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Speciation and Bioavailability of Potentially Toxic Elements (PTEs) in Soil and Water Samples Obtained from Jos, Nigeria

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Abstract

The study investigated the speciation and bioavailability of potentially toxic elements (PTEs) in soil and water samples from Jos, Nigeria. The results revealed significant contamination of soil with Pb, Cd, Hg, As, Cr, and Co, as well as elevated levels of Zn, Cu, Fe, Mn, Ti, Sr, and Zr. Water samples also showed contamination levels exceeding the Nigeria industrial standard (NIS) for raw water. Speciation analysis indicated consisted pollution patterns in the different fractions across study sites, revealed distinct associations: Co, Mn, Fe, and Cr were predominantly bond to the Fe-Mn oxide fraction, whereas Ni, Ti and Zr were mainly associated with the residual fraction. In contrast, Pb, Cu, and Cd were largely associated with the organic and exchangeable fractions, and Sr was primarily linked to the carbonate fraction. Pb, Zn, Cu, Fe, Mn, Co, Hg, and Sr exhibiting high mobility and potential bioavailability, while As, Ti, and Ni showed moderate mobility. These findings highlight the environmental and health risks associated with PTE contamination in Jos, emphasizing the need for comprehensive risk assessments and remediation strategies to mitigate these risks and promote environmental sustainability.

Keywords; Bioavailability, concentration, environmental risk, health risk, soil, water, speciation.

Introduction

The contamination of soil and water with potentially toxic elements (PTEs) poses a significant threat to global agricultural sustainability, primarily due to human activities such as farming, mining, and industrial processes [1]. Research consistently indicates that high levels of potentially toxic elements in soil and water pose significant risks to human health, compromise food safety, and disrupt the soil ecosystem [2, 3]. The global food safety landscape has been significantly compromised due to the accumulation of potentially toxic elements in crops grown on contaminated agricultural soils. Arsenic, cadmium, chromium, and lead are particularly concerning due to their well-documented adverse health effects and widespread presence [4]. Exceeding threshold

levels of potentially toxic elements in soil can significantly degrade soil quality and reduce its productivity.

Anthropogenic activities impact not only soil but also water bodies, which are often used for irrigation. Prolonged use of contaminated water for irrigation leads to the accumulation of potentially toxic elements and metalloids in soil, which can then be absorbed by edible parts of plants, such as vegetables [5, 6]. Potentially toxic elements are defined as metals and metalloids with a density of 5 g/cm^3 or higher [7]. While potentially toxic elements occur naturally in soil and sediment at a background concentration, human activities can lead to their accumulation and contamination in water and soil [8, 9]. The increase in industrial activities inevitably leads to environmental degradation and pollution, driven by toxic emissions containing hazardous elements that pose significant risks to human health [10]

Numerous studies have documented the levels of potentially toxic elements in water [11, 12, 13, 14] and soil [15, 16, 17]. Nevertheless a potential gap in speciation studies of potentially toxic elements in soil and water in Jos lies in the limited understudy of the chemical speciation of potentially toxic elements in diverse environmental settings while existing studies have assessed ground water potential quality in various regions, few have focused on the speciation of potentially toxic elements in soil and water which is crucial for understudy of their mobility, bioavailability and toxicity, hence this study focused on speciation, and bioavailability of the potentially toxic elements in soil and water obtained from Jos metropolis.

Materials and Methods

All the reagents used are of analytical grade. All glassware, polypropylene tubes, and Teflon beakers were thoroughly cleaned with detergent, rinsed with tap water and distilled water, and then acid-washed in 10% HNO_3 for 48 hours. [18]. The equipment was then re-washed with detergent and thoroughly rinsed with double-distilled water, followed by oven drying at 80^0C for 12 hours. The entire reagent used, viz. HCl, HNO_3, and NH_4OH.HCl (Park Scientific Ltd., Northampton, UK); H_2O_2 (Philip Harris Ltd., Birmingham, UK); $HClO_4$ (ES 5, Nottingham, England); CH_3COOH and $MgCl_2$ (M&B Ltd., Dagenham, UK), and CH_3COONa (Sigma-Aldrich Pty Ltd., Pretoria, South Africa).

