, RSU Research Farm, Etche; S2, RSU Farm, Emohua Campus; S3, IAUE Farm, Ndele Campus; S4, UNIPORT Farm, Choba. S2 and S3 lie on adjacent campuses about 25 m apart. Boundaries from Natural Earth.

Study design and soil sampling

A cross-sectional design with repeated sampling was used from April to June 2026, the early part of the rainy season. Two fixed stations were set up on each farm. Station 1 ST1 was within 10 m of the main waste disposal point and close to actively farmed beds. Station 2 ST2 was about 150–200 m from ST1 on the same farm, away from the disposal point. Samples were taken in the first and third weeks of each month, giving 48 composite samples (4 farms × 2 stations × 2 rounds × 3 months). At each station, five sub-samples were drawn at random from a 5 m × 5 m quadrat at 0–20 cm depth with a stainless-steel auger. The sub-samples were mixed into a single composite of about 1.5 kg, sealed in a labelled polyethylene bag, kept at 4 °C and delivered to the laboratory within 6 h. Samples were air-dried at 27 ± 1 °C to constant weight, gently crushed, passed through a 2 mm stainless-steel sieve and homogenised by coning and quartering.

Laboratory analysis and quality control

Analyses were carried out at the Research Laboratory, Department of Biology, Faculty of Natural and Applied Sciences, Ignatius Ajuru University of Education, Rumuolumeni, Port Harcourt. One gram of each sample was digested with 10 mL of freshly prepared aqua regia

3:1 HCl: HNO₃, analytical grade) at 95 °C for 2 h. The digest was filtered through Whatman No. 42 paper, made up to 50 mL with deionised water and stored at 4 °C for no more than 7 days. Pb, Cd, Cr, Co, Zn, K and Mg were measured by flame atomic absorption spectrophotometry (Buck Scientific 210 VGP), and As by graphite furnace atomic absorption spectrophotometry. Each composite was read in triplicate against five-point calibration curves prepared daily from certified standards. Every batch of 20 samples included a method blank, a duplicate, a spiked sample and a certified reference material (National Institute of Standards and Technology Standard Reference Material 2710a, Montana II Soil). Recoveries for the reference material were 95–105%, and replicate relative standard deviations were below 5%. Detection limits were set at three times the standard deviation of the blank.

Data analysis

The triplicate readings of each composite were averaged, and the 48 composite values were used in all tests. Concentrations were summarised as mean $\pm$ standard deviation (SD). They were compared with the Dutch target and intervention values (Ministry of Housing, Spatial Planning and the Environment, 2000), adopted in Nigeria's Environmental Guidelines and Standards for the Petroleum Industry (EGASPIN) (Department of Petroleum Resources, 2018), and the number of samples exceeding each target value was counted. No guideline values exist for K and Mg. The effects of farm (four levels), sampling station ST1, ST and month (April, May, June) on each element were tested together in a three-factor main-effects analysis of variance (ANOVA), with the two sampling rounds in each month as replicates ($n = 48$; 41 residual degrees of freedom). Testing the three factors in one model removes the variation due to the other two from the error term. Effect sizes are given as partial eta squared (η^2p). Significant farm and month effects were followed by Tukey's honestly significant difference (HSD) test using the residual mean square of the model. For each element, the number of matched pairs (same farm, month and round) in which ST1 exceeded ST2 was also counted. Normality of residuals was checked with the Shapiro–Wilk test, and the ANOVA was repeated on log-transformed concentrations as a sensitivity check. Relationships among the eight elements were examined with Pearson correlation ($n = 48$) and with PCA of the correlation matrix of standardised concentrations. The suitability of the data for PCA was checked with the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. Loadings with an absolute value of 0.50 or more were treated as strong. Analyses were performed in Python (NumPy and SciPy) and Microsoft Excel 365, with significance set at $p < 0.05$.

Results

Concentrations and comparison with guideline values

Table 1 shows that the mean concentrations of Zn (2.07–3.76 mg/kg), Pb (1.03–1.36 mg/kg), Cr (0.57–0.72 mg/kg), Co (0.50–0.82 mg/kg) and As (0.36–0.46 mg/kg) at the four farms were one to two orders of magnitude below their target values, and no sample exceeded any of these targets. Cd was the exception. Its overall mean of 0.72 mg/kg was close to the 0.8 mg/kg target value, and the Etche mean (0.82 ± 0.58 mg/kg) was marginally above it. Eighteen of the 48 samples (37.5%) exceeded the Cd target; these came from all four farms, and 15 of the 18 were from ST1. The highest Cd value, 2.09 mg/kg, was recorded at Etche ST1 in April. No sample approached any intervention value. K (106.50–116.89 mg/kg) and Mg (29.21–35.51 mg/kg) occurred at far higher concentrations than the heavy metals, as expected for essential plant nutrients.

