



Heavy-Metal Contamination and Depth-Wise Distribution in Industrial and Auto-Mechanic Workshop Soils in Anwai, Delta State, Nigeria

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ABSTRACT

One of the most significant, unregulated sources of soil heavy metal pollution in developing areas is from the disposal of industrial and automotive workshop waste. Moreover, there is limited baseline information for many hotspots in Nigeria. This study evaluated the levels of copper, chromium, cadmium, lead and zinc, along with pH and electrical conductivity, in soils of three industrial / auto-mechanic workshop sites (A, B, C) and one control site (D) in Anwai, Delta State, Nigeria. It employed three independent composites per site and depth (0-30, 30-60cm). Soil pH values ranged from 6.67–8.24. The levels of the five metals were significantly elevated at industrial sites as compared to control ($p < 0.001$). Two-way ANOVA showed significant side effects for all metals and higher subsoil than topsoil concentrations of copper, chromium, cadmium and lead, whereas zinc showed no overall depth effect. Contamination factors relative to the control ranked cadmium (6.9–10.2, very high) above zinc and copper (about 5, considerable), lead (3.4–4.0) and chromium (2.4–3.1). At all the industrial sites, cadmium, lead and copper exceeded the Nigerian DPR (EGASPIN) soil target values, while chromium and zinc did not exceed the intervention values. The higher subsoil concentrations indicate possible vertical redistribution, which requires confirmation with groundwater and geochemical data. These results suggested site-specific, metal-specific contamination from industrial sources, notably, from cadmium. Therefore, regular soil and groundwater monitoring, analytical validation with certified reference materials, and more rigorous waste-disposal regulation are required in the Anwai area of Asaba.

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INTRODUCTION

Open dumping is still the most prevalent form of solid waste disposal in many parts of Nigeria and developing nations. Open burning of waste is often common, leading to poor air quality, and dumpsites are unhygienic, breed disease vectors, and create leachate that carries toxic compounds with surface and subsurface runoff into surrounding soils and water (Kiogora *et al.*, 2023). In addition to these local nuisance effects, indiscriminate disposal of waste causes significant soil, water and food pollution with associated environmental and public health risks. This is particularly problematic in areas of fast industrialization, where there is limited regulatory oversight. Waste from industrial operations is a major source of hazardous waste such as used oil and spent batteries, metal scrap and chemical wastes that are dumped uncontrolled around water bodies and farmland (Ossai, 2014; Briffa *et al.*, 2020). Since heavy metals are not biodegradable, they linger in the environment after release, entering biota through atmospheric deposition, water transport, soil leaching and bioaccumulation in the food chain (Luo *et al.*, 2019).

After entering the biological systems, metals can bioaccumulate and bio magnify to levels that can cause significant health effects (Isukuru *et al.*, 2024; Uche *et al.*, 2026; Onwuka *et al.*, 2026b). While some metals such as cobalt, copper, iron, manganese, and zinc are essential

micronutrients for normal physiology, excess exposure to both essential and non-essential metals is detrimental (Ahmed *et al.*, 2024; Yadav *et al.*, 2024). Cadmium is known to cause toxic effects on the kidneys and skeleton at low exposure, while chromium is a known human carcinogen with a potential for long term tissue accumulation (Abdullahi *et al.*, 2021; Mitra *et al.*, 2022; Uche *et al.*, 2026). Multiple exposure to various metals contributes to the complexity of health outcomes by their synergistic and antagonistic relationships, which have not been sufficiently characterized in most exposed populations.

The two sources of metal contamination to soil are natural geochemical processes and anthropogenic activities (Briffa *et al.*, 2020). Traffic and industrial atmospheric releases are known sources of trace-metal pollution of particulate matter, both in rural and urban areas (Luo *et al.*, 2019). Multiple metals often are released from a single source, like industrial facilities, waste disposal sites, recycling operations, and vehicle maintenance workshops, resulting in contamination hot spots where nearby residents are at a higher risk. In certain areas of the Niger Delta and adjacent states, elevated metal loads have been observed in soil samples collected from automobile scrap and workshop sites, such as the soil samples from Agbor, Delta State, which had significantly higher metal loads than background (Ossai, 2014). Additionally, the

assessment of heavy metal contamination in soils around auto-mechanic workshops in Ozoro, Delta state by Emolade *et al.* (2025) reported detectable concentrations of heavy metals including Cu, Cd and Zn. Furthermore, soils collected from the mining impacted arable lands of north-central Nigeria had similar anthropogenic enrichment patterns determined by contamination indices (Onwuka *et al.*, 2024; Onwuka *et al.*, 2026a). These outcomes were largely attributed to anthropogenic activities associated with automobile repair and improper handling of workshop wastes. High levels of metal pollution have also been reported in waste-dumpsite soils in Gusau, north-west Nigeria (Ameh *et al.*, 2023), in automobile-workshop soils in Lokoja, Kogi State (Ojiego *et al.*, 2025) and in soils contaminated by palm-oil wastes in Abraka, Delta State (Udo *et al.*, 2025), reflecting the common occurrence of waste-related metal loading in Nigerian soils associated with waste activities.