Sample Collection and Treatment

Five different soil and water samples were collected randomly in different sites within Jos Metropolis using a hand-held stainless-steel towel for the soil into a polythene bag, while water samples were collected into a plastic bottle capped properly. These sites were selected to ensure a thorough representation of the various soil and water compositions and environmental Impacts across the region. The samples were transported to the Postgraduate Chemistry Laboratory of the University of Jos, for further treatment. The soil samples were air-dried and

ground into very fine particles using a porcelain pestle. From each of the ground samples, 1.0 g was accurately weighed and used for the analysis. Water samples were preserved with 5 cm^3 of concentrated HNO_3 [19]. For digestion, 3 cm^3 of concentrated HNO_3 was added to the 50 cm^3 of water samples, which were then heated gradually on a hot plate, covered with a watch glass, until digestion was complete [20]. The solution was evaporated to near dryness, cooled, and then treated with a small quantity of 1:1 concentrated hydrochloric acid and distilled water After warming and filtering, the volume was adjusted to 25 cm^3 for potentially toxic elements determination using atomic Absorption Spectroscopy (AAS), calibrated with internally added standards.

Determination of Total Metal Concentration

The method described by Ibrahim eta al [21] was followed. 1.0 g each of the dried sieved soil sample from each of the sites was digested with a mixture of 15 cm^3 concentrated hydrochloric acid and 25 cm^3 trioxonitrate (v) acid for 2 hours at 100°C. The mixture was filtered and made up to 50 cm^3 and analyzed with AAS.

Speciation and Distribution of Potentially Toxic Elements.

The Tessier *et al* (1979) five step sequential extraction method described by Lili et al., [21, 22] was employed to determine the speciation of potentially toxic elements. Table 1 outlines the operational methods and corresponding extraction forms. The proportion of each fraction was calculated as the ratio of its extraction concentration to the total extraction concentration of all five fractions. The extracted potentially toxic elements were quantified using Atomic Absorption Spectroscopy (AAS).

Table 1: Overview of the five-step sequential extraction procedure used in this work (Tessier et al, 1979)

Sequential Fractions	Extractant	Operating Conditions
Exchangeable Fraction	8 mL of 1.0 M MgC_{l2} (pH = 7.0)	Shake at 25 ± 1 ^{0}C for 1 h
Carbonate fraction	8 mL of 1.0 M NaAc pH = 5.0)	Shake at 25 ± 1 ^{0}C for 5 h
Fe-Mn Oxide fraction	20 mL of 0.04 M $NH_2OH.HCl$ in 25% (v/v) CH_3COOH	Shake at 96 ± 3 ^{0}C for 6 h

Organic fraction	3 mL of 0.02 M of HNO_3 5 mL of 30 % (v/v) H_2O_2 (pH = 2.0)	Shake at 85 ± 2 ^{0}C for 3 h
Residual fraction	7.5 mL of 37% HCl and 2,5 mL of HNO_3	Shake at 85 ± 2 ^{0}C for 1 h

Mobility Factor

The mobility factor (MF) is an index of potential metal Ion mobility in the soil, was calculated using relationship $MF = \frac{F1+F2+F3+F4}{F1+F2+F3+F4+F5} - - - - - - - - - - - - (1)$

Where F1, F2, F3, F4, and F5 represent the fractions bond to exchangeable, carbonate, Fe-Mn Oxide, Organic and Residual [23]

Results and Discussion

The potentially toxic elements concentrations in soil and water obtained from various Sites within Jos Metropolis are presented in Table 2 and 3, while the sequential extraction results are presented in Table 4 - 8 and the mobility factor results are presented in Figure 1.

