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Assessment of Potential Ecological Risk of Heavy Metals in Soils from Waste Dumpsites in Military Formations in Makurdi, Nigeria

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Abstract

Chemical fractionation of toxic metals (As, Cd and Zn) along the soil profile at waste dumpsites in military formations for dry and wet seasons using Tessier's sequential extraction procedure was determined using AAS techniques. The order of yield across the fractions was mainly: exchangeable (F_1) < carbonate-bound (F_2) < Fe/Mn oxide-bound (F_3) < organic matter-bound (F_4) < residual (F_5). Statistical analysis ($p < 0.05$) indicated that there was no significant variation between the values of results obtained from dumpsites A and B of each sampling station. However, the variation between the dumpsites and control was significant ($p > 0.05$) in most stations. The pollution index was assessed using the degree of contamination (C_d), the modified degree of contamination (mC_d), potential ecological risk and mobility factor. The C_d indicated that NFB top soil was considerably contaminated (16.3) while the soils (20 - 40 and 40 - 80 cm) recorded moderate (13.6) and low (5.60) contaminations respectively. Top soil of NSM was moderately contaminated while the contamination status of NPS, NFB and SFB waste dump soils across the depths was "low". The mC_d index for NFB dump soil was "moderate" (2.33) and subsoils (20 - 40 and 40 - 80 cm) were "low" (1.94) and "Nil to very low" (0.800) respectively. The mC_d for the other three dumpsites was "Nil to very low" except the top soil of NSM which was "low". The order of the toxic metals mobility in the studied soils using the Mobility factor (M_f) for dry and wet seasons was Cd > As > Zn and Zn > Cd > As respectively.

Keywords

Toxic Metals, Pollution Index, Military Formations, Dumpsites, Soil

1. Introduction

Open waste dumpsites are common sites at road junctions, riversides, uncompleted buildings and closed pits in Nigeria [1] [2] [3]. These poorly managed dumpsites, such as the one shown in **Figure 1**, may contain toxic wastes from industrial, domestic, electronics, hospital sources among others. According to Abdu-Salam *et al.* [4], the challenges of solid waste management to the environment range from soil and water contamination to health hazards and offensive odours. Most dumpsites are located within the vicinity of living communities and wetlands. Dumpsites are often not prepared for selective adsorption of toxic substances; consequently, they can easily release pollutants to the soil and nearby water sources as well as the atmosphere through leachates and dumpsite gases [5]. The indiscriminate refuse dumping has contaminated many soils and water sources making them hazardous to man and other living systems [6]. Since some heavy metals are systemic toxins with specific nephrotoxic, ferotoxic, carcinogenic and teratogenic effects, they could initiate metabolic disorders in man and other living organisms [7]. Good knowledge of the heavy metals bearing phases and their solubility in aqueous solution helps in determining their potential mobility and bioavailability (lability) [8]. Speciation of heavy metals in soils determines the availability of metals for plant uptake [9]. Therefore, information on speciation of metal in a soil is vital to assessing the hazard that these contaminants represent, and it can also guide the choice of remediation technologies [8]. Studies, on heavy metal contamination of waste dumpsites, in many cities across the globe, have shown the varying levels as well as effects of the toxic heavy metals on man and the environment [7] [10]-[16]. However, there has not been any report on the seasonal variation of heavy metals in waste dumpsites in military formations in Makurdi. This research, therefore investigated the seasonal chemical fractionation of As, Cd and Zn in some refuse dumpsites of Military formations in Makurdi Metropolis and the potential ecological risks associated with the waste dumpsites.

2. Materials and Methods

Analytical grade reagents from Sigma-Aldich Chemical Company (USA) were

Figure 1. Open Waste Dumpsite at NFB in Makurdi as at 14th March, 2015.

used for preparing all the solutions. Double-distilled de-ionised water from BDH Company limited was used for blank determinations. Buck 200A model Perkin Elmer AAS was used for the determination of heavy metals.