Industrial and mechanic-workshop dumpsites are of particular concern in Anwai, Delta State. Wastes are carelessly dumped on open lands and around water channels and visible markers (dark, oily soil surfaces and strong chemical odours) indicate significant contamination. Farmland and residential areas are situated close to these dumps, creating undocumented, unmonitored exposure pathways for residents and farmers. Although similar sites were reported elsewhere in Delta State as being highly

contaminated (Ossai, 2014, Chokor, 2016, Emolade *et al.*, 2025), the detailed study of the extent of heavy metal accumulation in Anwai soils or the potential risk posed by the contamination is still limited.

Considering the foregoing, this study aims to determine the concentrations and depth-wise distributions of Cu, Cr, Cd, Pb and Zn in soils around industrial and auto-mechanic workshops in Anwai, Delta State, and evaluate their contamination relative to local background conditions.

MATERIALS AND METHODS

Study Area and Site Selection

This study was conducted in Anwai, Delta State, Nigeria, a locality around the River Niger within the equatorial climatic zone, characterized by distinct wet (April–October) and dry (November–March) seasons. The study area covers approximately 268 km² of low-lying terrain (22–38 m above sea level) with ferrallitic, sandy-loam soils and mixed Niger Delta vegetation. Four sampling sites were selected based on documented industrial activity: three industrial / auto-mechanic locations (A, B and C) and one reference (control) site (D), which is relatively free of industrial operations, heavy traffic and automobile workshops. The description of each site and their geographic coordinates (decimal degrees, WGS84 datum) are given in Table 1.

Table 1: Description and Geographic Coordinates of the Sampling Sites in Anwai, Delta State

Site	Description	Latitude (°N)	Longitude (°E)
A	Mechanic Village / Mami Market: automobile spare-parts sales and workshop activities	6.214000	6.703000
B	Old Anwai Road mechanic area: automobile-mechanic workshops, fuel-related and other workshop wastes	6.245858	6.691038
C	Metal-scrap trading site: scrap from automobiles and electronic equipment	6.237375	6.705935
D (Control)	DOU Anwai campus (reference site): relatively free of industrial operations, heavy traffic and automobile workshops	6.254400	6.703000

Coordinates are in decimal degrees (WGS84 datum).

The locations of each of the above sites are illustrated in a schematic map (Figure 1). The industrial sites were 1.6–4.5 km from the control site (A–D, 4.49 km; B–D, 1.63 km; C–

D, 1.92 km) and 1.9–3.8 km from one another (A–B, 3.78 km; A–C, 2.62 km; B–C, 1.90 km); distances are straight-line estimates calculated from the coordinates.

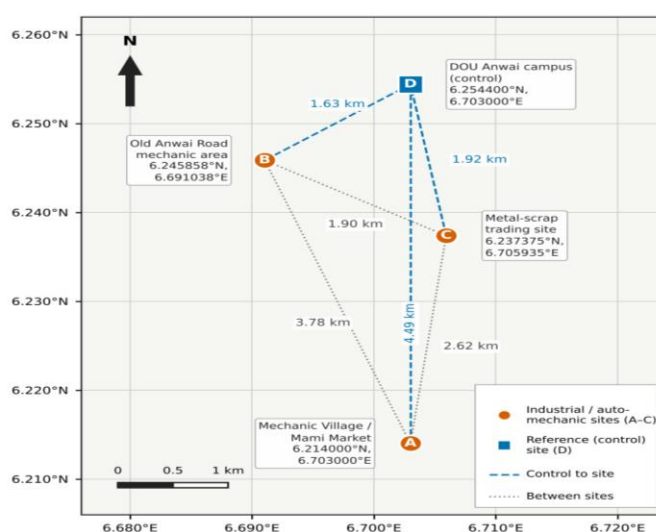


Figure 1: Schematic map of the sampling sites in Anwai, Asaba, Delta State, Nigeria, drawn from the site coordinates (decimal degrees, WGS84), showing the three industrial / auto-mechanic sites (A–C) and the reference (control) site (D). Straight-line distances between sites are given in km

Sample Collection and Preservation

Three separate composite soil samples were taken at each of the four sites at each of two depths (0–30 and 30–60 cm) with a stainless-steel auger to avoid cross contamination. The soil was sampled at three different locations within a site and depth band, resulting in three independent site–depth composites for each site–depth combination ($n = 3$) allowing for the capture of within-site spatial variability. Composites were numbered 1–6 within each site (A1–A6, B1–B6, C1–C6 and D1–D6), odd numbers denoting topsoil (0–30 cm) and even numbers subsoil (30–60 cm). The same predefined sampling points, sampling procedure and depth intervals were used at every site. Four sample sites, two depths, and three field replicates were used to get a total of 24 composite samples. A plot of size 20 m $\times$ 20 m was set up at each sampling location. Five soil cores were collected from each plot at each depth using a soil auger, from four approximately equidistant points within the plot and one central point, and combined to form one composite sample per sampling location and depth, so that each composite represents an independent field replicate. Composites were placed in clean labelled polyethylene bags and transported to the laboratory, where they were air-dried at room temperature, gently disaggregated and passed through a 2-mm sieve to remove coarse materials and debris before acid digestion.

