

Contamination of Soil and Groundwater with Toxic Heavy Metals near Lapite Dumpsite in Ibadan, Nigeria

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Abstract

Municipal solid wastes pose environmental challenges of seeping of leachates containing toxic heavy metals through soil to well water of nearby residential buildings. This contamination route is experienced by people residing in the vicinity of open dumpsite at Lapite in Ibadan. This objective of this study was to assess the impact of heavy metals arising from combustion process on soil and underground water in the vicinity of Lapite dumpsite in Ibadan of Nigeria. The soil sample was predominantly sandy with composition ranging from 73.2–87.2%. The levels of Cr ($25.2 \pm 12.5 \mu\text{g/g}$), Cd ($1.42 \pm 0.50 \mu\text{g/g}$), Pb ($111 \pm 101 \mu\text{g/g}$), Ni ($23.9 \pm 9.7 \mu\text{g/g}$), Zn ($1500 \pm 800 \mu\text{g/g}$), Cu ($689 \pm 340 \mu\text{g/g}$) and Mn ($1530 \pm 780 \mu\text{g/g}$) in the soil showed significant correlation with the corresponding levels in well water. When compared to the WHO guidelines, well water samples contained elevated concentrations of metals except for Cd. After ten years, the levels of these heavy metals increased by 19.4, 50.7, 7.5, 18.8, 1.33 and 3.0%, respectively stipulating that dumpsite soil at Lapite was contaminated with heavy metals. The contamination of nearby groundwater with toxic heavy metals might have resulted from the leaching of metals into aquifers that were near the dumpsite.

Introduction

Municipal Solid Waste (MSW) comprises households waste as well as waste generated from industrial, commercial and institutional sources [1]. The complexity of waste produced by modern civilizations is directly related to the standard of living, socio-economic status and cultural attributes of that particular society [2]. There has been increasing concern about the environment in which humans live. Solid waste, garbage, food waste and sewage are produced everyday by our urban society. In an attempt to dispose of these materials, humans carelessly pollute the environment [3, 4]. Solid waste management has become a serious environmental problem and is a major growing concern for urban areas worldwide [2]. The estimation of solid waste generation globally is 1200 to 2400 Tg annually. The generation of solid waste is projected to increase by about 70% by 2025 owing to increasing urbanisation and economic development [5]. Biodegradable material, especially food waste, usually accounts for over 50 wt% of the municipal waste stream in less developed countries [6]. Despite a lower level of commercial, industrial and institutional activity, solid waste from developing countries is not necessarily devoid of hazardous materials [7] because the regulatory framework and enforcement system to segregate and separately collect such waste are nearly non-existent. It is therefore common to find waste dumps on both cultivated and uncultivated land, making the soil a major sink for various contaminants and toxicants including heavy metals [8]. At unlined MSW dumpsites, groundwater contamination has been a concern due to leakage of leachate through the soil. Many studies have indicated heavy metals as one of the major soil contaminant from MSW dumpsites [9–11]. Many simple constructed dumpsites that have resulted to heavy metals contamination of groundwater include Henchir El Yahoudia dumpsite in Tunis [12], Matuail dumpsite in Bangladesh [13], Mediouna dumpsite in Morocco [10], Matang dumpsite in Malaysia [14] and the Suchi dumpsite in India [15]. When these heavy metals exceed natural background levels, they become toxic to the environment, humans, animals and plants. Certain edible crops are also found growing on the waste itself and near waste dumps.

Due to their known toxicity at high concentrations, certain heavy metals are likely to affect the health of humans who ingest crops grown on waste contaminated soil. Ingestion of heavy metals from food and ground water that are procured near solid waste dumpsites has been reported to introduce toxic metals into the human system [16]. Unethical waste disposal and management practices allow for metals that leached from contaminated soil to create problems for other environmental systems [17–19]. These practices can engender serious concern if allowed to remain unchecked, especially in developing countries that are ill-equipped to address the issue and that lack efficient waste disposal and management systems. Nigeria, the most populous developing country in Africa, is quickly developing full-service waste collection, but treatment of the disposed waste is inadequate. One of the cities that has suffered from poor solid waste management practices is Ibadan city. The city contain some non-standard dumpsites and has been selected for the study because of its high waste generation of about 996 102 tons per annum [20]. The population of Ibadan city rose in 1999 at a growth rate of 1.65% from 1963 and increased to 1,338,659 in 2006 at a growth rate of 2.35% [21]. Arising from the increasing population level of Ibadan city, there has been a concern on how to improve solid waste management and sanitation so as to prevent the spread of communicable diseases. Two main health outcomes have been reported to be associated with MSW exposure are cancer and congenital malfunctions [22]. One of the urgent effective steps to the improvement of sanitation is to report the effects of waste exposure via drinking water on human health. Being a universal solvent, water is a major source of infection caused by heavy metals occurrence at dumpsites. The possibility of heavy metals transfer by soil to groundwater require regular surveillance around dumpsites.

Research was conducted to determine the effect of solid waste on the soil of the Lapite dumpsite and nearby well water. This dumpsite is used for dumping waste generated by the public. Both recyclable and non-recyclable waste is disposed of in this dumpsite. The main objective of this study was to determine the levels of certain heavy metals in the dumpsite soil and in nearby well water that is utilized for drinking purposes. The distribution of metal concentrations at different soil depths was also investigated.

Materials and Methods

Description of the Lapite Dumpsite

The Lapite dumpsite is situated in the Akinyele Local Government of Ibadan. The study area lies between latitude 7° 34' 08" N and longitude 3° 54' 43" E (Fig. 1). This dumpsite is one of the few designated solid waste open areas in Ibadan city. A major road traverses the dumpsite, and vegetation is present on both sides of the road. A re-habitation centre, petrol filling station and a few residential buildings and huts surround the dumpsite. The geology of this area is characterized by crystalline rocks of the Pre-Cambrian era. Granite rocks occupy the area and are also from the Pre-Cambrian era [23]. A botanical garden (latitude 7° 24' 03" and longitude 3° 53' 49") at the University of Ibadan was purposely selected as a control site as this site has virgin land with no evidence of waste dumping.

Sample Collection

Samples were first collected during May of 2010 and later in July 2020. The current sample collection became expedient so as to ascertain the present status of metal concentrations in the samples. Soil samples were randomly collected at ten different locations at the Lapite dumpsite. The samples were collected at three depths with the aid of a soil auger: 0–15 cm, 15–30 cm, and 30–45 cm. Soil samples were collected in black polythene bags and labelled Lapite Soil Sample (LPSS). Control soil samples were collected from two different locations at a botanical garden and labelled Botanical Soil Sample (BGSS).

The samples were taken to a laboratory to investigate the levels of toxic heavy metals and their variations in soil at increasing soil depths. Well water samples were collected from eight households located in proximity to the dumpsite.

Preparation and Analysis of Samples

Soil samples were air-dried for several days. Large stones and sticks were removed by hand, and the soil samples were effectively ground using an agate mortar and pestle. The soil samples were then sieved through a 2 mm mesh and labelled accordingly. Heavy metal analysis was carried out using US EPA method 3050B. The soil samples were digested with $\text{HNO}_3\text{-HCl}$ (1:3, v/v). The water samples were digested using concentrated nitric acid. The concentrations of Chromium (Cr), Cadmium (Cd), Lead (Pb), Nickel (Ni), Zinc (Zn), Copper (Cu) and Manganese (Mn) were determined using a Shimadzu AA-6200 flame atomic absorption spectrophotometer (Shimadzu, Illinois, USA). The pH of the soil and water samples was measured electrometrically. Soil particle size distribution was determined using the bouyoucos hydrometer method [24].