Table 1: Mean Concentrations of Heavy Metals and Macro Elements in University Farm Soils Compared With Soil Guideline Values (mg/kg)

Element	Emohua	Etche	Ndele	Choba	Overall mean	Target value	Intervention value	Samples > target (of 48)
Zn	2.07 ± 0.54	2.80 ± 1.03	3.76 ± 2.00	2.75 ± 1.38	2.85	140	720	0
Pb	1.15 ± 0.38	1.03 ± 0.37	1.36 ± 0.51	1.36 ± 0.56	1.23	85	530	0
Cd	0.71 ± 0.27	0.82 ± 0.58	0.72 ± 0.32	0.62 ± 0.23	0.72	0.8	12	18
Cr	0.60 ± 0.24	0.57 ± 0.26	0.61 ± 0.16	0.72 ± 0.32	0.63	100	380	0
Co	0.50 ± 0.19	0.72 ± 0.21	0.82 ± 0.43	0.80 ± 0.40	0.71	9	240	0
As	0.46 ± 0.13	0.43 ± 0.23	0.44 ± 0.21	0.36 ± 0.10	0.42	29	55	0
K	106.50 ± 18.53	113.53 ± 9.27	116.89 ± 18.90	114.35 ± 14.32	—	—	—	—
Mg	34.65 ± 8.99	29.21 ± 8.21	32.02 ± 7.23	35.51 ± 6.38	—	—	—	—

Note. Farm values are mean ± SD of 12 composite samples (2 stations × 2 rounds × 3 months), mg/kg dry weight. Target and intervention values are the Dutch values (Ministry of Housing, Spatial Planning and the Environment, 2000) adopted in EGASPIN (Department of Petroleum Resources, 2018); none exist for K and Mg.

After station and month were accounted for, only three elements differed significantly between farms Table 2: Zn F3, 41 = 8.45, $p < 0.001$, $\eta^2p = 0.38$), Co F 3, 41 = 4.04, $p = 0.013$, $\eta^2p = 0.23$ and Mg F 3, 41 = 3.59, $p = 0.022$, $\eta^2p = 0.21$). Tukey's test (Table 5) showed that Zn was higher at Ndele than at Emohua (difference 1.69 mg/kg, $p < 0.001$), Choba (1.01 mg/kg, $p = 0.023$) and Etche (0.96 mg/kg, $p = 0.033$). Co was lower at Emohua than at Ndele (0.32 mg/kg, $p = 0.019$) and Choba (0.31 mg/kg, $p = 0.027$), and Mg was higher at Choba than at Etche (6.30 mg/kg, $p = 0.025$). Pb ($p = 0.090$), K ($p = 0.143$), As ($p = 0.259$), Cr ($p = 0.295$) and Cd ($p = 0.479$) did not differ between farms. Differences between farms were therefore limited and smaller than the differences between stations described next.

Table 2: Three-Factor Analysis of Variance (ANOVA) of Element Concentrations by Farm, Sampling Station and Month

Element	Farm (df = 3, 41)			Station (df = 1, 41)			Month (df = 2, 41)		
	F	p	η^2p	F	P	η^2p	F	p	η^2p
Zn	8.45	< 0.001	0.38	41.23	< 0.001	0.50	17.10	< 0.001	0.45
Pb	2.32	0.090	0.15	18.47	< 0.001	0.31	4.02	0.025	0.16
Cd	0.84	0.479	0.06	17.47	< 0.001	0.30	5.73	0.006	0.22
Cr	1.28	0.295	0.09	12.72	< 0.001	0.24	5.87	0.006	0.22
Co	4.04	0.013	0.23	12.04	0.001	0.23	9.83	< 0.001	0.32
As	1.39	0.259	0.09	39.28	< 0.001	0.49	3.94	0.027	0.16

Element	Farm (df = 3, 41)			Station (df = 1, 41)			Month (df = 2, 41)		
	F	p	η^2p	F	P	η^2p	F	p	η^2p
K	1.91	0.143	0.12	32.76	< 0.001	0.44	6.95	0.003	0.25
Mg	3.59	0.021	0.21	47.28	< 0.001	0.54	4.97	0.012	0.20

Note. Model: element = farm + station + month (additive main effects; n = 48; residual df = 41); each effect is adjusted for the other two. η^2p = partial eta squared. Values in bold are significant at p < 0.05.

Spatial variation between stations in the study area

Every element was significantly more concentrated at ST1, near the waste disposal points, than at ST2 after farm and month were allowed for (Tables 2 and 3; Figure 2). The station effect was the largest of the three factors for seven of the eight elements (all except Co). Mean Zn was 3.61 mg/kg at ST1 against 2.08 mg/kg at ST2, Cd 0.90 against 0.54 mg/kg, Pb 1.46 against 0.99 mg/kg and as 0.53 against 0.31 mg/kg; overall, the six heavy metals were 40–74% higher at ST1. ST1 exceeded ST2 in 20 to 24 of the 24 matched pairs, depending on the element, and in all 24 for K, Zn and As. The station effects stayed significant when the analysis was repeated on log-transformed data.