Sample Preparation and Acid Digestion

Acid digestion mixture is made up from perchloric acid (HClO_4), nitric acid (HNO_3) and sulfuric acid (H_2SO_4) in the ratio of 1:2:2 by volume. Two grams (2g) of the dried, sieved soil was placed in the mixture and 20 mL of distilled water to the soil sample, and then the soil was heated to 100–120°C, for 30 minutes, cooled, diluted with 10 mL of distilled water. It was further heated for another 15 minutes, and filtered with Whatman No. 42. Thereafter, it was transferred to a 50 mL volumetric flask and made up to volume with distilled water. The solution obtained was collected in labelled plastic bottles (100 mL) and stored at room temperature for instrumental analysis.

Instrument Calibration

The calibration standards for copper, cadmium, chromium, lead and zinc were prepared from 1000 mg/L stock standards, and five working standards were used to create external linear calibration curves ($R^2 > 0.99$) using the instrument software, and reagent blanks were used for background correction.

Heavy Metal Analysis

The concentrations of the selected heavy metals in the digested soil samples were determined using a Flame Atomic Absorption Spectrophotometer (FAAS; Buck Scientific Model 210 VGP, USA) with element-specific hollow cathode lamps under manufacturer-recommended conditions. Analytical precision was obtained by triplicate analysis of samples, and instrumental parameters (lamp current, slit width, flame composition) were optimized for each metal, to maximize sensitivity and minimize spectral interference. Measurements used an air–acetylene flame at the following wavelengths: Cu 324.8 nm, Cr 357.9 nm, Cd 228.8 nm, Pb 217.0 nm and Zn 213.9 nm.

Quality Control

All glasswares were rinsed with deionized water and air-dried before use. Analytical-grade (Analar) reagents were used throughout. The reagent blanks and equipment blanks were collected for each analytical batch to ensure that there was no contamination by the reagents or equipment. Precision across

the three independent field composites, expressed as the coefficient of variation (CV) of each site–depth cell, was 0.7–2.5% for Cu, 1.4–3.8% for Cr, 1.0–5.6% for Cd, 0.5–2.5% for Zn and 1.3–13.5% for Pb. Cadmium in the control soil (0.69–0.82 mg/kg) corresponds to only about 0.03 mg/L in the 50 mL digest indicated below, which were close to the lower working frame of the flame AAS. Thus, the Cd contamination factors, which used these values as denominators, are less than those of other metals.

Soil Physicochemical Analysis

Soil pH

Two grams (2 g) of soil were placed in 20 mL of distilled water, then left to stand for 30 minutes and pH measured using a calibrated digital pH meter (accuracy of ± 0.01 units).

Electrical Conductivity

A 1:1 soil: water slurry was equilibrated for 30 minutes and then filtered using a Whatman No. 1 filter paper followed by measurement with a calibrated conductivity meter. Results were expressed in $\mu\text{S}/\text{cm}$.

Data Handling and Statistical Analysis

The sampling design consisted three separate composite samples per site–depth combination, and each composite sample was digested and separately analyzed in triplicate using flame atomic absorption spectrophotometry. Three instrumental readings were made per composite and the composite-level means were used as a unit of replication ($n = 3$ per site–depth cell) for all inferential statistics. To test for differences among the three industrial sites (A, B and C) at each depth for each metal, Welch's one-way ANOVA (robust to unequal variances) was used, and the classical one-way ANOVA was computed for comparison; to compare (i) pooled concentrations of the three industrial sites with the pooled concentrations of the control site (D) and (ii) pooled topsoil with pooled subsoil concentrations for each metal, Welch's independent-samples t-tests were used, with two-sided Mann–Whitney U tests as non-parametric checks. Data were analyzed in Python (version 3.12.3), with descriptive statistics performed with NumPy (version 2.4.4) and ANOVA and t-tests conducted using SciPy (version 1.17.1) with p -values < 0.05 considered statistically significant. To distinguish the effects of site, depth and their interaction, a two-way fixed-effects analysis of variance (two-way ANOVA; factors: site, depth and the site $\times$ depth interaction) was fitted separately for each metal to the 24 composite means (four sites $\times$ two depths $\times$ three composites; error degrees of freedom = 16). A significant interaction was interpreted as evidence that the depth effect differs among sites. Homogeneity of variance across the eight site–depth cells was tested with Levene's test in its Brown–Forsythe form (median-centred Levene). Additionally, normality of the two-way ANOVA residuals was tested with the Shapiro–Wilk test. These additional analyses (Welch's ANOVA, two-way ANOVA, Levene and Shapiro–Wilk tests) were run in Python 3.13.16 with NumPy 2.5.3 and SciPy 1.18.1; the two-way ANOVA and Welch's ANOVA were implemented from their standard formulae.

A contamination factor (CF) was determined and interpreted for all metals at all industrial sites and depths, independently of statistical testing, based on Håkanson (1980), as also applied to Nigerian dumpsite soils (Ameh *et al.*, 2023) as follows:

$$\text{CF} = \frac{\text{SM}}{\text{CM}}$$
 Where, SM = Mean value at a site, CM = Mean value of the control at an equivalent depth

It is worthy to state that, “contamination factor (CF)” refers only to the ratio of the site mean to the control mean at the same depth; and “enrichment” is used descriptively for $CF > 1$, and no enrichment factor normalized to a reference element was calculated.