The geoaccumulation index (I_{geo}) as detailed in the literature [25] was evaluated for each heavy metal. The I_{geo} is a widely employed expression to quantify the degree of metal pollution in soil. Soil is categorised as uncontaminated with a particular toxic metal when $I_{geo} < 0$, uncontaminated to moderately contaminated when $I_{geo} = 1$, moderately contaminated when $I_{geo} = 2$, moderately contaminated to highly contaminated when $I_{geo} = 3$, highly contaminated when $I_{geo} = 4$, highly contaminated to very highly contaminated when $I_{geo} = 5$ and very highly contaminated when $I_{geo} = 6$.

Validation of the Analytical Procedure

Reagent blanks were included in all digestion batches. A recovery study was conducted by spiking samples with standard solutions of the metals under investigation. High recovery was obtained for Cr: $94.2 \pm 1.1\%$, Cd: $90 \pm 0.8\%$, Pb: $93.2 \pm 1.4\%$, Ni: $95.2 \pm 1.2\%$, Zn: $90.9 \pm 0.4\%$, and Cu: $95.3 \pm 1.2\%$.

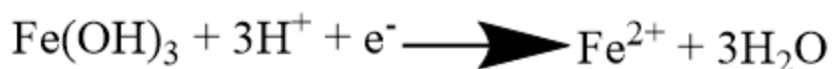
Data Analysis

Data obtained were subjected to descriptive analysis (means and standard deviations). The Pearson's correlation coefficient (r) was employed in order to establish whether there is a linear relationship between metal concentrations in soil and water samples.

Results and Discussion

pH and Particle Size Composition of the Soil

The pH of the soil from the Lapite dumpsite varied from 6.0 to 6.5 and was similar to the pH of soil from the control site (pH 6.2–6.7). Thus, soil samples from the Lapite dumpsite and the control site were found to be acidic (Table 1). The pH of the soil increased with increasing soil depth. pH is an important parameter in oxidation-reduction reactions in soil. Both O_2 and ferric ion are more readily reduced when the soil is acidic. The chemical equations shown below describe reduction reactions in soil that are driven by protons and electrons generated by the oxidation of carbohydrate containing substances to provide pyruvic acid.



Soil from the Lapite dumpsite and the control site is composed mainly of sand grain. The sand fraction varied from $70.1 \pm 2.5\%$ to $76.2 \pm 5.2\%$ (Table 1). The effect of this textural soil class on the ability of soil to hold water and dissolve contaminants is significant, particularly for plants. The dominance of sand grain in Lapite dumpsite soil implies that the soil has more space, which reduces the soil's capacity to hold dissolved contaminants. Sand-sized particles in soil can be a hindrance to cultivation. Thus, soil from the Lapite dumpsite is less suitable for crop production but can be made fertile if organic matter is increased.

Metal Concentrations in Soil

The variations of Mn, Cu and Zn concentrations with increasing soil depth are shown in Fig. 2a. The levels of these heavy metals were relatively high at a depth of 0–15 cm and appeared to gradually increase with soil depth. High levels of Cr, Pb and Ni were also observed at 15–30 cm depth in year 2010. The topsoil is regularly turned over by caterpillars, and this activity can be responsible for having layers of less contaminated soil with Cr, Pb and Ni to a depth of 0–15 cm over more contaminated soil at the depth of 15–30 cm in year 2010. In ten years after the first sampling was carried out, similar trend of reductions in the concentrations of Mn, Cu, Zn, Cr and Ni in topsoil as the soil depth increases were

observed. Metal concentrations in the soil from the control site were much lower at all soil depths compared to the corresponding concentrations of metals in dumpsite soil. The high metal concentrations in the dumpsite soil results from the stripping of metals from metal scraps, leakage of lead from batteries and deposition of metals, particularly lead, from vehicular exhaust. An increase in the rate of disposal of solid wastes from industries and residences onto Lapite dumpsite was observed over ten years ago. Within this period, there has not been any new dumpsite in which some of these wastes could possibly be disposed. Therefore, the dumps increased in volume and were likely to have increased the levels of toxic heavy metals in the soil and leachates from the dumpsite.

Heavy metal concentrations in topsoil only were previously reported for this dumpsite [26] but data for sub-soil layers were not reported for comparison. In this study, reduced levels

Table 1
Average values of soil pH and sand, clay and silt compositions

Location	Sample code (Depth)	pH		Sand (%)		Clay (%)		Silt (%)	
		Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Lapite dumpsite	LPSS (0–15 cm)	6.0 $\pm$ 0.3	5.5–6.2	70.1 $\pm$ 2.5	50.5–86.4	8.1 $\pm$ 1.4	5.4–16.2	21.8 $\pm$ 1.6	7.28–29.3
	LPSS (15–30 cm)	6.1 $\pm$ 0.1	5.8–6.7	74.3 $\pm$ 6.1	60.2–84.6	7.2 $\pm$ 2.1	6.48–8.60	18.5 $\pm$ 0.4	10.1–21.3
	LPSS (30–45 cm)	6.5 $\pm$ 0.1	6.0–6.8	76.2 $\pm$ 5.2	70.1–86.4	7.3 $\pm$ 1.8	3.15–9.81	16.5 $\pm$ 1.5	9.04–23.3
Control site	BGSS (0–15 cm)	6.2 $\pm$ 0.3	6.1–6.3	84.5 $\pm$ 1.1	80.1–86.4	5.1 $\pm$ 1.2	3.04–5.84	10.4 $\pm$ 0.9	9.52–10.7
	BGSS (15–30 cm)	6.5 $\pm$ 0.1	6.0–6.9	86.2 $\pm$ 0.5	82.1–87.1	6.2 $\pm$ 1.6	3.04–7.14	7.60 $\pm$ 0.40	8.41–10.7
	BGSS (30–45 cm)	6.7 $\pm$ 0.1	6.5–6.9	86.9 $\pm$ 3.2	81.4–90.2	6.8 $\pm$ 1.2	3.04–7.28	6.30 $\pm$ 0.80	6.10–11.2

LPSS = Lapite soil sample; BGSS = Botanical soil sample.

of Cr, Pb and Ni were observed compared to previous literature data for heavy metals in Lapite soil (Table 2). The levels of Cr, Pb and Ni in soil samples from a metallurgical landfill in France were 61-, 8- and 13-fold higher than in the Lapite soil. Only Zn and Cu levels were significantly higher in Lapite soil compared to soil from the metallurgical landfill (Table 2). When comparing the levels of metals in this

study with those from an unlined landfill in Thessaloniki, it can be concluded that the metal concentrations in soil from the Thessaloniki landfill are low because the area faces less pollution. Although the area northwest of Thessaloniki is heavily industrialised, it is not a significant source of metal pollution for the landfill. Considering the heavy metal concentrations in Mogla Bazar of Bangladesh with those in this study, higher levels of Cd, Pb, Zn, Cu and Mn were observed in Lapite dumpsite soil (Table 2). The trend of heavy metal concentrations in Lapite dumpsite soil is $Mn > Zn > Cu > Pb > Cr > Ni > Cd$ with respective I_{geo} values of 0.2630(Mn), 3.396(Zn), 3.352(Cu), 1.888(Pb), -2.421(Cr), -2.094(Ni) and 1.658(Cd). The I_{geo} values revealed the Lapite dumpsite soil to be moderately contaminated with Cd and Pb; highly contaminated with Zn and Cu. The dumpsite soil in Khames-Mushat of Saudi Arabia was reported to be acidic with pH of 6.2 ± 0.3 , which is about the soil pH of Lapite dumpsite, but have lower heavy metal concentrations when compared with those of Lapite dumpsite soil (Table 2).