Table 3: Concentrations of Heavy Metals and Macro Elements at Stations Near (ST1) and Away From (ST2) the Waste Disposal Points

Element	ST1 mean $\pm$ SD (mg/kg)	ST2 mean $\pm$ SD (mg/kg)	ST1 higher by (%)	F(1,41)	P	Pairs with ST1 > ST2 (of 24)
K	122.03 $\pm$ 14.75	103.60 $\pm$ 10.51	18	32.77	< 0.001	24
Zn	3.61 $\pm$ 1.57	2.08 $\pm$ 0.73	74	41.23	< 0.001	24
Mg	38.00 $\pm$ 4.35	27.69 $\pm$ 7.32	37	47.28	< 0.001	22
Pb	1.46 $\pm$ 0.40	0.99 $\pm$ 0.42	47	18.47	< 0.001	22
As	0.53 $\pm$ 0.17	0.31 $\pm$ 0.08	71	39.28	< 0.001	24
Cd	0.90 $\pm$ 0.39	0.54 $\pm$ 0.24	67	17.48	< 0.001	20
Cr	0.73 $\pm$ 0.24	0.52 $\pm$ 0.21	40	12.72	< 0.001	20
Co	0.84 $\pm$ 0.35	0.58 $\pm$ 0.28	45	12.04	0.001	20

Note. n = 24 samples per station. F and p are for the station effect in the three-factor ANOVA (element = farm + station + month), adjusted for farm and month; η^2p = 0.23–0.54. Pairs are matched by farm, month and sampling round.

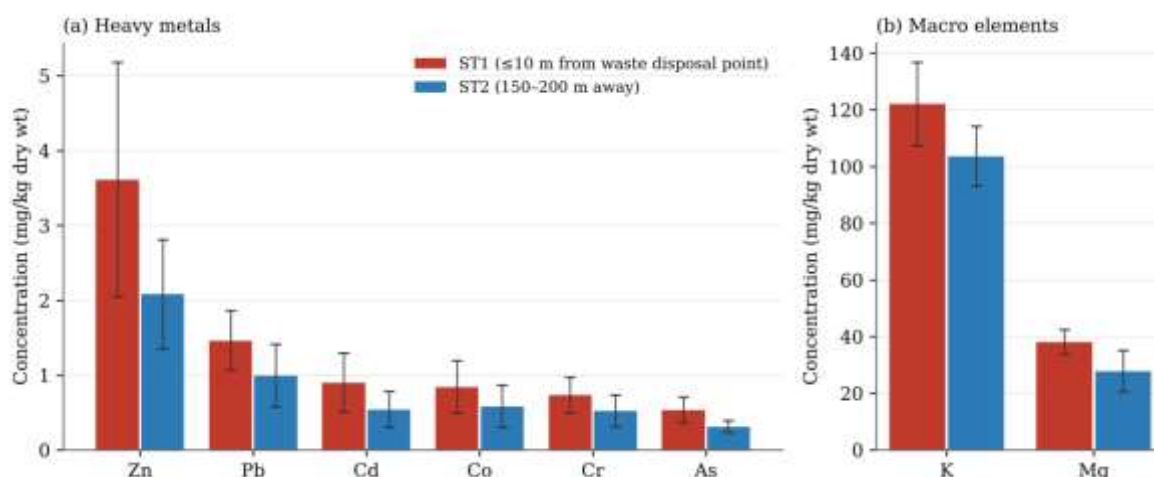


Figure 2. Mean ($\pm$ SD) concentrations of (a) heavy metals and (b) macro elements at stations within 10 m of the waste disposal points (ST1) and 150–200 m away (ST2), across four university farms in Rivers State ($n = 24$ per station).

Spatial variation across months in the study area

Tukey's test identified which months differed (Table 4). Three patterns were seen. For K, Mg, Pb, As, Cd and Cr, the lowest mean occurred in May, and the significant differences lay mainly between April and May: April exceeded May by 13.19 mg/kg for K, 5.75 mg/kg for Mg, 0.33 mg/kg for Pb, 0.11 mg/kg for As, 0.35 mg/kg for Cd and 0.24 mg/kg for Cr ($p = 0.005$ – 0.046). K also rose again from May to June (12.22 mg/kg, $p = 0.010$), and Cr was higher in April than in June (0.19 mg/kg, $p = 0.036$). Zn fell steadily, from 3.76 mg/kg in April to 2.70 mg/kg in May and 2.07 mg/kg in June, a decline of 45%, with April significantly higher than both May ($p = 0.002$) and June ($p < 0.001$). Co followed the opposite course and was highest in June (0.93 mg/kg), significantly above both April (by 0.26 mg/kg, $p = 0.017$) and May (by 0.39 mg/kg, $p < 0.001$). The largest single increases in Co-occurred at ST1 of Choba and Ndele in June. When the analysis was repeated on log-transformed data, the month effects for Mg ($p = 0.069$) and As ($p = 0.073$) were no longer significant, so these two should be read with caution. All other month effects were unchanged.