The CF was interpreted using the standard bands: $CF < 1$, low; $1 \leq CF < 3$, moderate; $3 \leq CF < 6$, considerable; $CF \geq 6$, very high. Measured concentrations were also compared with the soil target and intervention values of the Nigerian Department of Petroleum Resources (DPR) given in EGASPIN (DPR, 2002): Cd 0.8/12, Cr 100/380, Cu 36/190, Pb 85/530 and Zn 140/720 mg/kg (Table 5). These values are derived from the Dutch soil remediation criteria (VROM, 2000) and are widely applied as the regulatory benchmark for soils in Nigeria. Target values denote sustainable soil quality, whereas intervention values denote serious impairment of soil functions. They are not specific to the soil type, land use or exposure scenario at Anwai and the Dutch standard-soil correction for clay and organic-matter content was not applied as these properties were not measured. Thus, exceedance indicates a need for follow-up and not a quantified risk. The ranges provided by Alloway (2013) and Kabata-Pendias (2011) were only used as additional background

RESULTS AND DISCUSSION

Physicochemical Properties

The mean values of the eight site–depth cells ($n = 3$ independent composites each) were slightly acidic to moderately alkaline (6.67–8.24). The pH of the control site (D) was near neutral to slightly alkaline (7.40–7.76) compared to a broader range at the industrial sites (6.67–8.24), with Site B having the most alkaline conditions at both depths and Site C the most acidic subsoil. Electrical conductivity (EC) was, on average, highest at the control site (342.89–522.11 $\mu\text{S}/\text{cm}$), exceeding the industrial sites at every depth.

Heavy Metal Concentrations

Table 2 summarizes the pH, EC, and concentrations (mean $\pm$ SD across three independently collected composite samples per site–depth cell) of Cu, Cr, Cd, Pb, and Zn. All five metals were markedly and significantly higher at the three industrial sites than at the control, pooled across depths (Welch’s t -test on composite means, $p < 0.001$ for every metal; industrial means 59.26, 65.73, 6.51, 104.67, and 82.54 mg/kg for Cu, Cr, Cd, Pb, and Zn respectively, against control means of 11.70, 24.60, 0.76, 28.48, and 15.96 mg/kg).

Welch’s one-way ANOVA across the three industrial sites ($n = 3$ composites per site) yielded a more complex result. In topsoil, concentrations differed significantly among Sites A, B and C for Cd ($p < 0.001$), Zn ($p = 0.004$) and Cu ($p = 0.007$), differed only marginally for Pb (Welch $p = 0.066$; classical ANOVA $p = 0.013$) and did not differ for Cr ($p = 0.32$). The pattern was partly reversed in subsoil, where Cu ($p = 0.008$), Cr ($p = 0.004$) and Cd ($p = 0.002$) differed significantly among sites but Pb ($p = 0.97$) and Zn ($p = 0.32$) did not. The Pb difference among sites in topsoil that was significant under the classical ANOVA was therefore not robust to the unequal variances.

Copper level was highest at Site A subsoil (64.97 ± 0.90 mg/kg) and lowest at the control topsoil (11.17 ± 0.28 mg/kg). The soil sample with the highest concentration of chromium was from Site B, subsoil (76.13 ± 1.93 mg/kg). The metal with the highest relative enrichment was cadmium with concentrations of 4.75–8.35 mg/kg at the industrial sites, compared to 0.69–0.82 mg/kg at the control. However, the within-site spatial variability (SD across the three independent composites) was generally low (typically $< 6\%$ of the mean) but higher for the contaminant Pb, with Site B subsoil (114.35 ± 15.41 mg/kg; approximately 13%) and Site C subsoil (111.78 ± 10.21 mg/kg; about 9%) exhibiting localized hotspots of lead contamination that a single composite sample would not have detected.

Table 2: Physicochemical Properties and Heavy Metal Concentrations in Soil Samples from Anwai, Delta State.

Sample	Depth (cm)	pH	EC ($\mu\text{S}/\text{cm}$)	Cu (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
A	0–30	7.16 $\pm$ 0.11	303.33 $\pm$ 52.00	60.98 $\pm$ 1.29	62.62 $\pm$ 2.11	5.68 $\pm$ 0.32	100.92 $\pm$ 2.55	86.47 $\pm$ 1.15
A	30–60	7.95 $\pm$ 0.09	231.44 $\pm$ 52.01	64.97 $\pm$ 0.90	70.30 $\pm$ 1.10	8.35 $\pm$ 0.27	111.69 $\pm$ 2.13	82.83 $\pm$ 1.60
B	0–30	8.15 $\pm$ 0.07	245.22 $\pm$ 8.04	54.45 $\pm$ 0.87	59.56 $\pm$ 2.26	4.75 $\pm$ 0.17	95.21 $\pm$ 1.28	81.19 $\pm$ 0.59
B	30–60	8.24 $\pm$ 0.04	127.28 $\pm$ 13.74	60.73 $\pm$ 0.42	76.13 $\pm$ 1.93	6.37 $\pm$ 0.13	114.35 $\pm$ 15.41	83.36 $\pm$ 0.93
C	0–30	7.10 $\pm$ 0.06	299.44 $\pm$ 11.67	56.58 $\pm$ 0.75	60.14 $\pm$ 1.62	6.74 $\pm$ 0.14	94.09 $\pm$ 2.11	79.83 $\pm$ 0.38
C	30–60	6.67 $\pm$ 0.09	123.66 $\pm$ 4.00	57.89 $\pm$ 1.44	65.63 $\pm$ 0.94	7.17 $\pm$ 0.07	111.78 $\pm$ 10.21	81.56 $\pm$ 1.34
D	0–30	7.76 $\pm$ 0.06	522.11 $\pm$ 105.00	11.17 $\pm$ 0.28	24.38 $\pm$ 0.59	0.69 $\pm$ 0.03	28.11 $\pm$ 0.44	15.82 $\pm$ 0.26
(Control)								
D	30–60	7.40 $\pm$ 0.04	342.89 $\pm$ 9.89	12.22 $\pm$ 0.15	24.81 $\pm$ 0.57	0.82 $\pm$ 0.02	28.84 $\pm$ 0.66	16.10 $\pm$ 0.40
(Control)								