Metal Concentrations in Water

There was clear evidence of heavy metals in well water near the Lapite dumpsite. Figure 3 shows that the metal concentrations in well water were elevated compared to WHO and SON limits. The only exception was Cd whose concentration in water was less than the detection limit of $0.001 \mu\text{g/mL}$. High concentrations of these metals presumably reflect the leaching of metals from the dumpsite. At ten years, an increase in the levels of Zn, Cu and Mn were observed. Various kinds of waste were dumped all over the dumpsite. Large volume of E-waste were found littering everywhere on the dumpsite, which could be responsible for high levels of Zn and Cu in the soil. The well water in the vicinity of the dumpsite could have possibly been enriched with these metals through seepage. Table 3 shows that the metal concentrations in water samples significantly correlated with the corresponding metal concentrations in dumpsite soil except for lead.

The disposal of solid wastes had been reported to cause serious groundwater contamination near dumpsites in China due to the leakage of leachates. Such regions of China include Henan [27] ; Guizhou [9]; Shanghai [28] and Guangzhou [29]. The groundwater qualities in these regions were assessed “very bad” following the grading method of China. The reported levels of Mn, Cd, and Pb in groundwater in East China were 273, 0.85 and 1.27 mg/L, while the corresponding levels in Northwest China were 3.93, 0.14 and 2.36 mg/L

Table 2: Comparison of metal concentrations ($\mu\text{g/g}$) in topsoil at the Lapite dumpsite with other studies

Dumpsite/Landfill	Cr	Cd	Pb	Ni	Zn	Cu	Mn	Reference
Lapite top soil (Ibadan, Year 2010)	25.2 ± 12.5	1.42 ± 0.50	111 ± 101	23.9 ± 9.7	1500 ± 800	689 ± 340	1530 ± 780	This study
Lapite top soil (Ibadan, Year 2020)	30.1 ± 4.3	2.14 ± 1.1	120 ± 5	28.4 ± 3.6	1520 ± 10	710 ± 12	1580 ± 21	This study
Lapite top soil	37.7 ± 0.5	-	127 ± 2.5	69.9 ± 4.0	107 ± 17	192 ± 22	-	[26]
Metallurgical landfill, France	1536	-	835	308	302	183	-	[32]
Unlined landfill, Thessaloniki	3.88–172	0.50–18.8	2.50–92.5	5.63–63.8	6.38–344	8.13–356	-	[33]
Mogla Bazar, Bangladesh	-	0.15 ± 0.21	14.2 ± 14.6		3.75 ± 5.04	1.63 ± 1.38	31.2 ± 30.5	[34]
Rachi, Jharkhand, India	12.0 ± 2.0	-	-	1.0 ± 7.7	21.7 ± 7.7	4.4 ± 2.2	17.8 ± 7.7	[25]
Khames-Mushait, Saudi Arabia	10.2–540	-	3.0–46.5	4.8–42.4	17.3–146	3.0–47.6	69.7–540	[35]

Table 3: Correlations for metal concentrations in soil and well water samples

	Cr (water)	Cd (water)	Pb (water)	Ni (water)	Zn (water)	Cu (water)	Mn (water)
Cr (soil)	1						
Cd (soil)	0.922	1					
Pb (soil)	0.097	0.154	1				
Ni (soil)	0.902	0.839	0.101	1			
Zn (soil)	0.989	0.898	0.054	0.833	1		
Cu (soil)	0.973	0.924	0.067	0.786	0.991	1	
Mn (soil)	0.926	0.787	0.131	0.692	0.964	0.957	1

respectively [9]. Thus, the heavy metal levels in groundwater near dumpsite in China were much higher than the corresponding levels observed in this study.

Conclusions

Heavy metals such as Cr, Pb, Ni, Zn, Cu and Mn were observed in groundwaters near the Lapite dumpsite. Solid waste dumpsites have the potential to generate an extensive metal pollution source for nearby groundwater. It is therefore unhygienic to use such water for drinking purposes. The most obvious finding as revealed from this study is that there is bound to be deleterious effects of waste on humans and the environment if the use of the dumpsite continues without proper management.

Declarations

Conflict of Interest

The authors declare no conflict of interest

Consent to Publish

Not Applicable

Ethics Declaration

Not applicable

Consent to Participate

Not applicable

Funding

The authors declare there was no funding

Author Contribution

A. R. I and N. C. I carried out the experiment in the field after the design, data analysis, wrote the manuscript and prepare the Figures . O.O.F prepared the chats. All authors reviewed the manuscript

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Data Availability

All data generated and analysed during this study are included in the supplementary information