The results of potentially toxic elements in soil presented in Table 2, revealed that all sampling sites are contaminated with Pb, with concentrations from 53.90 mg/kg (site B, the farm site) to 271.90 mg/kg (site E, the Dam site). Notably, sites A, C, and E which corresponds to industrial, dumpsite, and dam areas, respectively, have higher Pb concentrations (121.90, 126.80, and 271.90 mg/kg) compared to the control site (81.80 mg/kg). These findings suggest that industrial activities, waste disposal and dam-related processes may be significant sources of Pb pollution in the environment. Previous work also reported high level of Pb from dumpsite [22] which agreed with this finding. Soil contamination with Pb can enter the human body through the food chain, posing a significant health risk, particularly for vulnerable populations such as young children and pregnant women. Pb poisoning can affect nearly every organ and system being primary target in both children, exposure to pb can lead to developmental issues, including reduced IQ, attention span deficits, hyperactivity, impaired growth, and various disabilities [24].

The concentration of essential trace elements like Zn, Cu, Fe, and Mn varied across the studied sites as indicated in Table 2. For Zn the concentrations ranged 144.10 mg/kg at the control site to 298.80 mg/kg at the dam site, with industrial, farm, and dam sites having concentrations of 215.50, 155.50, and 178.80 mg/kg respectively. Cu concentrations ranged from 83.90 to 126.10 mg/kg, with the control site (111.30 mg/kg) exceeding the dam and farm sites. Fe concentrations were highest at the control site, consistent with the general abundant of Fe in soil.

A similar trend was observed for Mn, except at the farm site, which had the higher concentration (202.20 mg/kg) than the control site (197.80 mg/kg).

Other potentially toxic elements, including Cd, Hg, and As, exhibited varying concentrations across the sites, with Cd ranging from 74.60 to 120.30 mg/kg. Hg from 26.00 to 47.20 mg/kg, and As from 15.10 to 46.00 mg/kg. Given their toxicity even at low concentrations, these findings raise concerns about potential ground water pollution and long- term soil contamination.

According to Table 2, the control site had the lowest concentration of Co (67.40 mg/kg) and Cr (75.10 mg/kg) compared to other sites. In contrast, the control site's Ni concentration (117.00 mg/kg) was higher than those of the industrial (82.90 mg/kg), dumpsite (88.00 mg/kg), and dam site (70.70 mg/kg) but lower than farm site's concentration (121.50 mg/kg), this may be attributed to agricultural practices at the farm. Co can be toxic to plants and microorganisms at a higher concentrations and excessive Co can also harm human health. Cr specifically hexavalent species is highly toxic and carcinogenic while Ni can be toxic to plants and animals. The concentrations of other elements including Ti, Sr, and Zr, are presented in Table 2 and although they vary in concentrations, they are generally considered non-toxic.

The concentrations of potentially toxic elements in water samples are presented in Table 3. The results show varying levels of these elements across different sites. Notably, Pb, Cd, Hg, As, and Ni exceeded the standard organization of Nigeria guidelines for raw water, with concentrations surpassing the limits of 0.01, 0.003, 0.001, 0.01, and 0.002 mg/L, respectively. In contrast, Cu, Mn, and Fe concentrations were within the acceptable limits, falling below the guideline values of 1.0, 20.0 and 0.3 mg/L respectively except for the dumpsite with the concentration of Fe 0.397 slightly higher than the standard (0.3 mg/L) [25].

Speciation of Potentially Toxic Elements

The results of sequential extraction of potentially toxic elements are presented from Table 4 - 8. The results for Pb in soils, presented in Table 4 – 8, reveal a similar trend across the studied sites, with Pb predominantly found in the exchangeable and carbonate fractions. Specifically, the industrial, farm, and control sites showed higher concentrations of Pb in both exchangeable and carbonate fractions compared to other fractions. However, the dumpsite and dam sites exhibited a different pattern, with Pb concentrations higher in the carbonate fraction than in the exchangeable fraction. Other studies reported similar trends [13, 26].

In the industrial site, Cd exhibited higher concentrations in the exchangeable (26.60 mg/kg) and carbonate (18.30 mg/kg) fractions, as shown in Table 4. In contrast, the control site had the lowest Cd concentration (1.30 mg/kg).