Table 4: Spatial Variations in Heavy Metal Concentrations (Mean $\pm$ SD, mg/kg) in University Farm Soils across Stations and Months

Month	Location	Station	K	Zn	Mg	Pb	As	Cd	Cr	Co
Month 1	Emohua	ST1	143.43 $\pm$ 0.08	2.45 $\pm$ 0.12	37.48 $\pm$ 0.44	1.41 $\pm$ 0.05	0.49 $\pm$ 0.03	1.06 $\pm$ 0.05	0.88 $\pm$ 0.06	0.72 $\pm$ 0.04
	Emohua	ST2	93.38 $\pm$ 0.17	1.64 $\pm$ 0.12	45.45 $\pm$ 0.08	0.55 $\pm$ 0.03	0.25 $\pm$ 0.02	0.78 $\pm$ 0.02	0.48 $\pm$ 0.04	0.42 $\pm$ 0.03
	Etche	ST1	122.87 $\pm$ 1.53	4.41 $\pm$ 0.09	37.14 $\pm$ 0.05	1.16 $\pm$ 0.04	0.78 $\pm$ 0.03	1.79 $\pm$ 0.04	0.52 $\pm$ 0.03	0.82 $\pm$ 0.06
	Etche	ST2	100.29 $\pm$ 0.08	2.33 $\pm$ 0.03	15.22 $\pm$ 0.09	0.78 $\pm$ 0.02	0.26 $\pm$ 0.04	0.49 $\pm$ 0.04	0.80 $\pm$ 0.11	0.52 $\pm$ 0.07
	Ndele	ST1	141.27 $\pm$ 0.03	7.22 $\pm$ 0.20	39.64 $\pm$ 0.27	0.80 $\pm$ 0.03	0.69 $\pm$ 0.07	0.61 $\pm$ 0.03	0.37 $\pm$ 0.01	0.42 $\pm$ 0.03
	Ndele	ST2	120.04 $\pm$ 0.02	3.93 $\pm$ 0.19	27.33 $\pm$ 0.21	1.83 $\pm$ 0.16	0.39 $\pm$ 0.02	0.27 $\pm$ 0.01	0.38 $\pm$ 0.03	0.46 $\pm$ 0.05
	Choba	ST1	106.19 $\pm$ 0.70	5.17 $\pm$ 0.16	41.25 $\pm$ 0.29	1.82 $\pm$ 0.09	0.35 $\pm$ 0.02	0.86 $\pm$ 0.04	1.17 $\pm$ 0.05	0.37 $\pm$ 0.04
	Choba	ST2	105.07 $\pm$ 0.06	1.34 $\pm$ 0.07	34.19 $\pm$ 0.07	1.39 $\pm$ 0.03	0.20 $\pm$ 0.01	0.38 $\pm$ 0.04	0.64 $\pm$ 0.02	0.78 $\pm$ 0.04
Month 2	Emohua	ST1	106.59 $\pm$ 2.34	2.44 $\pm$ 0.05	27.26 $\pm$ 0.15	1.44 $\pm$ 0.14	0.57 $\pm$ 0.03	0.61 $\pm$ 0.03	0.46 $\pm$ 0.04	0.48 $\pm$ 0.04
	Emohua	ST2	92.10 $\pm$ 0.11	1.79 $\pm$ 0.20	23.81 $\pm$ 0.79	0.74 $\pm$ 0.08	0.34 $\pm$ 0.05	0.43 $\pm$ 0.01	0.35 $\pm$ 0.05	0.33 $\pm$ 0.04
	Etche	ST1	111.32 $\pm$ 0.42	3.40 $\pm$ 0.34	32.62 $\pm$ 1.52	0.93 $\pm$ 0.04	0.27 $\pm$ 0.03	0.50 $\pm$ 0.02	0.60 $\pm$ 0.06	0.75 $\pm$ 0.05
	Etche	ST2	106.48 $\pm$ 2.33	2.01 $\pm$ 0.04	27.54 $\pm$ 0.49	0.42 $\pm$ 0.04	0.25 $\pm$ 0.02	0.31 $\pm$ 0.03	0.37 $\pm$ 0.04	0.44 $\pm$ 0.05
	Ndele	ST1	106.27 $\pm$ 2.74	4.07 $\pm$ 0.14	37.47 $\pm$ 0.87	1.98 $\pm$ 0.24	0.56 $\pm$ 0.04	0.97 $\pm$ 0.05	0.71 $\pm$ 0.04	0.92 $\pm$ 0.12
	Ndele	ST2	84.02 $\pm$ 0.32	2.16 $\pm$ 0.15	24.94 $\pm$ 0.67	0.88 $\pm$ 0.02	0.24 $\pm$ 0.03	0.34 $\pm$ 0.03	0.67 $\pm$ 0.06	0.26 $\pm$ 0.05