Values are mean $\pm$ standard deviation across three independently collected composite samples per site–depth combination ($n = 3$), each analyzed in triplicate. EC = electrical conductivity.

A consistent depth pattern emerged for four of the five metals: Cu, Cr, Cd, and Pb were significantly higher in subsoil (30–60 cm) than in topsoil (0–30 cm) when pooled across the three industrial sites (Welch’s t -test on composite means, $n = 9$ per depth: Cu, $p = 0.018$; Cr, $p < 0.001$; Cd, $p = 0.002$; Pb, $p < 0.001$). This direction was held at every individual industrial site without exception. At the level of individual sites ($n = 3$

versus 3), the increase with depth was significant (Welch $p < 0.05$) at all three sites for Cr and Cd, at Sites A and B for Cu, and at Site A only for Pb (Site B, $p = 0.16$; Site C, $p = 0.090$). Consequently, the site-level Cu and Pb differences should be regarded as directional, not conclusive. Figure 2 illustrates this pattern across all five metals, sites, and depths.

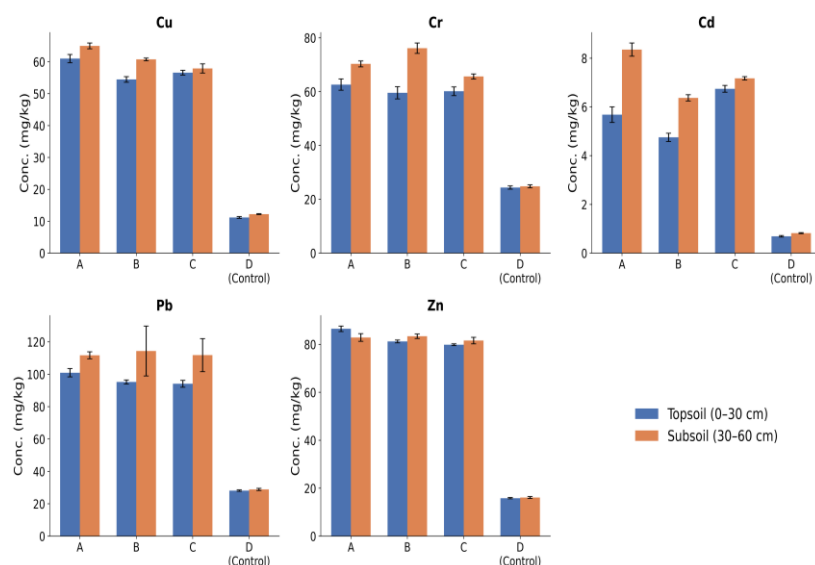


Figure 2: Heavy metal concentrations (mean $\pm$ SD across three independent field composites) at each site and depth

The consistently elevated subsoil (orange) bars relative to topsoil (blue) bars for Cu, Cr, Cd, and Pb at Sites A–C, the near-identical bar heights for Zn, and the visibly wider error bars for Pb at Sites B and C subsoil, reflecting genuine within-site spatial heterogeneity.

A two-way ANOVA (site $\times$ depth; 4 sites $\times$ 2 depths; $n = 3$ composites per cell; error $df = 16$) separated the effects of site, depth and their interaction (Table 3). Site had a significant effect on all five metals ($p < 0.001$), and this was driven predominantly by the differences between the industrial sites and the control. Depth had a significant effect on Cu, Cr, Cd and Pb ($p < 0.001$) but not on Zn ($p = 0.738$). The site $\times$ depth interaction was significant for Cu, Cr, Cd and Zn ($p < 0.001$), indicating that the size, and for Zn the direction, of the topsoil–subsoil difference varied among sites, whereas Pb showed no significant interaction ($p = 0.110$). Furthermore, the overall depth effect was not observed for Zn because of

the significant Zn interaction, which indicates that there were some differences between the depths at specific sites.