Meanwhile, Hg was predominantly found in the organic fraction (11.80 mg/kg), followed by the carbonate fraction (4.90 mg/kg). As, on the other hand, was mostly concentrated in the residual fraction (26.50 mg/kg), with a significant presence also in the carbonate fraction (6.20 mg/kg), both observed in the industrial site. [14, 17]

A similar trend was observed in the farm site, where Cd was predominantly found in the carbonate fraction (18.80 mg/kg), followed by the exchangeable fraction (16.50 mg/kg). The control site had the least Cd concentration (1.10 mg/kg). In contrast, Hg was mostly concentrated in the organic fraction 910.20 mg/kg), with minimal presence in the exchangeable fraction (0.20 mg/kg). Meanwhile, As was primarily associated with the residual fraction (14.30 mg/kg), with the least concentration found in the organic fraction (1.60 mg/kg), as shown in Table 5.

In the dumpsite, Cd was predominantly found in the carbonate fraction (28.30 mg/kg), with the lowest concentration in the residual fraction (2.80 mg/kg). The order of Cd concentration was carbonate > exchangeable > Fe-Mn oxide > organic > residual. In contrast, Hg concentrations followed the order: organic > residual > Fe-Mn oxide > carbonate > exchangeable. As was primarily associated with the residual fraction, followed by Fe-Mn oxide, organic and exchangeable fractions (Table 6).

In the control site, Cd was highest in the carbonate fraction, followed by the Fe-Mn oxide fraction, and least in the organic fraction. Hg concentrations followed the order; organic > Fe-Mn oxide > residual, with equal concentrations in the carbonate and exchangeable fractions (0.30 mg/kg). The distribution of arsenic (As) in the control site, from highest to lowest concentration, was residual fraction > organic fraction > Fe-Mn oxide fraction > exchangeable fraction (Table 7).

In the dam site, Cd was predominantly found in the carbonate fraction (28.30 mg/kg), followed by the exchangeable fraction (21.10 mg/kg), with the lowest concentration in the residual fraction (1.60 mg/kg0. In contrast, Hg was highest in the organic fraction (15.80 mg/kg) and lowest in the Fe-Mn oxide fraction (1.60 mg/kg). Meanwhile, As was primarily associated with the residual fraction (13.10 mg/kg), with the lowest concentration in the carbonate fraction (0.90 mg/kg) as shown in Table 8.

The speciation results for other potentially toxic elements (Cr, Co), essential elements (Cu, Fe, Mn, Ni) and non-toxic elements (Ti, Sr, Zr) in the different study sites (Table 4 – 8) revealed distinct associations. Specifically, Cr was predominantly associated with the residual and Fe-Mn oxide fractions, Cu with organic and exchangeable fractions, Fe and Mn with the Fe-Mn oxide fraction, and Ni with the residual fraction. Additionally, Ti and Zr were primarily associated with the residual fraction, while Sr was linked to the carbonate fraction.

Mobility Factor

The mobility factor is a crucial parameter in speciation studies, enabling researchers and practitioners to better understand and manage environmental risks associated with element mobility in soil. The results presented in Figure 1, reveal that Pb, Zn, Cu, Fe, Mn, Cr, Hg, and Sr exhibit high mobility (0.8 – 0.9) across all the studied sites, indicating potential bioavailability. This warrants caution, particularly for highly toxic elements like Pb, Hg, and Cd which can enter food chain through plant uptake and pose carcinogenic risks to humans. In contrast, Cr shows moderate mobility (0.5 – 0.6) across all sites, suggesting potential bioavailability. Other elements display varying mobility patterns. Co is moderately mobile in dumpsite (0.543) but less mobile in other sites (0.2 -0.4) across most sites, except for Ti is moderate mobility in farm, dumpsite, control, and dam sites (0.5) and low mobility in the industrial site 0.2.[13,17]

Conclusion

In conclusion the speciation and bioavailability of potentially toxic elements (PTEs) in soil and water samples from Jos Metropolis revealed alarming levels of contamination: Pb, Cd, Hg, As, Cr, and Co were found in high concentrations in soil, while water samples exceeded Nigeria's industrial standard for raw water; posing significant health risks. The consistent pollution patterns across study sites and high mobility of Pb, Zn, Cu, Fe, Mn, Co, Hg, and Sr underscore the urgent need for remediation. Given the carcinogenic risks associated with Pb, Hg, and Cd, comprehensive risk assessments and effective remediation strategies are critical to mitigate these risks and promote environmental sustainability. this study's findings emphasize the importance of addressing PTE contamination to protect human health and the environment.