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Figures

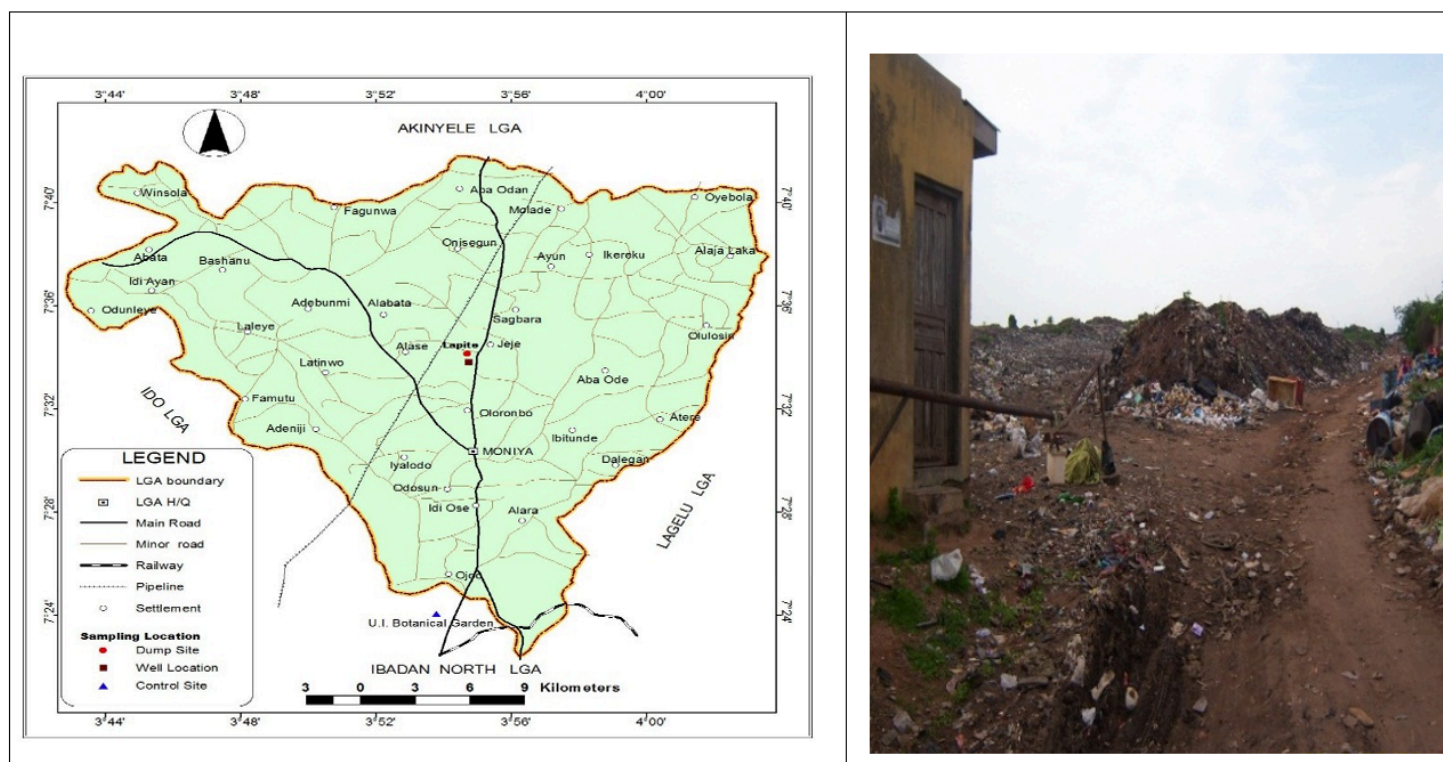


Figure 1

Selected portions of Ibadan city showing Lapite dumpsite

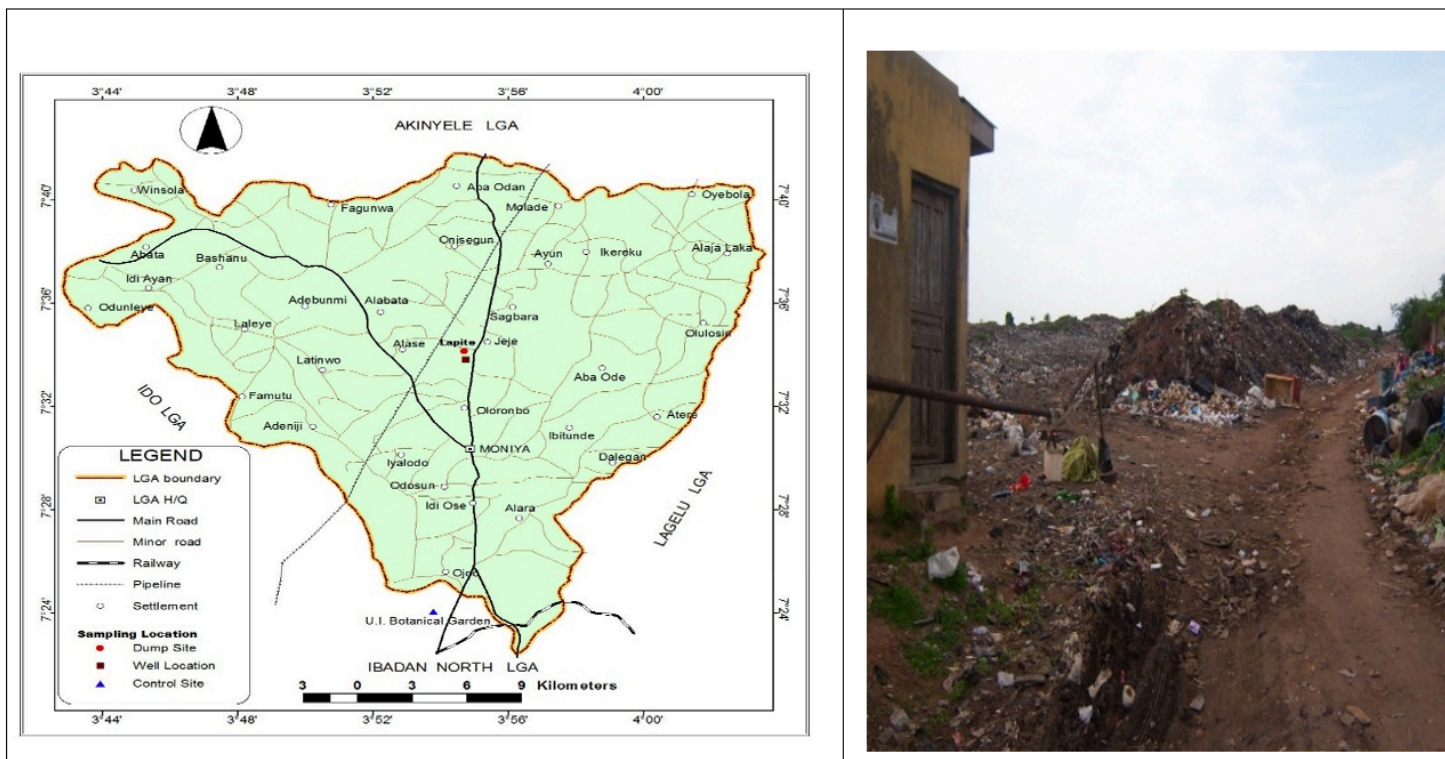


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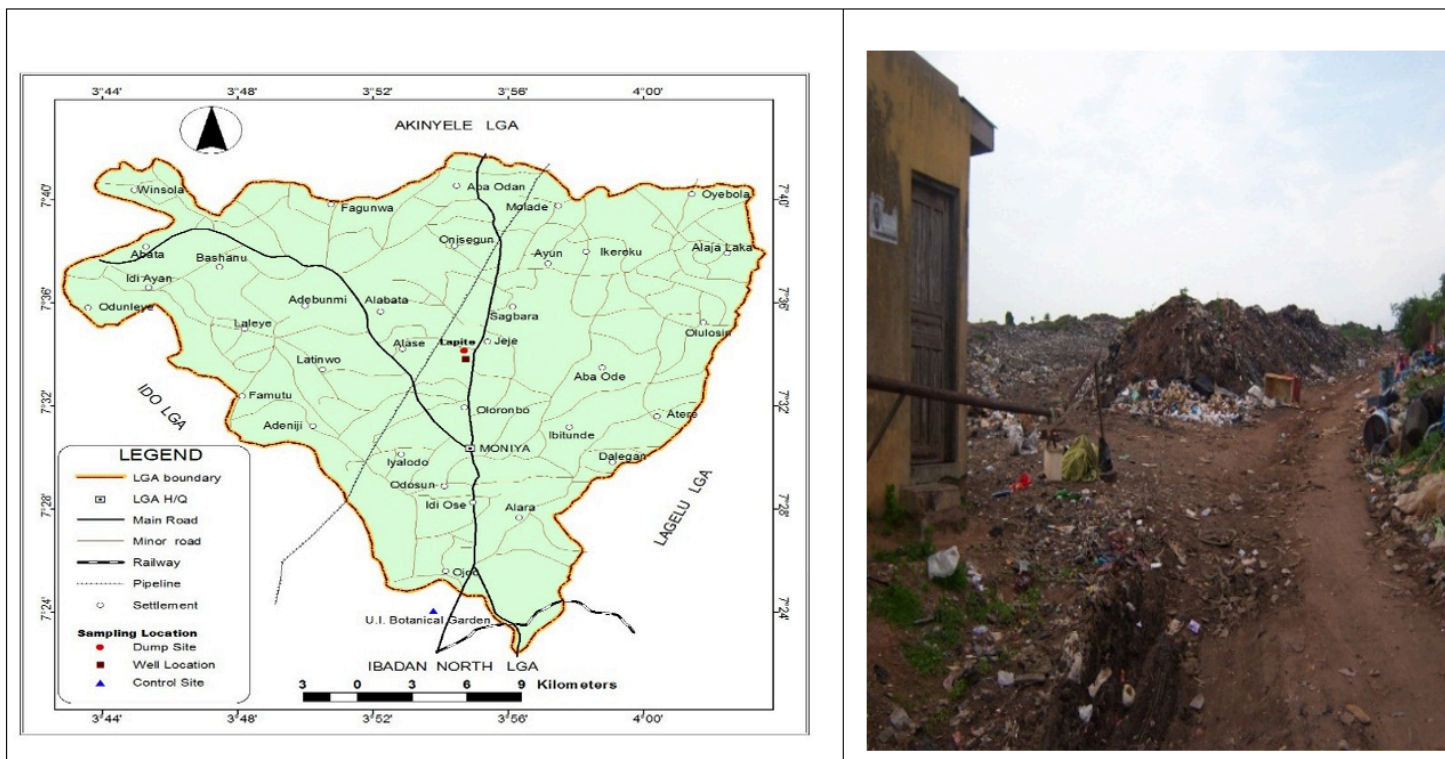