2.1. Study Area

Makurdi is situated at Latitude 8˚25' to 8˚50' North and Longitude 7˚35' to 7˚55'East. Its elevation is 104 meters above mean sea level. The climate of Makurdi is tropical savanna with dry and wet seasons. The dry season which lasts from November to March is commonly accompanied by harmattan and high weather temperatures (21˚C - 37˚C) while the wet season, April to October, is characterised by high rainfall of about 1200 mm - 1650 mm and relative low daily temperatures of 18˚C - 34˚C [17]. A map of Makurdi showing the geographical coordinates, the sampling locations and streets is shown in **Figure 2**. The military formations in Makurdi are the Nigerian Army School of Military Engineering (NSM), the 72 Special Forces Battalion (SFB), the Nigerian Navy Provost and Regulating School (NPS) and Nigerian Air Force Base (NFB). The Germin (GPS map 76 CSx) was used to obtain the coordinates of the dumpsites as indicated at the sampling points. The co-ordinates are listed on the map in the Universal Transverse Mercator (UTM) coordinate system.

2.2. Sampling Design and Soil Sampling

Soil samples were collected randomly with a soil auger at depths of; 0 - 20 cm, 20 - 40 cm and 40 - 80 cm in each dumpsite. Two dumpsites designated as A and B in each military formation were considered. The soil samples from each part per dumpsite were pooled together to form composite soil samples [18]. Control samples were obtained for each dumpsite at same depths with the other samples and at a distance of above 50 meter upstream. A total of eight dumpsites from

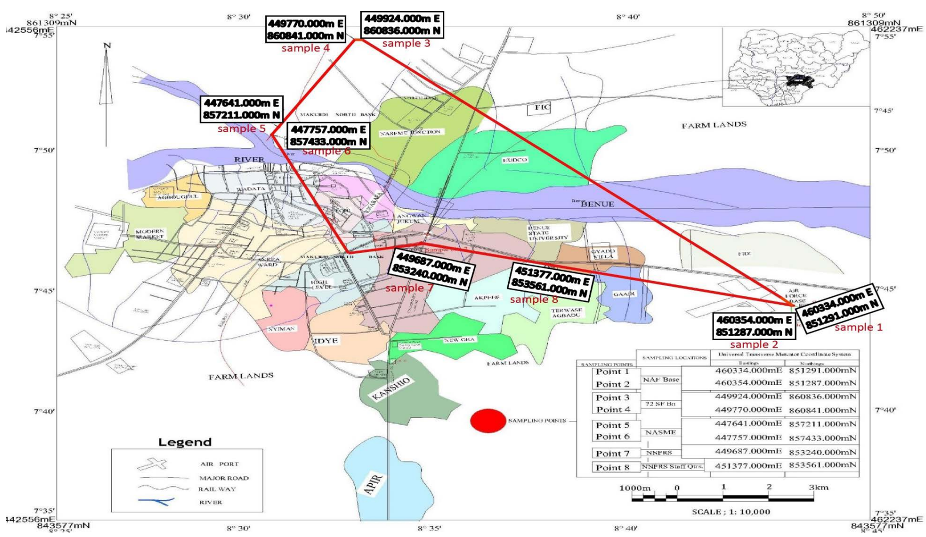

Figure 2. Map of Makurdi Metropolis showing the study area (Source: Ministry of Land and Survey Makurdi, 2014).

four military formations generated twenty four composite samples from the three depths just as the control samples. The samples were then taken to the laboratory for sorting and sample preparation. Sampling was done at the peak of the dry season (March, 2015) and the peak of wet season (August, 2015).

2.3. Sample Preparation, Pretreatment and Digestion

The samples were kept in polythene bags that were free from heavy metals and well covered while transporting from the field to the laboratory to avoid contamination from external environment. Samples were then air dried in the laboratory, ground, sieved to give < 2 mm particle size and composited. Standard operating procedures were used to test soil properties: pH, organic matter and the total metal concentration after digestion with aqua regia [7] [13]. Exactly 1.0 g of the sieved sample was weighed into a beaker where a mixture of 5 mL HF and 5 mL aqua regia was added and digested in a water bath at 100˚C for 1.5 hours. Thereafter, another 5 mL HF and 5 mL aqua regia were added and digested for another 1.5 hours for complete decomposition of the sample. The sample was allowed to cool at ambient temperature and 20 mL saturated boric acid (H_3BO_3) was added and filtered into 50 mL standard flask using Whatman No. 1 filter paper. The filtrates were made up to mark after rinsates were transferred with deionised water and properly labeled prior to AAS analysis [18].