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Table 2: Heavy metals concentration in soil samples obtained from various location in Jos Metropolis (mg/kg)

sample	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
A	121.90 ± 2.34	215.50 ± 2.50	74.60 ± 1.45	72.60 ± 1.20	126.10 ± 2.75	140.90 ± 2.95	211.40 ± 3.34	166.80 ± 3.20	35.60 ± 0.34	82.90 ± 1.34	82.90 ± 1.45	34.50 ± 0.34	47.40 ± 1.20	25.70 ±0.94
B	53.90 ± 2.10	155.50 ± 3.34	87.10 ± 1.34	69.40 ± 1.24	83.90 ± 2.04	84.40 ± 2.10	82.30 ± 2.30	202.20 ± 3.34	41.80 ± 0.94	171.30 ± 4.34	105.20 ± 3.34	46.00 ± 2.34	35.10 ± 0.74	38.50 ± 0.84
C	126.80 ± 3.57	178.80 ± 3.68	78.20 ± 2.50	110.50 ± 3.50	140.70 ± 5.20	114.70 ± 4.20	233.90 ± 5.75	156.70 ± 4.50	47.20 ± 1.95	88.00 ± 2.85	117.30 ± 5.34	77.90 ± 2.20	53.30 ± 1.54	29.70 ± 0.34
D	81.80 ± 2.40	144.10 ± 4.50	76.00 ± 2.70	67.40 ± 1.70	111.30 ± 4.20	75.00 ± 2.10	375.40 ± 5.90	197.80 ± 4.90	32.60 ± 2.30	117.50 ± 3.60	46.90 ± 2.10	23.80 ± 1.20	60.40 ± 1.20	21.60 ± 1.40
E	271.90 ± 5.30	298.80 ± 6.34	120.30 ± 3.54	155.30 ± 4.04	73.50 ± 2.04	119.50 ± 4.34	264.80 ± 5.34	185.20 ± 3.34	26.00 ± 2.05	70.70 ± 0.90	87.80 ± 2.20	15.10 ± 0.34	49.10 ± 1.80	19.90 ± 1.50

Table 3: Heavy metals concentration in water samples obtained from various location in Jos Metropolis (mg/L)

sample	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
A	0.062 ±0.020	0.071 ±0.010	0.054 ±0.012	0.045 ±0.020	0.145 ±0.021	0.076 ±0.020	0.235 ±0.010	0.098 ±0.020	0.020 ±0.005	0.061 ±0.030	0.017 ±0.003	0.043 ±0.010	0.022 ±0.010	0.018 ±0.010
B	0.058 ±0.020	0.047 ±0.010	0.069 ±0.020	0.059 ±0.030	0.179 ±0.020	0.081 ±0.010	0.250 ±0.120	0.076 ±0.020	0.026 ±0.010	0.018 ±0.010	0.044 ±0.020	0.027 ±0.010	0.018 ±0.010	0.012 ± 0.010
C	0.051 ±0.010	0.230 ±0.020	0.098 ±0.030	0.257 ±0.020	0.228 ±0.020	0.364 ±0.120	0.397 ±0.010	0.202 ±0.010	0.025 ±0.010	0.161 ±0.020	0.071 ±0.010	0.075 ±0.010	0.075 ±0.010	0.120 ± 0.102
D	0.028 ±0.010	0.082 ±0.020	0.062 ±0.020	0.036 ±0.003	0.108 ±0.002	0.073 ±0.004	0.081 ±0.002	0.081 ±0.012	0.077 ±0.010	0.038 ±0.010	0.012 ±0.002	0.009 ±0.001	0.056 ±0.002	0.020 ± 0.001
E	0.152 ±0.003	0.162 ±0.020	0.073 ±0.010	0.242 ±0.003	0.210 ±0.002	0.243 ±0.003	0.263 ±0.040	0.149 ±0.003	0.108 ±0.010	0.207 ±0.002	0.037 ±0.002	0.101 ±0.010	0/108 ±0.003	0.025 ±0.002