The Brown–Forsythe (median-centred Levene) test did not reject homogeneity of variance across the eight site–depth cells for any metal (Cu, $p = 0.72$; Cr, $p = 0.83$; Cd, $p = 0.41$; Pb, $p = 0.61$; Zn, $p = 0.77$). Likewise, the Shapiro–Wilk test did not reject normality of the ANOVA residuals for Cu, Cr, Cd and Zn ($p = 0.21$ – 0.57) but did so for Pb ($p = 0.001$). Repeating the two-way ANOVA on log₁₀-transformed concentrations gave the same pattern of significance for every effect and metal (Pb: depth, $p < 0.001$; interaction, $p = 0.128$), and the Mann–Whitney tests above support the Pb depth effect. Therefore, the primary conclusions are not based on the assumptions of equal variance and normality. These assumption tests are, however, of low power given that only three composites per cell.

Table 3: Two-Way ANOVA (Site $\times$ Depth) for Heavy Metal Concentrations in Soils from Anwai, Delta State: All Four Sites (A–D)

Metal	Site F (3, 16)	<i>p</i>	Depth F (1, 16)	<i>P</i>	Site $\times$ Depth F (3, 16)	<i>p</i>
Cu	4476.80	<0.001	78.01	<0.001	11.94	<0.001
Cr	1098.55	<0.001	146.23	<0.001	29.21	<0.001
Cd	1720.78	<0.001	290.55	<0.001	67.08	<0.001
Pb	194.13	<0.001	19.51	<0.001	2.36	0.110
Zn	7326.72	<0.001	0.12	0.738	11.51	<0.001

Two-way fixed-effects ANOVA on the 24 composite means ($n = 3$ per site–depth cell). F is the ANOVA test statistic for the effect named in the column heading with degrees of freedom (numerator error) in brackets; p is the corresponding probability, and $p < 0.05$ indicates a significant effect. Error $df = 16$. Type I, II and III sums of squares coincide since the design is balanced.

Table 4 presents contamination factors (CF) calculated from the composite means relative to the control site at matching depth. Cadmium showed the highest CF at every site and depth (6.85–10.20, "very high" contamination), followed by

zinc and copper (both in the 4.7–5.5 range, "considerable"), lead (3.35–3.96, "considerable"), and chromium (2.44–3.07, "moderate to considerable", the lowest of the five metals).

Table 4: Contamination Factors (CF) Of Heavy Metals at Three Locations Relative to Control Sites at Corresponding Depths

Sample	Depth (cm)	Cu	Cr	Cd	Pb	Zn
A	0–30	5.46	2.57	8.19	3.59	5.46
A	30–60	5.32	2.83	10.20	3.87	5.14
B	0–30	4.87	2.44	6.85	3.39	5.13
B	30–60	4.97	3.07	7.78	3.96	5.18
C	0–30	5.06	2.47	9.72	3.35	5.05
C	30–60	4.74	2.64	8.76	3.88	5.07

Comparison with Nigerian Soil Guideline Values

The measured concentrations are compared to the DPR (EGASPIN) target and intervention values in Table 5. Cd, Pb and Cu exceeded their target values at every industrial site and depth (Cd by about 6- to 10-fold, Cu by 1.5- to 1.8-fold and Pb by 1.1- to 1.35-fold). However, Cr and Zn remained

below their target values throughout. None of the metal exceeded the intervention values although the highest concentration for Cd was 8.35 mg/kg (Site A subsoil), which is approximately 70% of the Cd intervention value of 12 mg/kg. The Cd level for control site (0.69–0.82 mg/kg) was near the target concentration 0.8 mg/kg.

Table 5: Metal Concentrations in Anwai Soils Compared with DPR (EGASPIN) Soil Target and Intervention Values (Mg/Kg)

Metal	Industrial sites (range)	Control (range)	Target value	Intervention value	Industrial target	Assessment
Cu	54.45–64.97	11.17–12.22	36	190	1.51–1.80	Above target; below intervention
Cr	59.56–76.13	24.38–24.81	100	380	0.60–0.76	Below target
Cd	4.75–8.35	0.69–0.82	0.8	12	5.94–10.44	Above target; below intervention
Pb	94.09–114.35	28.11–28.84	85	530	1.11–1.35	Above target; below intervention
Zn	79.83–86.47	15.82–16.10	140	720	0.57–0.62	Below target

Target and intervention values: DPR (2002), originating from VROM (2000). Ranges are the minimum–maximum of site–depth means in Table 2.

Discussion

Heavy metal contamination at industrial and mechanic-workshop sites has been conventionally dealt with as a surface-soil issue, contained to the area in which waste is discarded. Findings from the current study at Anwai, Asaba, suggest that elevated concentrations may extend below the surface layer. The physicochemical properties and metal content of soils from the industrial and mechanic-workshop sites differed from the control site, although not always in the predicted direction. The high range of Electrical conductivity (EC) measured at Control site when compared to the industrial sites indicates a natural background soil chemistry and not industrial input. This is consistent with the interpretation that EC alone is not a diagnostic tool of metal contamination in this context (Isukuru *et al.*, 2024). On the contrary, Ihejirika *et al.* (2016) who assessed soils around the auto mechanic villages and refuse dumps in Owerri, Imo State found that the EC of the soils in the auto mechanic villages (248.4–300.4 $\mu\text{S}/\text{cm}$) were higher than those around the refuse dumps (150.6–195.8 $\mu\text{S}/\text{cm}$). This difference in results is most likely due to the different geologic and ground-water conditions at the two sites. Soil pH at Anwai ranged from slightly acidic to moderately alkaline (6.67–8.24). The moderately alkaline conditions at most sites would be expected to favor precipitation and adsorption of several of the measured metals, but not mobilization, due to the strong influence of pH on metal solubility, nutrient availability and microbial activity (Olatunde *et al.*, 2022).