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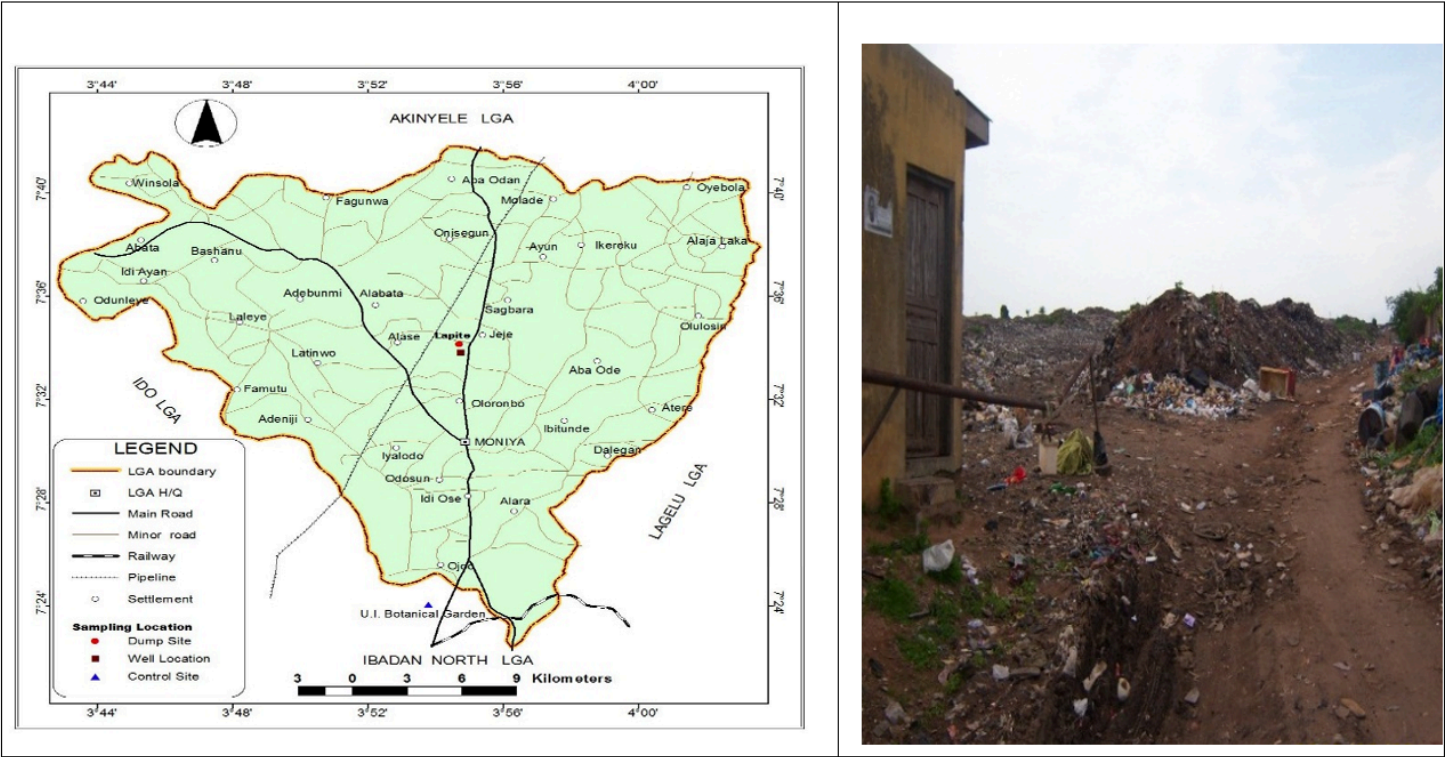


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Selected portions of Ibadan city showing Lapite dumpsite

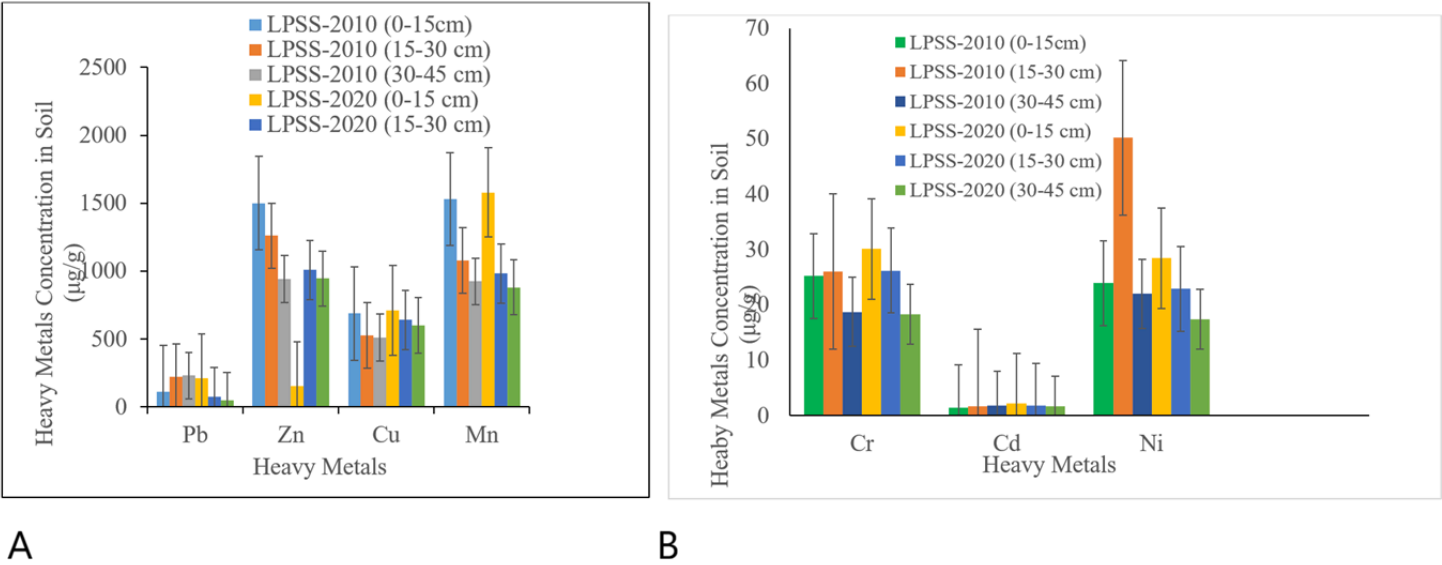
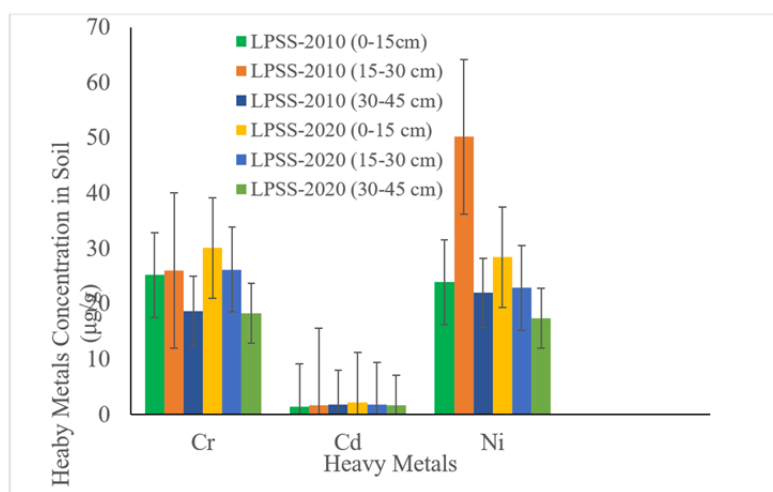
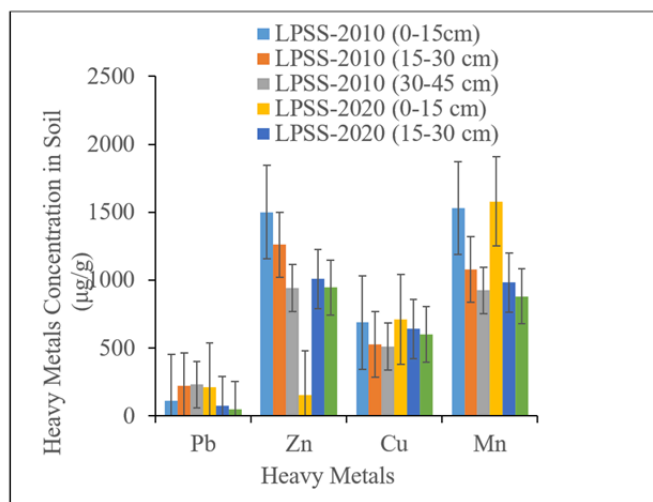