Key: A = sample obtained from Industrial site, B = sample obtained from farm site, C = sample obtained from the dumpsite, D = sample obtained from control site, E = sample obtained from Dam

Table 4: Speciation of heavy metals in soil sample obtained from Industrial site in Jos Metropolis

Fractions	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
Exch. F	21.10	14.50	28.60	6.10	19.90	2.60	2.30	4.70	2.30	2.10	1.20	5.00	1.40	6.30
	±2.20	±1.30	±3.20	±0.80	±2.50	±0.40	±0.20	±0.80	±0.20	±0.20	±0.10	±2.10	±0.10	±0.60
Carbon F	12.80	11.40	18.30	9.20	5.40	3.70	3.30	1.30	4.90	0.50	1.00	6.20	15.30	2.10
	±2.50	±1.20	±2.20	±1.50	±1.20	±0.20	±0.10	±0.20	±1.20	±0.20	±0.04	±1.20	±2.60	±0.20
Fe-Mn. F	0.80	2.00	10.30	14.10	3.90	11.10	27.20	41.90	1.40	0.50	3.60	3.40	0.20	0.60
	±0.20	±0.20	±1.20	±2.30	±1.20	±2.70	±3.80	±4.20	±0.20	±0.20	±1.20	±0.30	±0.10	±0.20
Organic F	2.10	19.20	1.30	4.10	14.60	2.60	1.20	2.00	11.80	2.40	0.40	2.80	1.10	3.70
	±0.20	±2.20	±0.20	±0.40	±2.10	±0.40	±0.20	±0.20	±2.20	±0.10	±0.20	±1.30	±0.20	±1.20
Residual F	1.80	0.50	9.60	4.50	1.90	12.70	4.00	2.50	2.10	21.50	20.20	26.50	3.10	25.00
	±0.20	±0.10	±1.20	±1.50	±0.70	±1.20	±0.40	±0.20	±0.20	±2.20	±2.10	±2.40	±0.30	±2.60

Table 5: Speciation of Heavy metals in soil sample obtained from Farm Sie in Jos Metropolis

Fractions	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
Exch. F	13.00	12.00	16.50	1.70	14.60	1.40	1.40	7.60	0.20	2.10	2.40	5.60	5.30	4.50
	±2.20	±2.10	±2.20	±0.20	±2.10	±0.20	±0.20	±1.20	±0.10	±0.20	±0.20	±1.20	±1.20	±0.20
Carbon F	11.90	11.80	18.80	1.00	2.70	2.70	1.90	3.00	0.30	1.90	8.00	4.10	24.20	0.60
	±1.20	±1.20	±2.20	±0.20	±0.20	±0.20	±0.20	±0.30	±0.10	±0.20	±1.20	±0.60	±2.20	±0.20
Fe-Mn. F	2.90	2.40	3.10	14.30	8.30	12.30	19.00	12.70	3.60	3.20	0.90	5.70	1.60	2.00
	±0.20	±0.20	±0.20	±1.20	±1.20	±2.20	±2.20	±1.20	±0.20	±0.40	±0.20	±1.20	±0.20	±0.20
Organic F	2.70	17.10	1.10	4.70	17.50	5.40	1.10	1.40	10.70	3.50	2.70	1.60	1.60	1.00
	±0.20	±2.20	±0.20	±0.50	±2.20	±1.20	±0.20	±0.20	±1.20	±0.20	±0.20	±0.20	±0.20	±0.10
Residual F	3.30	2.00	2.80	1.80	1.90	21.30	2.40	1.30	0.30	22.70	10.00	14.30	1.20	12.20
	±0.20	±0.20	±0.20	±0.30	±0.20	±2.20	±0.20	±0.20	±0.10	±2.20	±1.20	±2.20	±0.20	±2.20