Significantly higher concentrations of copper, chromium, cadmium, lead and zinc at the three industrial sites compared to the control ($p < 0.001$ for each metal, pooled across depths) are consistent with the inputs associated with discarded batteries, wiring, worn machinery parts, lubricants and metal scrap associated with mechanic-workshop and small-

industrial waste streams (Briffa *et al.*, 2020; Apuyor *et al.*, 2025; Ovwighose *et al.*, 2026). The contamination-factor of cadmium which was classified as "very high" contamination at every industrial site and depth, considerably exceeding the enrichment seen for the other four metals analysis is consistent with cadmium's well-documented association with battery and metal-plating waste and its high mobility relative to other trace metals (Abdullahi *et al.*, 2021; Mitra *et al.*, 2022). Unlike the situation at Anwai, where concentrations are high, Orji *et al.* (2018) surveyed a single automobile mechanic workshop in Gwagwalada, Abuja, and reported significantly lower concentrations of all of the shared metals in the contaminated soil (mean Cu 17.14, Cr 3.17, Cd 0.01, Pb 60.41, and Zn 16.40 mg/kg), with correspondingly low geo-accumulation index values. The authors concluded that the heavy metals at the site in question "have not caused any harm yet". The disparity between the outcome of their study and the present study may be due to the age of the workshops, amount of waste and the duration of the uncontrolled dumping between the comparatively new and better contained workshop at Abuja and the long-established workshops at Anwai, industrial/mechanic cluster. A comparison against the DPR (EGASPIN) soil target and intervention values (DPR, 2002) clarifies this picture.

Cadmium exceeded the DPR (EGASPIN) target value (0.8 mg/kg) by about 6- to 10-fold at every industrial site and depth, corroborating Ossai (2014), who reported mean cadmium concentrations of 4.00–11.55 mg/kg at automobile scrap sites in Agbor, also in Delta State, closely overlapping the 4.75–8.35 mg/kg range found in this study and reinforcing cadmium as the metal of greatest regional concern. Although all Cd values were below the intervention value of 12 mg/kg, the highest value (8.35 mg/kg) approached it, which warrants monitoring. The soils from the workshops of Lokoja (in Kogi

State) also recorded the presence of excess levels of both Pb and Cd above the FAO/WHO limits (85 ± 3.0 and 3.2 ± 0.2 mg/kg, respectively) but at lower concentrations when compared with the soil samples from the workshop at Anwai (Pb 94.09–114.35 and Cd 4.75–8.35 mg/kg, respectively), thereby strengthening the hypothesis of Pb and Cd as priority metals in workshop soils in Nigeria.

Lead exceeded the DPR (EGASPIN) target value (85 mg/kg) at every industrial site and depth (1.1- to 1.35-fold), with the highest subsoil values at all three sites (111.69–114.35 mg/kg), and the greatest within-site spatial variability of any metal, indicates that some points within these sites are likely well above the mean value reported. This corroborates the reports of Ibrahim *et al.* (2019), who found broadly comparable, or moderately higher, chromium (81.4–163.3 mg/kg), lead (80.2–101.2 mg/kg), and copper (28.8–50.1 mg/kg) at automobile mechanic workshops in Biu, Borno State, but a far lower cadmium range (0.88–1.31 mg/kg). Again, this highlights the exceptionally high result of cadmium in the Anwai outcome relative to other highly polluted workshop locations in Nigeria.

The concentration of copper in all the industrial sites of Anwai was found to be greater than the recommended guideline of 36 mg/kg by about 1.5 to 1.8 times. Their elevation above the control therefore reflects anthropogenic enrichment of the local background. Relative to the guideline values, cadmium, lead and copper are the principal concerns, and none of the five metals attained the intervention values. A similar pattern, in which Zn, Pb and Cu had the highest contamination factors among the metals determined, was reported for waste-dumpsite soils in Gusau using the same Håkanson (1980) classes (Ameh *et al.*, 2023). However, their study used average shale values rather than a local control as the reference, which limits direct comparison of CF values.

The consistent tendency for Cu, Cr, Cd, and Pb to be higher in subsoil than topsoil at all three industrial sites is a notable and somewhat counter-intuitive finding that also diverges from some of the published Nigerian literature. At Anwai, the concentrations of these elements increased with subsoil depth, whereas Chokor (2016), who carried out a similar study at Sapele, Delta State, on automobile workshop soils at four depth bands (0–15, 15–30, 30–45 and 45–60 cm), reported a progressive decrease with depth for Zn, Mn, Pb, Cu, Cr and Cd. Duru *et al.* (2024), using the same 0–30/30–60 cm two-depth design as the present study at an auto-mechanic cluster in Nsukka, Enugu State, reported an overall decrease with depth for Cu, Cd, and Fe, but an increase with depth for Pb and Zn, partially corroborating the present findings for lead while disagreeing with them for zinc, which showed no significant depth effect at Anwai. In addition, Duru *et al.* (2024) found significantly lower absolute concentrations for all measured metals that were common in both studies. In comparison, this difference might stem from methodological differences, because the present study adopted a digestion in tri-acid ($\text{HClO}_4\text{--HNO}_3\text{--H}_2\text{SO}_4$) that typically releases a larger fraction of the total metal content than the single-acid (dilute HNO_3) digestion used by Duru *et al.* (2024). A possible explanation for the depth-pattern disagreements is that a surface-decreasing profile is indicative of continuing, relatively recent surface deposition. However, the opposite profile obtained at Anwai may be consistent with vertical redistribution (leaching) following long-term dumping, or with preferential retention of these metals in the subsoil horizon, although neither mechanism was tested in this study. Generally, metal loads vary with workshop age and waste volume (with longer operating workshops having higher loads, as observed in Port Harcourt, Muze *et al.*, 2020,