Month	Location	Station	K	Zn	Mg	Pb	As	Cd	Cr	Co
	Choba	ST1	121.45 ± 0.05	3.24 ± 0.06	37.50 ± 0.11	0.92 ± 0.14	0.52 ± 0.03	0.42 ± 0.03	0.58 ± 0.03	0.67 ± 0.05
	Choba	ST2	104.42 ± 0.91	2.37 ± 0.07	25.62 ± 0.09	0.64 ± 0.10	0.30 ± 0.09	0.56 ± 0.06	0.43 ± 0.03	0.37 ± 0.06
Month 3	Emohua	ST1	102.69 ± 0.94	2.54 ± 0.12	43.54 ± 0.32	1.38 ± 0.07	0.56 ± 0.07	0.68 ± 0.02	0.80 ± 0.03	0.50 ± 0.01
	Emohua	ST2	97.49 ± 0.60	1.21 ± 0.06	27.95 ± 1.91	1.08 ± 0.02	0.39 ± 0.04	0.47 ± 0.07	0.38 ± 0.02	0.30 ± 0.03
	Etche	ST1	125.35 ± 2.16	2.42 ± 0.10	37.49 ± 0.40	1.50 ± 0.24	0.51 ± 0.02	1.01 ± 0.13	0.52 ± 0.12	0.91 ± 0.04
	Etche	ST2	113.00 ± 2.51	1.78 ± 0.05	23.60 ± 0.73	1.11 ± 0.04	0.34 ± 0.05	0.49 ± 0.02	0.25 ± 0.04	0.59 ± 0.09
	Ndele	ST1	128.30 ± 5.70	2.70 ± 0.25	37.13 ± 2.65	1.30 ± 0.03	0.34 ± 0.03	0.80 ± 0.03	0.82 ± 0.08	1.42 ± 0.09
	Ndele	ST2	118.64 ± 0.50	1.86 ± 0.07	22.60 ± 1.45	1.00 ± 0.02	0.20 ± 0.03	1.12 ± 0.09	0.50 ± 0.09	1.18 ± 0.15
	Choba	ST1	141.83 ± 1.14	2.06 ± 0.12	42.36 ± 2.18	2.05 ± 0.06	0.37 ± 0.04	0.85 ± 0.07	0.81 ± 0.04	1.51 ± 0.15
	Choba	ST2	104.09 ± 2.52	1.80 ± 0.05	29.79 ± 2.85	1.03 ± 0.02	0.29 ± 0.05	0.42 ± 0.05	0.42 ± 0.05	0.86 ± 0.11

Values are mean ± SD of triplicate determinations of the first sampling round (Sample 1) of each month. Results for both sampling rounds are given in Appendix I, and the statistical tests in this section use all 48 samples.

Table 4 shows that heavy metal concentrations varied across the four university farms. Ndele recorded the highest mean concentration of Zn (3.76 ± 2.00 mg/kg) and Emohua the lowest (2.07 ± 0.54 mg/kg). Etche had the highest mean Cd (0.82 ± 0.58 mg/kg) and Choba the lowest (0.62 ± 0.23 mg/kg), while Pb was highest at Ndele and Choba (1.36 mg/kg). The macro elements K and Mg occurred at much higher concentrations than the heavy metals, with K ranging from 106.50 ± 18.53 mg/kg at Emohua to 116.89 ± 18.90 mg/kg at Ndele. Compared with the Dutch target values adopted in EGASPIN (Table 1), the mean concentrations of Zn, Pb, As, Cr and Co were one to two orders of magnitude below their targets, and no individual sample exceeded them. The overall mean Cd concentration (0.72 ± 0.37 mg/kg) was close to its target value of 0.8 mg/kg but not significantly above it, although the farm mean at Etche (0.82 mg/kg) was marginally above it. However, 18 of the 48 samples (37.5%) exceeded 0.8 mg/kg; 15 of these were from ST1 stations, and they occurred at all four farms. The highest value was 2.09 mg/kg, at Etche ST1 in Month 1.

Table 5: Tukey's Honestly Significant Difference (HSD) Test of Differences in Element Concentrations between Farms and Between Months (mg/kg)

Comparison	Zn	Pb	Cd	Cr	Co	As	K	Mg
(a) Farm								
Ndele – Emohua	1.69 (< 0.001)	–	–	–	0.32 (0.019)	–	–	–2.63 (0.606)
Ndele – Etche	0.96 (0.033)	–	–	–	0.10 (0.763)	–	–	2.81 (0.552)
Ndele – Choba	1.01 (0.023)	–	–	–	0.01 (0.999)	–	–	–3.49 (0.366)
Choba – Emohua	–0.68 (0.203)	–	–	–	0.31 (0.027)	–	–	0.86 (0.977)
Choba – Etche	–0.05 (0.999)	–	–	–	0.09 (0.838)	–	–	6.30 (0.025)
Etche – Emohua	–0.73 (0.154)	–	–	–	0.22 (0.169)	–	–	–5.44 (0.065)
(b) Month								
April – May	1.06 (0.002)	0.33 (0.040)	0.35 (0.005)	0.24 (0.006)	0.13 (0.314)	0.11 (0.046)	13.19 (0.005)	5.75 (0.009)
April – June	1.69 (< 0.001)	0.02 (0.986)	0.13 (0.414)	0.19 (0.036)	–0.26 (0.017)	0.10 (0.055)	0.98 (0.967)	2.24 (0.450)
June – May	–0.63 (0.091)	0.31 (0.057)	0.22 (0.108)	0.05 (0.777)	0.39 (< 0.001)	0.00 (0.996)	12.22 (0.010)	3.51 (0.149)

Note. Values are mean differences (first level minus second level, mg/kg) with Tukey HSD p values in parentheses, based on the residual mean square of the three-factor ANOVA (df = 41). Farm means are based on 12 samples and month means on 16 samples. Values in bold are significant at $p < 0.05$. –, Tukey's test not applied because the farm effect was not significant (Table 2).