Table 6: Speciation of Heavy metals in soil sample obtained from Dumpsite in Jos Metropolis

Fractions	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
Exch. F	0.284	32.400	10.700	3.700	21.200	3.600	3.300	1.700	0.030	3.100	4.200	0.500	0.300	2.300
	±0.018	±5.018	±2.010	±0.901	±4.502	±0.905	±0.780	±0.503	±0.010	±0.050	±0.502	±0.078	±0.020	±0.405
Carbon F	14.500	24.800	28.300	2.900	2.200	0.900	2.600	4.400	0.400	2.700	6.600	0.600	12.200	0.900
	±2.018	±3.218	±3.040	±0.050	±0.501	±0.020	±0.060	±2.018	±0.060	±0.518	±1.504	±0.018	±3.601	±0.307
Fe-Mn. F	3.800	0.300	4.100	13.100	2.800	17.00	51.000	16.400	0.500	2.300	7.000	2.700	3.200	3.700
	±0.045	±0.030	±0.602	±2.704	±0.070	±4.503	±6.5-8	±6.402	±0.205	±0.603	±1.503	±0.502	±0.901	±0.604
Organic F	5.500	10.600	3.800	3.500	15.800	3.800	6.100	6.400	12.200	1.400	3.200	1.100	3.800	2.500
	±0.803	±2.405	±0.503	±0.603	±4.504	±0.604	±0.895	±0.903	±4.603	±0.705	±0.705	±0.504	±0.518	±0.028
Residual F	1.400	0.400	2.800	7.900	1.100	18.200	1.800	7.200	0.600	28.200	10.600	16.200	2.100	15.300
	±0.605	±0.018	±0.028	±0.503	±0.405	±4.502	±0.506	±0.818	±0.018	±7.502	±2.507	±5.901	±0.418	±3.780

Table 7: Speciation of Heavy metals in soil sample obtained from Control site in Jos Metropolis

Fractions	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
Exch. F	22.300	15.500	18.200	2.600	18.200	3.100	4.000	4.500	0.300	3.200	9.400	2.400	6.700	5.600
	±3.605	±1,302	±2.405	±0.805	±2.405	±0.780	±0.905	±0.705	±0.105	±0.805	±2.501	±0.305	±1.605	±1.205
Carbon F	17.400	12.400	38.700	4.300	0.800	2.500	5.400	6.500	0.300	1.800	4.700	2.800	23.000	7.800
	±4.605	±3.605	±10.605	±1.605	±0.505	±0.805	±0.705	±0.805	±0.105	±0.405	±0.805	±0.405	±4.701	±1.605
Fe-Mn. F	0.400	0.200	19.600	18.000	3.700	17.800	20.700	24.200	0.700	1.900	8.800	1.700	1.700	5.900
	±0.150	±0.050	±3.502	±3.705	±0.801	±4.503	±5.605	±6.505	±0.405	±0.605	±1.605	±0.505	±0.605	±1.605
Organic F	2.500	15.000	7.900	2.600	14.700	3.100	1.500	6.600	12.900	1.600	3.300	2.800	1.100	6.300
	±0.850	±4.507	±2.508	±0.805	±4.504	±0.805	±0.405	±0.705	±3.605	±0.505	±0.905	±0.620	±0.610	±1.705
Residual F	3.600	0.600	9.300	5.200	2.600	15.700	1.500	6.600	0.400	21.000	15.800	34.800	1.100	32.400
	±0.650	±0.205	±2.605	±0.906	±0.708	±3.501	±0.670	±2.500	±0.105	±5.605	±3.605	±10.605	±0.705	±10.602

Table 8: Speciation of Heavy metals in soil sample obtained from Dam in Jos Metropolis