2.4. Assessment Indices

Three assessment indices were used to ascertain the potential ecological risk of the soils at military formations dumpsites. These include C_d, mC_d and potential ecological risk. A quantitative evaluation of contamination and potential ecological risks of heavy metals in soils can be described in terms of the contamination factor: $C_f^i < 1$, low contamination factor; $1 \le C_f^i < 3$, moderate contamination factors; $3 \le C_f^i < 6$, considerable contamination factor; and $C_f^i \ge 6$, very high contamination factor [19]. The contamination factor (C_f^i) was further expanded to be defined as:

$$C_f^i = \frac{C_i}{C_{ri}} \quad (1)$$

where C_i is the content of metal *i* instead of mean content from at least 5 sample sites; C_{ri} is the reference value, baseline level, or national criteria of metal *i* [20]. When the sediment quality guideline is selected for the C_{ri}, the contamination factor (CF) is equal to the sediment quality guidelines such as effect range low (*ERL*)/effect range median (*ERM*), and threshold effect level (*TEL*)/probable effect level (*PEL*) [21].

2.4.1. Modified Degree of Contamination

A method employed by Xu *et al.* [22] was used to find out the degree of contamination (C_d) and modified degree of contamination (mC_d), which can describe the toxicity of a metal. An overall indicator of contamination, known as degree of contamination, (C_d) is based on the calculation of contamination factor (CF) for each pollutant. It is a measure of the degree of overall contamination in surface layers as given in Equation (2):

$$\mathrm{Cd} = \sum_{i=1}^{n} \mathrm{CF} \tag{2}$$

where n = number of analysed elements, i = i^{th} element (or pollutant), CF = Contamination factor. CF is determined as the ratio of metal concentration in soil to the metals' background value [23].

Modified degree of contamination (mC_d) is the sum of all the contamination factors for a given set of pollutants divided by the number of analysed pollutants. It averages the contamination of all elements at a particular site by a single value according to Equation (3):

$$\mathrm{mC_d} = \frac{\sum_{i=1}^{n} \mathrm{CF}}{n} \tag{3}$$

2.4.2. Percentage Compositions

The percentage of heavy metals (As, Cd and Zn) in different fractions of soil at the various waste dumpsites for dry and wet seasons were calculated in accordance with Tessier *et al.* [24]. The metal concentration (mg/kg) in each fraction was converted to extraction yield (%) using the Equation (4):

$$\text{Extraction Yield } (\%) = \frac{\mathrm{F}_i}{\sum_{i=1}^{5} \mathrm{F}_i} \times 100 \tag{4}$$

where $\sum_{i=1}^{5} \mathrm{F}_i = \mathrm{F}_1 + \mathrm{F}_2 + \mathrm{F}_3 + \mathrm{F}_4 + \mathrm{F}_5$.

2.4.3. Mobility Factor

The Mobility Factor (M_f) of soils samples (%) was calculated relative to F_1 and F_2 which are considered to constitute the most weakly bound metals as expressed in Equation (5) [17].

$$\mathrm{M_f} = \left(\frac{\mathrm{F}_1 + \mathrm{F}_2}{\mathrm{F}_1 + \mathrm{F}_2 + \mathrm{F}_3 + \mathrm{F}_4 + \mathrm{F}_5} \right) \times 100 \tag{5}$$

2.4.4. Potential Ecological Risk

An ecological risk factor (E_r^i) to quantitatively express the potential ecological risk of a given contaminant suggested by Hakanson [19] was used as in Equation (6).

$$E_r^i = T_r^i C_f^i \tag{6}$$

where T_r^i is the toxic-response factor for a given substance with values for Zn = 1, As = 10, Cd = 30, and C_f^i is the contamination factor of each metal. The potential ecological risks were classified on the basis of the values of the risk factor as: $E_r^i < 40$, low potential ecological risk; $40 \le E_r^i < 80$, moderate potential ecological risk; $80 \le E_r^i < 160$, considerable potential ecological risk; $160 \le E_r^i < 320$, high potential ecological risk; and $E_r^i \ge 320$, very high potential ecological risk.