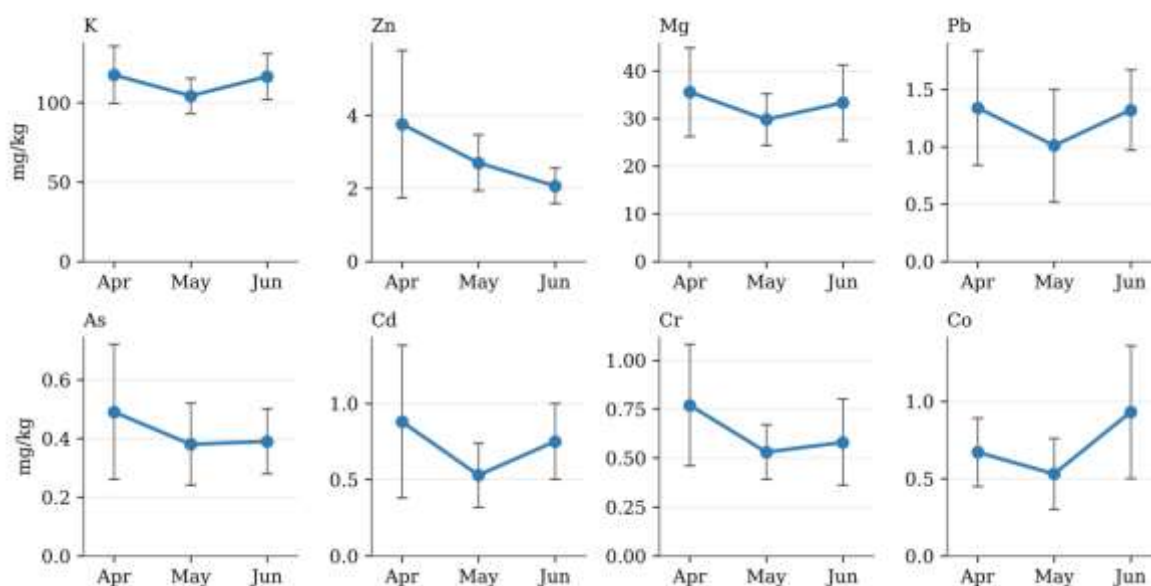


Figure 3. Monthly mean ($\pm$ SD) concentrations of the eight elements in university farm soils from April to June 2026 ($n = 16$ samples per month). The y-axis scale differs between panels.

Inter-element relationships and principal component analysis

Table 5 shows the most pairs of elements were positively correlated, and no pair was significantly negatively correlated. The strongest relationships were As–Zn ($r = 0.67$), Co–K ($r = 0.61$), As–Cd ($r = 0.58$) and Cr–Pb $r = 0.51$, all $p < 0.001$. The full correlation matrix is given in Table 5.

Table 6: Pearson Correlation Matrix of Heavy Metals and Macro Elements in University Farm Soils ($n = 48$)

	K	Zn	Mg	Pb	As	Cd	Cr	Co
K	1							
Zn	0.44**	1						
Mg	0.41**	0.38**	1					
Pb	0.42**	0.28	0.41**	1				
As	0.49**	0.67**	0.44**	0.36*	1			
Cd	0.45**	0.32*	0.42**	0.34*	0.58**	1		
Cr	0.16	0.25	0.39**	0.50**	0.13	0.38**	1	
Co	0.61**	–0.03	0.30*	0.47**	0.07	0.49**	0.31*	1

Note. Values are Pearson correlation coefficients (r) calculated across the 48 composite samples. * $p < 0.05$; ** $p < 0.01$.

The data were suitable for PCA (KMO = 0.64; Bartlett's test, $\chi^2 (28) = 165.1$, $p < 0.001$). The first three components explained 74.7% of the total variance Table 6; Figure 4. PC1 (eigenvalue 3.65; 45.6% of variance) loaded positively and strongly on all eight elements 0.56–0.75, most of all on K, Cd, As, Mg and Pb, and therefore represents their joint enrichment, in line with the positive correlations between most pairs of elements. It separated the two stations clearly: ST1 samples had a mean PC1 score of 1.49 and ST2 samples a mean of –1.49. The highest PC1 scores were at Etche ST1 in April (3.48), Choba ST1 in June (2.74) and Emohua ST1 in April (2.53), and the lowest at Emohua ST2 (–2.68) and Ndele ST2 (–2.62) in May.

PC2 (eigenvalue 1.36; 17.0%) contrasted Co (0.67), Cr (0.33) and Pb (0.28) with Zn (−0.63) and As (−0.57). The correlation matrix (Table 5) supports this split: Zn and As were strongly correlated with each other ($r = 0.67$, $p < 0.01$) but not with Co ($r = -0.03$ and 0.07), whereas Co was correlated with K ($r = 0.61$), Cd ($r = 0.49$), Pb ($r = 0.47$) and Cr ($r = 0.31$), and Pb with Cr ($r = 0.51$). PC2 picked out two distinct sample groups. Ndele ST1 in April had the most negative PC2 score (−3.47), reflecting its high Zn and As, while Choba ST1 in June had the highest score (2.48), reflecting its high Co. PC3 (eigenvalue 0.97, just below the Kaiser criterion of 1; 12.1%) was dominated by Cr (0.66), set against K (−0.50) and Co (−0.37), and was highest at Choba ST1 in April. This agrees with the weak, non-significant correlations of Cr with K ($r = 0.16$), As ($r = 0.13$) and Zn ($r = 0.25$) in Table 5, which show that Cr varied partly independently of the other elements.