Fractions	Pb	Zn	Cd	Co	Cu	Cr	Fe	Mn	Hg	Ni	Ti	As	Sr	Zr
Exch. F	10.700	14.500	21.100	5.400	17.200	4.500	2.600	8.900	3.500	1.800	2.000	5.800	4.700	3.700
	±2.705	±3.540	±6.705	±0.905	±4.501	±1.604	±0.705	±2.705	±0.805	±0.620	±0.650	±2.504	±1.504	±1.901
Carbon F	12.600	11.300	28.300	2.400	1.500	4.400	3.200	2.200	2.100	3.800	6.700	0.900	26.400	5.400
	±3.503	±2.890	±10.450	±0.850	±0.704	±0.950	±0.902	±0.805	±0.801	±1.602	±2.402	±0.440	±8.705	±2.501
Fe-Mn. F	4.300	17.000	5.500	19.900	3.300	11.400	18.300	35.200	1.600	1.600	6.400	2.400	4.200	0.200
	±1.202	±3.603	±1.901	±4.501	±0.801	±2,902	±5.701	±10.201	±0.702	±0.702	±2.401	±0.801	±0.950	±0.020
Organic F	6.100	11.300	6.700	3.900	13.000	3.800	1.400	3.300	15.800	2.900	5.000	2.800	4.200	5.400
	±2.403	±3.450	±2.702	±0.805	±3.701	±0.850	±0.805	±1.502	±4.503	±0.805	±1.406	±0.702	±1.205	±1.803
Residual F	3.000	0.600	1.600	1.500	3.000	19.900	2.000	1.700	2.100	15.200	16.700	13.100	1.200	24.500
	±0.701	±0.202	±0.502	±0.450	±0.750	±4.504	±0.750	±0.650	±0.860	±3.503	±4.501	±4.520	±0.650	±8.502

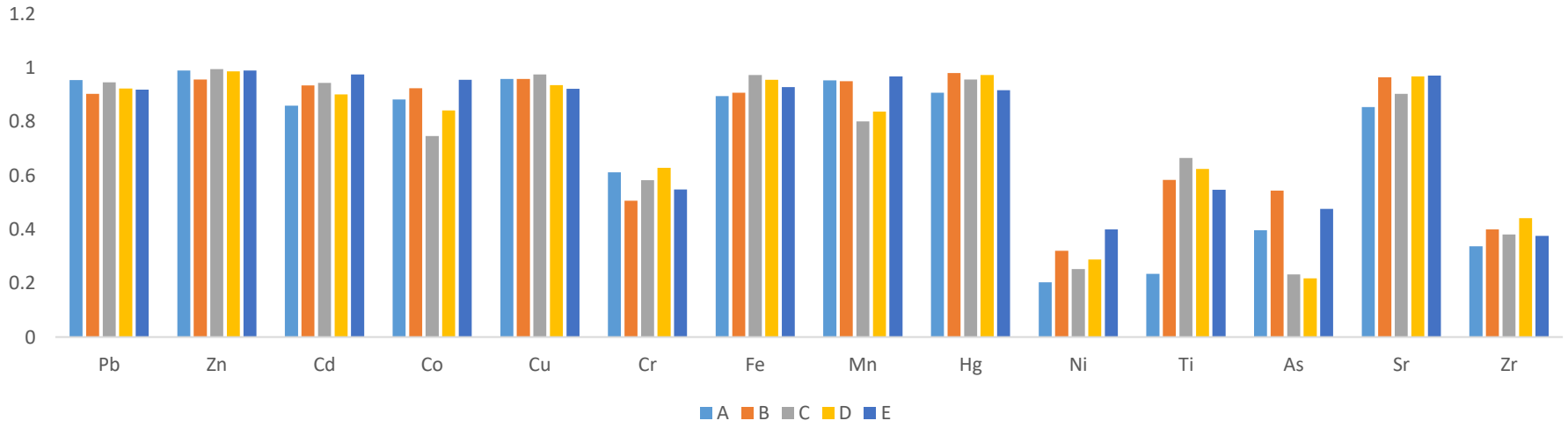

Figure 1: Mobility factor of potentially toxic elements from various studied site in Jos Metropolis

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