Figure 2

a: Variation of concentrations of lead, zinc, copper and manganese with soil depth

b: Variation of concentrations of chromium, cadmium and nickel with soil depth



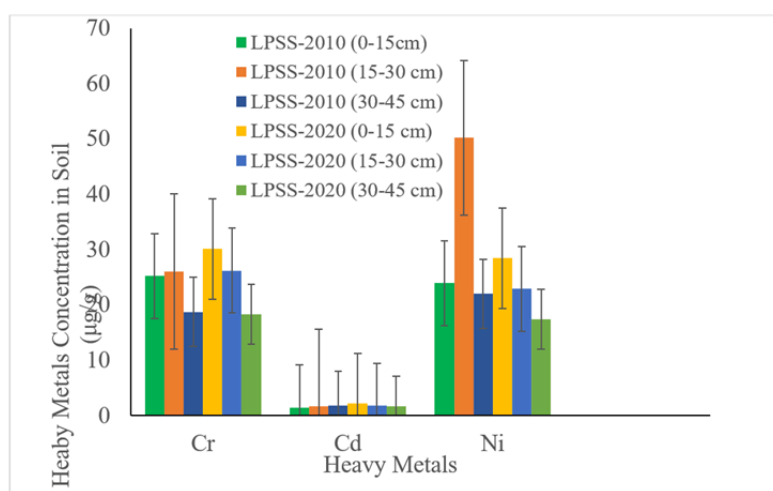
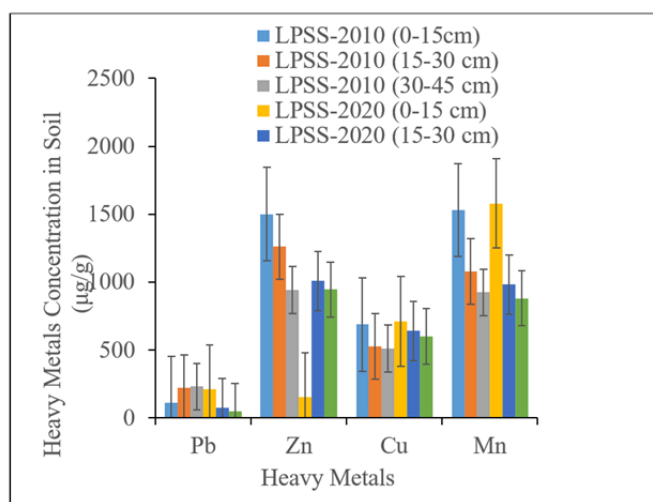
A

B

Figure 2

a: Variation of concentrations of lead, zinc, copper and manganese with soil depth

b: Variation of concentrations of chromium, cadmium and nickel with soil depth



A

B

Figure 2

a: Variation of concentrations of lead, zinc, copper and manganese with soil depth