Table 6: Principal Component Loadings of Element Concentrations in University Farm Soils (n = 48)

Element	PC1	PC2	PC3
K	0.751	0.038	−0.496
Cd	0.747	0.033	−0.129
As	0.715	−0.570	−0.106
Mg	0.701	−0.044	0.209
Pb	0.696	0.284	0.250
Zn	0.615	−0.633	0.118
Co	0.591	0.665	−0.368
Cr	0.555	0.332	0.663
Eigenvalue	3.65	1.36	0.97
Variance explained (%)	45.6	17.0	12.1
Cumulative (%)	45.6	62.6	74.7

Note. Loadings are correlations between each element and the component, from the correlation matrix of standardised concentrations. Bold values: $|\text{loading}| \geq 0.50$. KMO = 0.64; Bartlett's test $\chi^2(28) = 165.1$, $p < 0.001$.

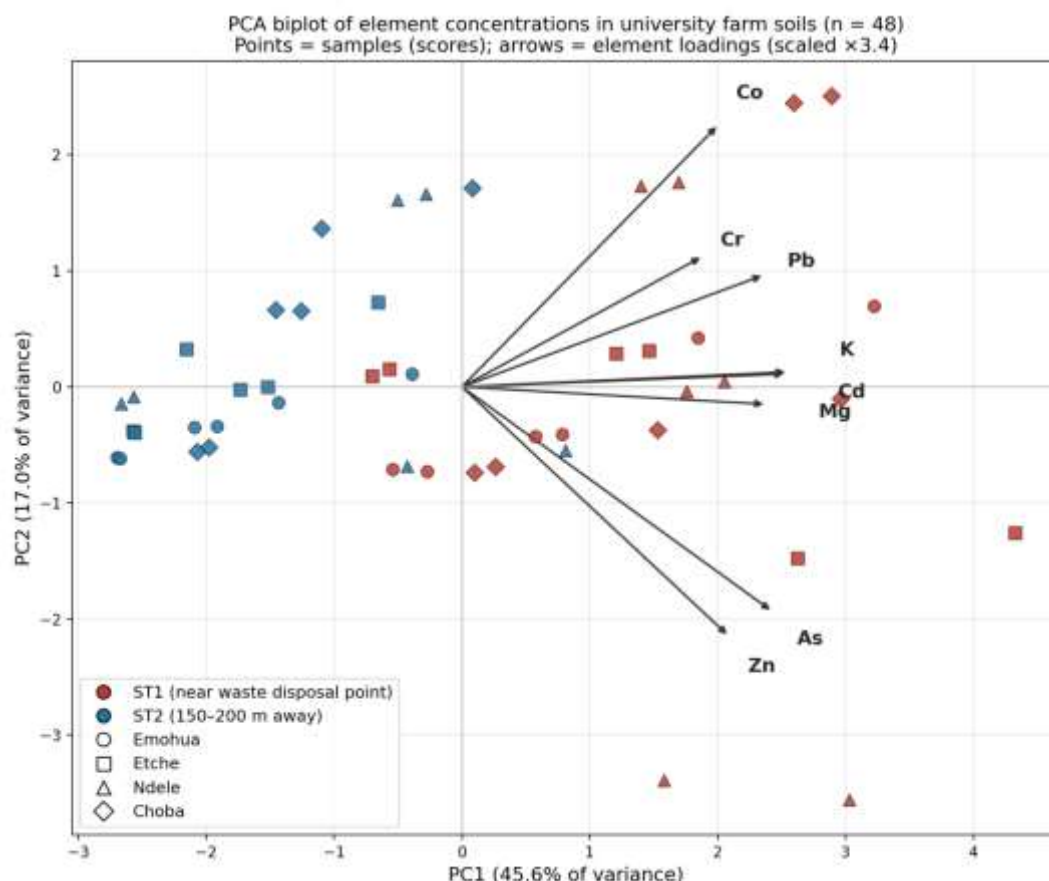


Figure 4. PCA biplot of element concentrations in university farm soils (n = 48). Points are sample scores, coloured by station (red, ST1 near the waste disposal point; blue, ST2) and shaped by farm; arrows are element loadings (scaled $\times 3.4$).

Discussion

Metal levels in context

By Nigerian and international standards, metal levels on the four farms were low. They were far below those of mining areas in south-eastern Nigeria, where Obiora et al. (2016) found Zn above 200 mg/kg in about 31% of arable soils around the Enyigba Pb–Zn mines and Chukwu and Oji (2018) reported mean Zn of 210 mg/kg and Cd of 8.57 mg/kg around an abandoned mine at Mkpuma Ekwoku. The parameters were also below farmland in Girei, Adamawa State (Zn 15.0–30.1 mg/kg; Cd 3.38–7.58 mg/kg) (Hope et al., 2025), and were closest to farmland around the Ashangwa rice mill in Nasarawa State (Zn 0.10–0.81 mg/kg; Cd 0.014–0.565 mg/kg) (Augustine et al., 2025). Farmland near industry in Anxin County, China, held far more Zn (171.7 mg/kg) but a similar level of Cd (0.73 mg/kg) (Zhao et al., 2022).