which is a function of time), and similarly to the cumulative deposition along the river bank. This results in the oldest workshops reporting higher loads than the newly established ones. The significant site $\times$ depth interactions for Cu, Cr, Cd and Zn show that the depth profile is itself site-dependent, which argues against attributing the subsoil concentrations to a single, uniform downward-migration process.

In view of Anwai's close proximity to the River Niger and the seasonal fluctuations in water-table levels typical of equatorial lowland environments, there is a legitimate reason to be concerned that this study, which sampled at only two depths and that did not include any groundwater analysis, may not be able to rule out the possibility of downward transport to the water-table (Luo *et al.*, 2019). The findings of these depth-resolved studies in Nigeria suggest that the vertical distribution of metals at auto-mechanic sites is not a universal pattern, but varies according to the site-specific conditions, likely influenced by the age of the workshop, waste mix and soil texture. Since vertical redistribution can only be demonstrated with additional evidence, such as groundwater and pore-water concentrations, soil texture, organic matter, cation-exchange capacity, Fe/Mn-oxide content and sequential extraction; the depth profiles reported here should therefore be regarded as suggestive.

Cadmium is nephrotoxic and tends to bio accumulate in the bone, even at low chronic exposures, while lead is neurotoxic and has well-documented effects on child cognitive development and on hematological indices (Mitra *et al.*, 2022; Yu *et al.*, 2023). The close proximity of farmland to the residential areas in Anwai increases the risk of crop uptake and direct soil contact (especially for children) for both metals. This cadmium narrative is corroborated by an earlier study conducted on leafy vegetables sold in Ogbogonogo market of the same Asaba metropolis used for the current study (Ogonegbu *et al.*, 2026). The authors reported that the concentration of cadmium in pumpkin leaves exceeded the FAO/WHO recommended levels and its target hazard quotient (THQ) and hazard index (HI) were greater than the recommended values. Although the present study measured total soil metal content only and cannot directly comment on bioavailability or actual dietary or dermal exposure, emerging evidence suggests that the cadmium content of soils around Asaba may be of concern.

Limitations of the Study

This study provides preliminary baseline data on soil heavy metal levels in Anwai, however, several limitations exist. Three field composites were collected independently at each site–depth cell, which provide statistical inference for the spatial difference between the sites and depths. However, a larger number would give a better estimation of the within-site variance and more confidence in the reported site-by-depth interaction in this study (e.g., five to ten per site). In addition, the study focused on soil only; additional studies of the actual exposure pathways and bioaccumulation risk were not conducted in conjunction with the soil sample results presented here, including analysis of crops, ground water, and surface water. Furthermore, only the total concentration of metals was determined not chemical speciation, limiting inferences concerning bioavailability and potential toxicity. Lastly, no certified reference material was analyzed to assess recovery and the detection/quantification limit were not reported.

CONCLUSION

This study has provided a field-replicated, metal-specific evaluation of the levels of the metals in the soils of industrial/

mechanic workshops in Anwai, Delta State in comparison with a reference site on the DOU Anwai campus. Copper, chromium, cadmium, lead and zinc were all significantly elevated at the industrial sites compared to the control site and cadmium had by far the highest relative enrichment (contamination factor 6.85–10.20 – "very high") and the most pronounced exceedance of the DPR (EGASPIN) target value (0.8 mg/kg), followed by lead and copper; no metal reached its intervention value. Chromium and zinc were also significantly enriched relative to the local control (CF 2.44–3.07 and 5.05–5.46, respectively) but remained below their DPR (EGASPIN) target values. There were notable differences between the three industrial sites in most cases but not all, suggesting that contamination at Anwai is affected by surface inputs that differ from site to site and by similar subsurface processes. The statistically significant depth-wise pattern, pooled across the industrial sites, of higher concentrations of Cu, Cr, Cd and Pb in subsoil than in topsoil (the direction held at every industrial site), may indicate vertical redistribution of metals, although this cannot be confirmed from concentration profiles alone.

In future investigations of this nature, downward migration of metals should be investigated through direct study of groundwater quality. Additionally, the spatial sampling should be expanded beyond the current three composites per site, and speciation or bioavailability data should be acquired to support strong claims of contamination or public-health risk. Furthermore, the analytical data should be validated with certified reference materials. Such validation particularly with the cadmium result, would help in the cause of more stringent environmental controls, regular monitoring, and community-based plans for remediation in the Anwai area of Asaba. Finally, phytoremediation and other low-cost remediation options are also recommended.

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