b: Variation of concentrations of chromium, cadmium and nickel with soil depth

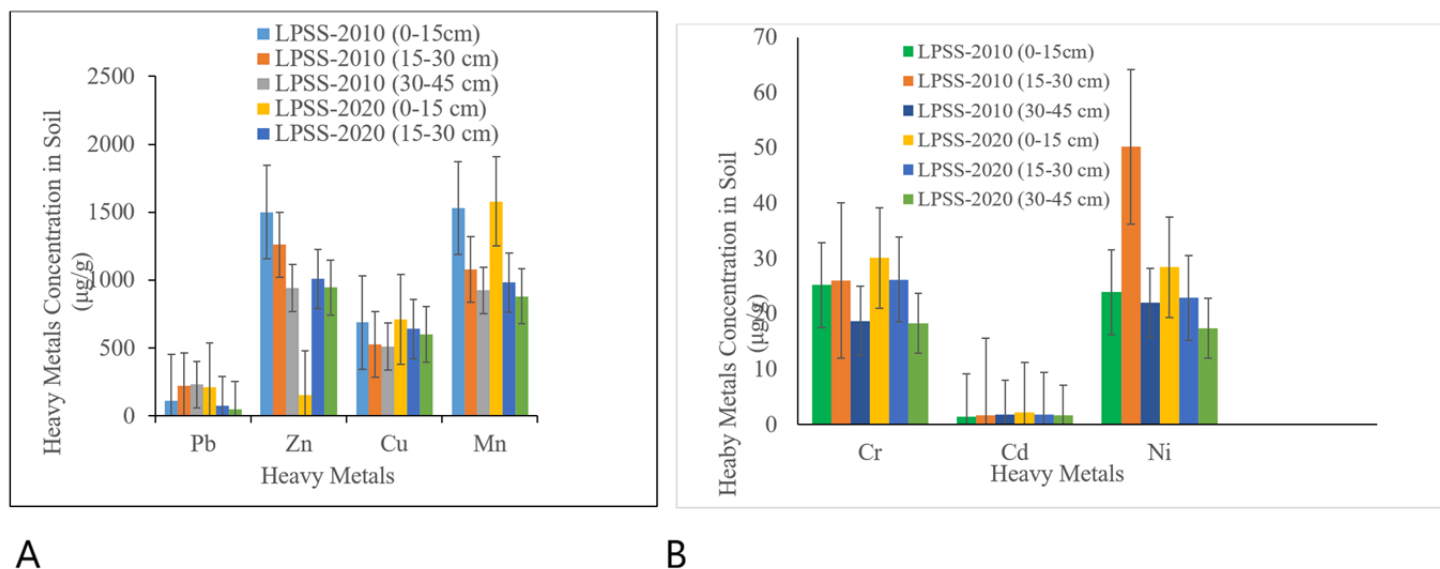


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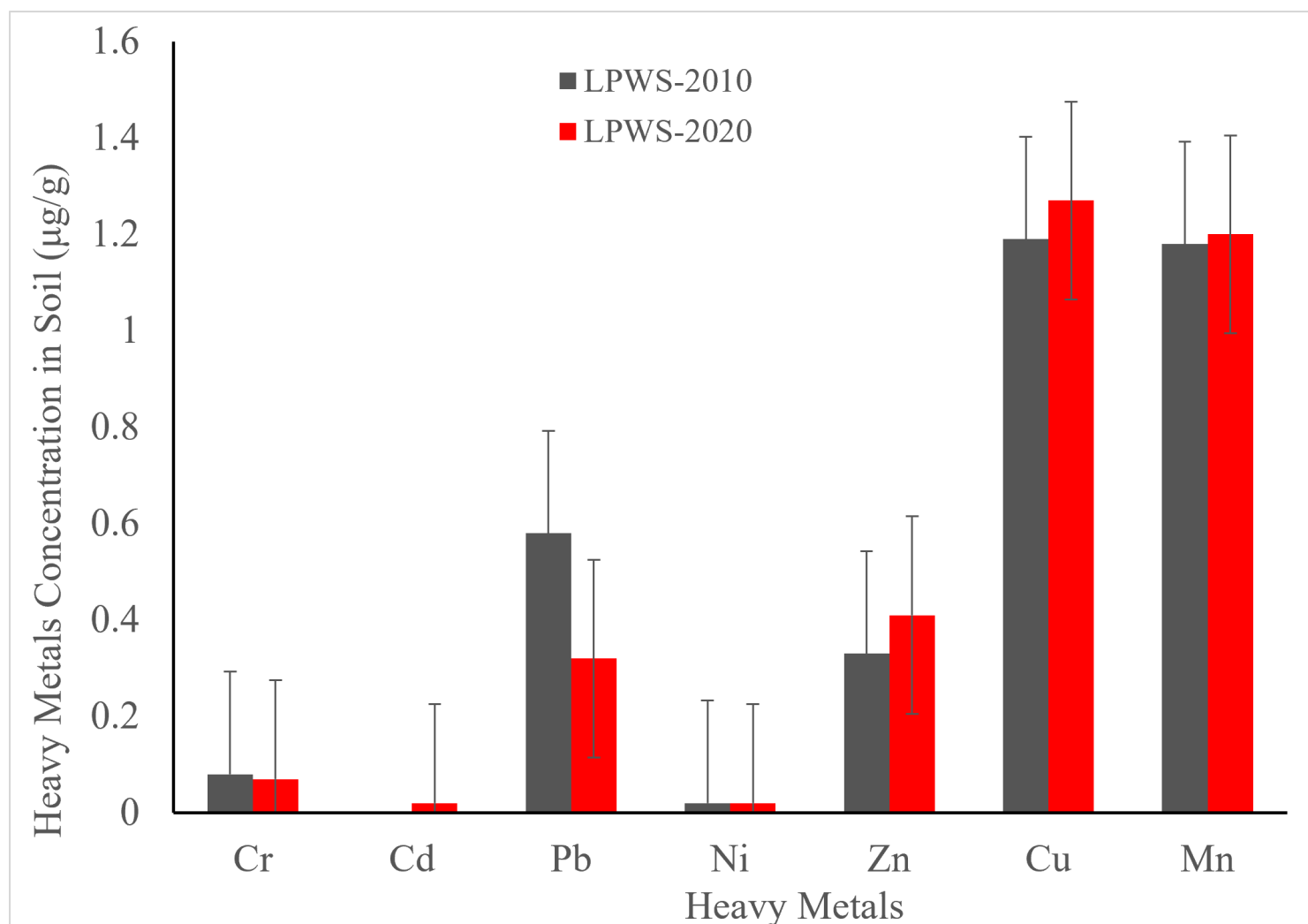


Figure 3

Metal concentrations in water samples in year 2010 and ten years after

(LPWS = Lapite dumpsite well water; NS = Not specified; ^aWHO Source = [30] ^bNIS Source = [31])

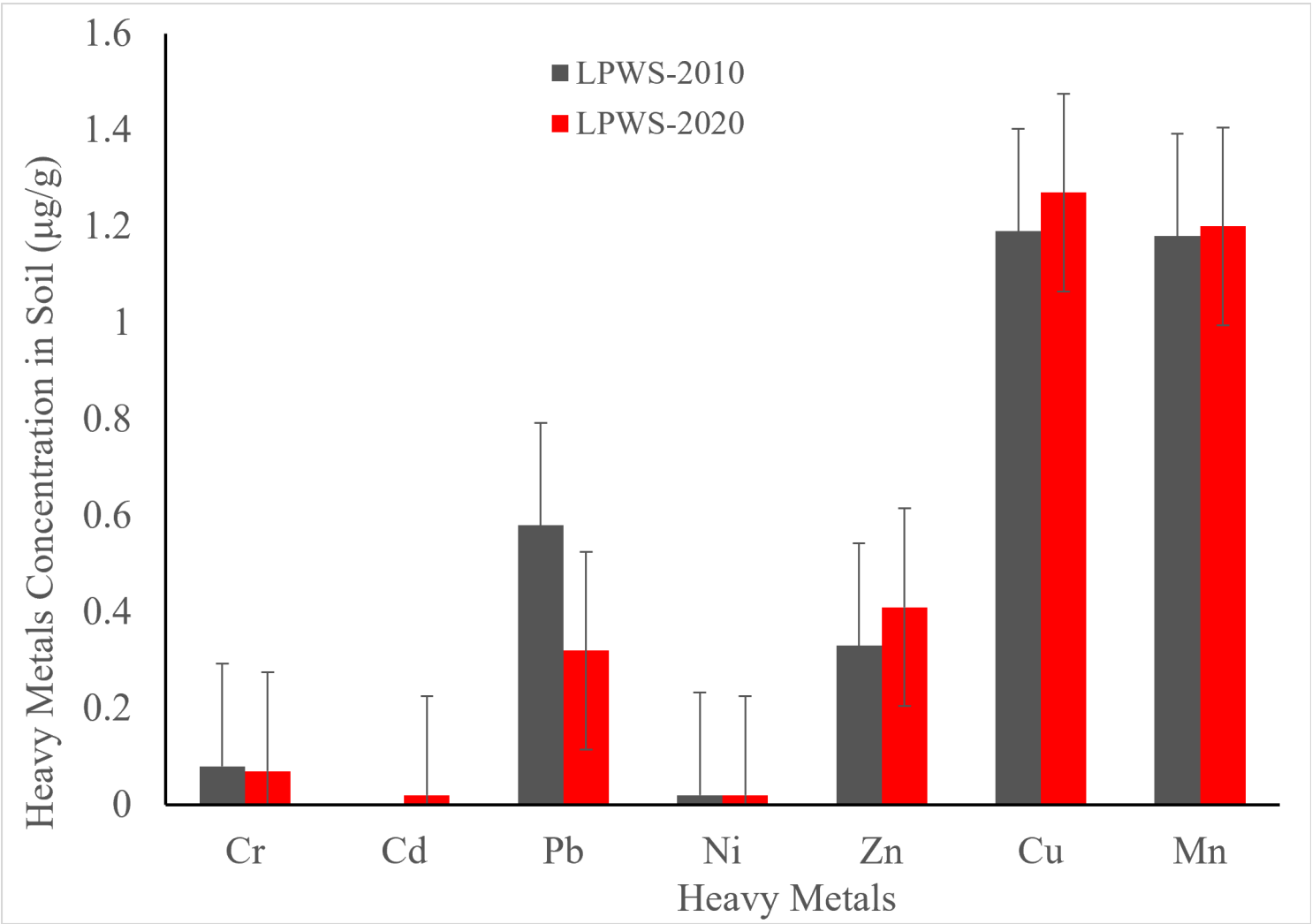


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Metal concentrations in water samples in year 2010 and ten years after

(LPWS = Lapite dumpsite well water; NS = Not specified; ^aWHO Source = [30] ^bNIS Source = [31])