The most direct comparison is with Iyama et al. (2022), sampled farms of the same three institutions. The Cd means of the present study (0.62–0.82 mg/kg) fall within same range of 0.46–1.42 mg/kg, which supports the view that Cd is the metal of most concern on these farms. The present Pb means 1.03–1.36 mg/kg, however, were about three to seven times lower than result obtained from that study ranging between 4.35–6.80 mg/kg, and the Cr means about eight to fifteen times lower. The earlier study sampled farms inside Port Harcourt metropolis, where traffic and urban runoff add Pb and Cr, and used X-ray fluorescence, which measures total content, including the silicate-bound fraction that aqua regia does not dissolve.

Waste disposal points as hotspots of metal enrichment

The clearest finding of the study is that soil within 10 m of each farm's waste disposal point was richer in every element measured than soil 150–200 m away, a pattern seen across all four farms. The station effect was larger than the farm effect for almost every element, so where soil sits in relation to the disposal point mattered more than which farm it belonged to. This agrees with studies of soils beside municipal dumpsites in Nigeria (Ekere et al., 2020; Ihedioha et al., 2017; Omada et al., 2024) and with the near–far contrast reported by Jolly et al. (2025) in Bangladesh, where cropland next to a disposal site carried several times more Pb, Cd and Zn. The contrast on the university farms was smaller (40–74% for the heavy metals), which fits the smaller size and largely organic make-up of farm waste heaps compared with municipal dumps. The enrichment of K and Mg together with the heavy metals is informative. These nutrients are released as crop residues and other organic waste decompose. Their rise at ST1 alongside Zn, Cd, Pb and As suggests that the disposal points act as a combined source, delivering both nutrients and metals to nearby soil, rather than one particular item in the heap being responsible. Cadmium near the disposal points deserves particular attention. Although the overall Cd mean stayed just below the target value, 15 of the 18 exceedances came from ST1, and the highest value 2.09 mg/kg. Etche ST1 was more than two and a half times the target. The Dutch target assumes a standard soil with 25% clay and 10% organic matter (Ministry of Housing, Spatial Planning and the Environment, 2000), so the corrected target for the sandy loam soils of the study area would be lower than 0.8 mg/kg, and the exceedances are, if anything, understated. Because ST1 lies beside cultivated beds, crops grown nearest the disposal points are the ones most likely to take up Cd.

Short-term spatial variation

Significant changes over only three months show that soil metal levels on these farms are not static during the rainy season. For most elements, levels dropped from April to May and partly recovered in June. The sampling window covers the onset of the rains, and one plausible explanation is that early heavy rainfall leached or washed metals from the topsoil, after which new waste and farm inputs began to restore them. Zn, which fell steadily across all three months, may be more mobile under these conditions, while the rise in Co in June was concentrated at the ST1 stations of Choba and Ndele and may reflect a fresh input at those disposal points. These explanations remain tentative, because rainfall, soil pH and organic matter were not measured, and the month effects for Mg and As were not robust to log transformation. The practical point is clear. The mean Zn concentration in April was 1.8 times that in June, and Cd was 1.7 times higher in April than in May. A single round of sampling therefore over- or under-estimate soil metal levels considerably, depending on when it is done. Monitoring programmes and health risk assessments on these farms should use repeated sampling over time rather than one-off measurements.

Likely sources of the elements

The positive correlations among most elements and the strong loading of all eight on PC1 point to a shared source, and the clear separation of ST1 from ST2 samples along PC1 identifies the waste disposal points as that source. Similar positive inter-element correlations were attributed to common sources by Chukwu and Oji (2018) and Nuralkyzy et al. (2021).

PC2 adds a second layer. It contrasted a Zn–As group with a Co–Cr–Pb group, and each was driven by particular samples: Zn and As peaked at Ndele ST1 in April, and Co at Choba ST1 in June. The strong As–Zn correlation $r = 0.67$ is consistent with agrochemical inputs, since some fertilizers and pesticides contain both elements (Wan et al., 2024), whereas the Co–Cr–Pb group may reflect discarded containers, metal scraps or other non-organic items in the heaps. PCA alone cannot confirm these sources. Analysis of the waste heaps themselves, or

source-specific methods such as positive matrix factorization or isotope tracing, would be needed.

Conclusion

Heavy metal levels in the soils of four university farms in Rivers State were low and, except for Cd, well below Nigerian target values. Waste disposal points are nevertheless clear local hotspots: all eight elements measured were significantly more concentrated within 10 m of the disposal points than 150–200 m away, and PCA confirmed that the elements are enriched together at these points. Cd exceeded its target value in 37.5% of samples, mostly near the disposal points. Concentrations also changed significantly from month to month within a single rainy season.

Recommendations

1. Farm managements should segregate waste at source, compost the organic fraction and remove plastics, fertilizer bags and agrochemical containers from the farm.
2. Waste disposal points should be relocated away from cultivated beds, and crops should not be grown in the immediate vicinity of existing heaps.
3. Soil Cd should be monitored routinely, with more frequent sampling near disposal points, and phosphate fertilizers should be used with caution.
4. Monitoring and risk assessments should rely on repeated sampling across both wet and dry seasons rather than a single round.

Further studies should sample along transects at increasing distances from the disposal points, include an uncontaminated reference site, record rainfall, measure soil physicochemical properties and metal uptake by crops, and characterize the waste heaps directly to confirm the sources suggested here.

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