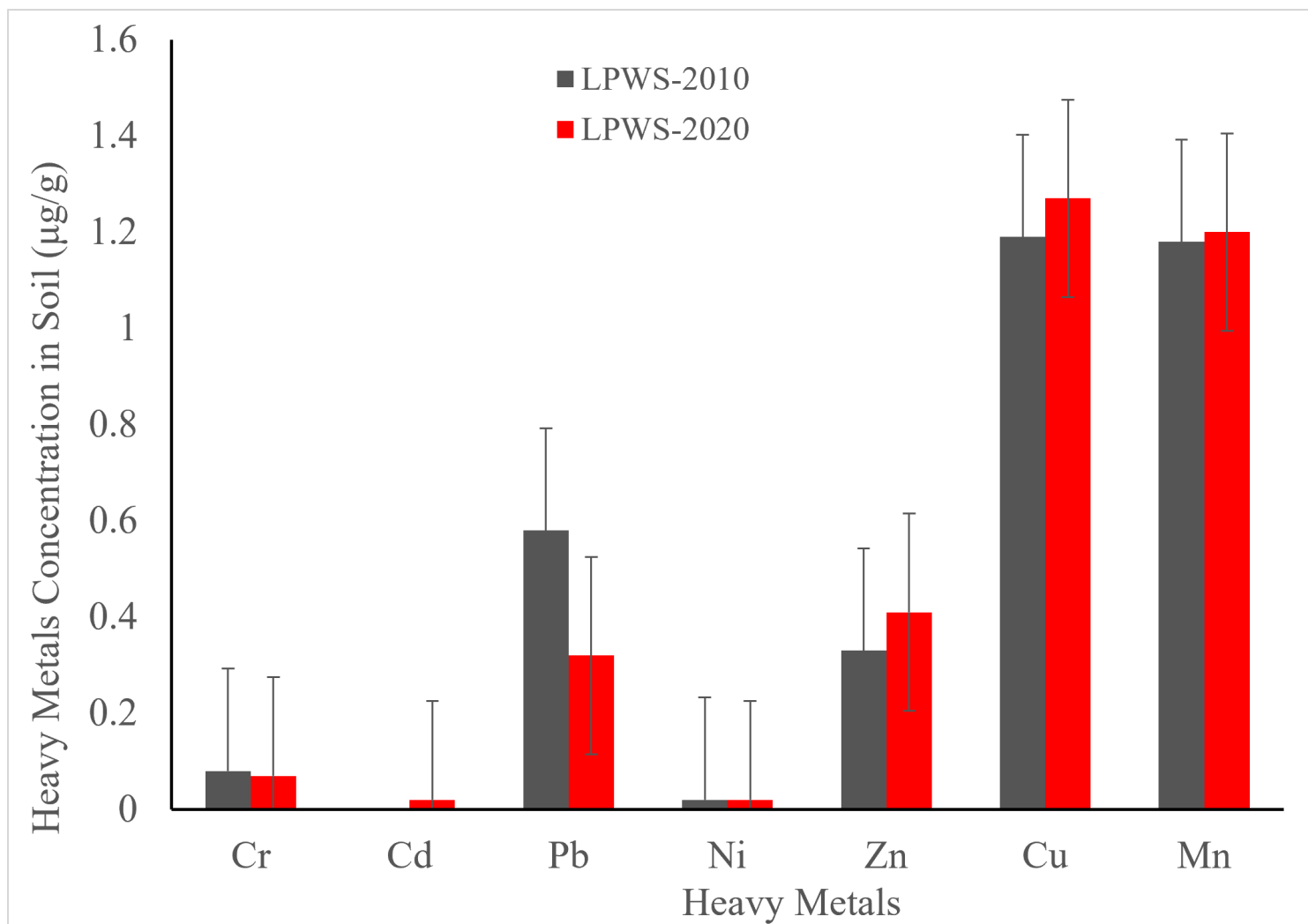


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Metal concentrations in water samples in year 2010 and ten years after

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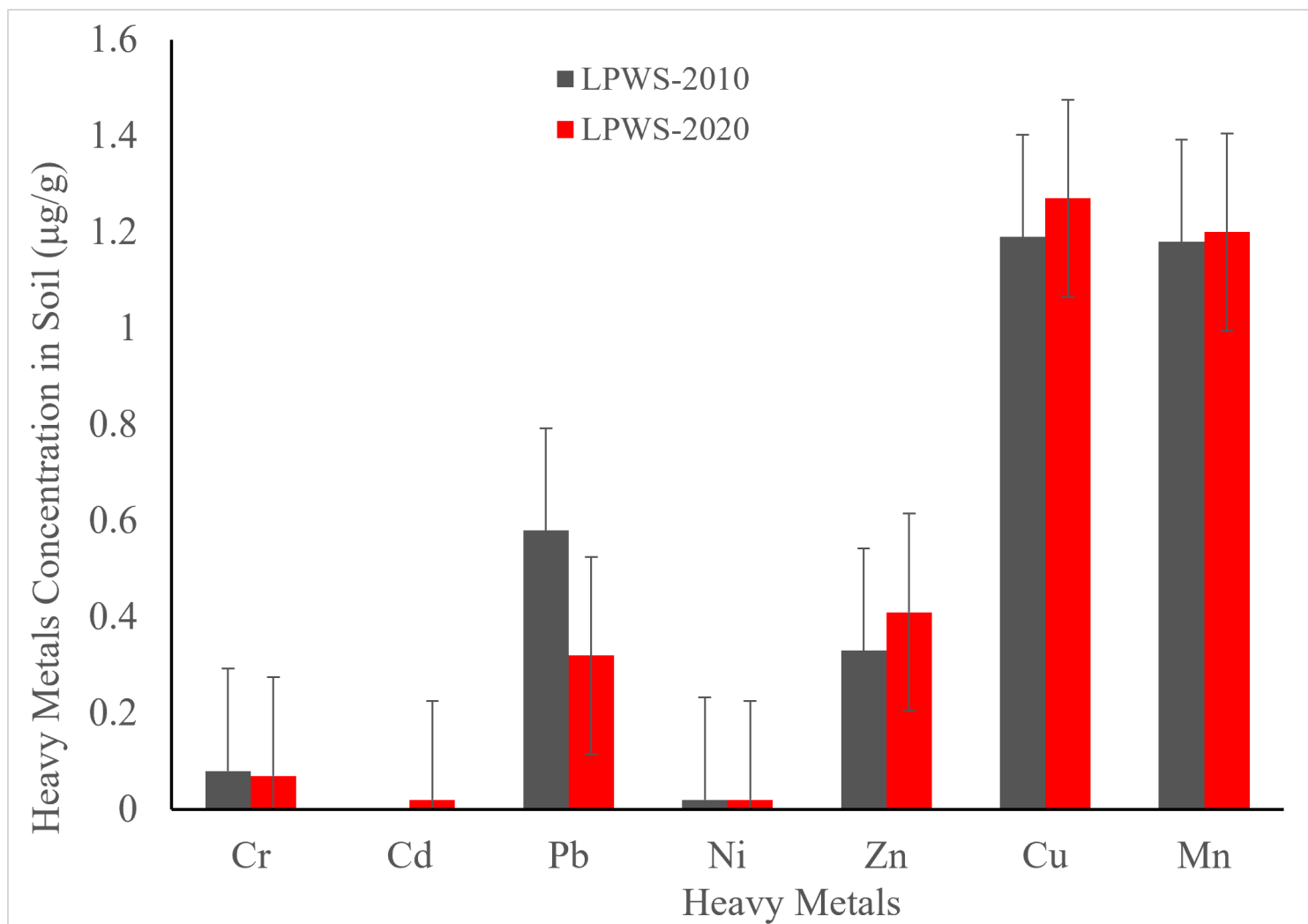


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Supplementary Files

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