2.5. Data Analysis

Statistical analysis was performed on triplicate results of each sample and the mean and standard deviation of each value was calculated using SPSS 16.0. Analysis of variance (2-way) was used to compare the difference in mean values across the various sites and the various soil depths with level of significance set at P = 0.05 (two-tailed).

3. Results and Discussion

3.1. Chemical Fractionation

The levels of heavy metals (As, Cd and Zn) in different fractions of the soil across various waste dumpsites for dry and wet seasons are illustrated in **Figures 3-14**. It was observed that the toxic metals were predominantly present in the soil depth of mostly between 0 - 40 cm for As and Cd while Zn was found in all the soil profiles investigated. This indicated that Zn can leach deeper or faster into the soil than As and Cd.

The seasonal variation in the levels of the metals could be due to dilution and run-off effects, which can respectively leach and remove the metals during wet season. However, the metals may concentrate during the dry season because of evaporation and burning of the wastes, which is a common practice at the dumpsites.

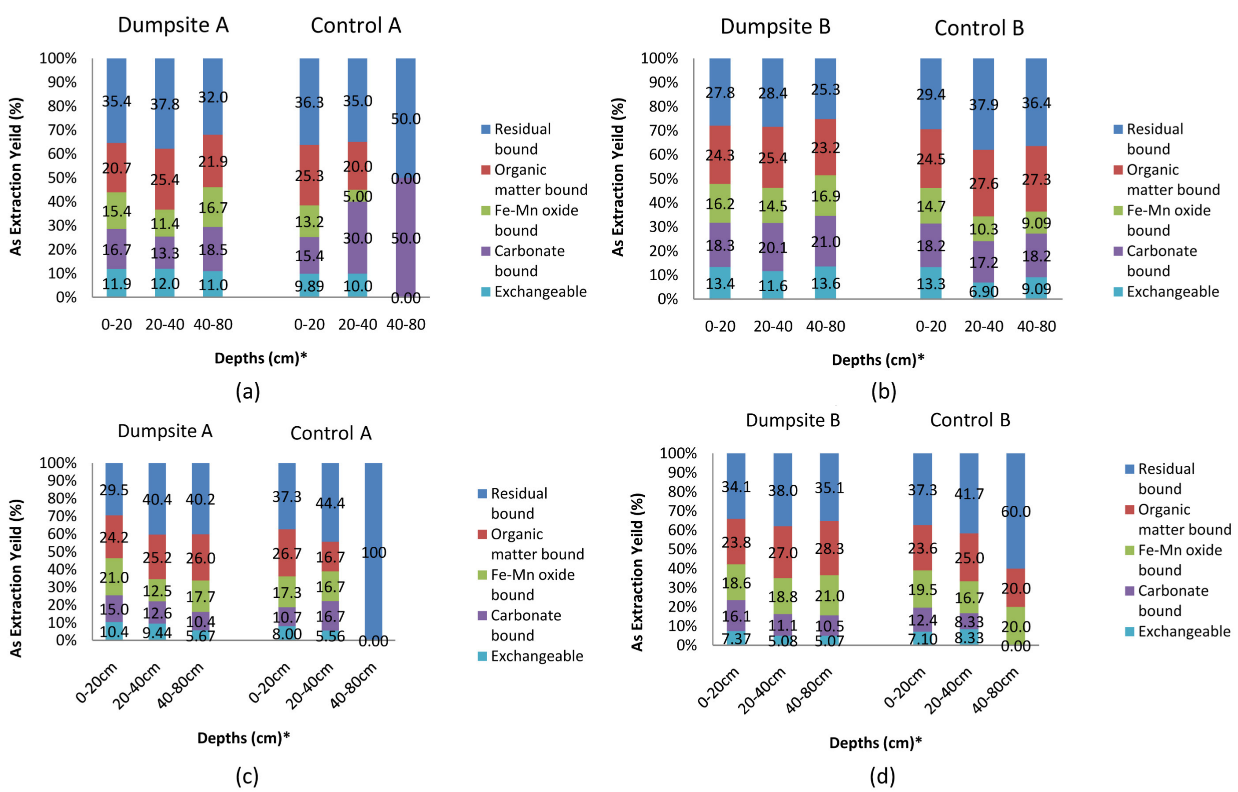

Figure 3. Arsenic extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NFB waste dumpsites.

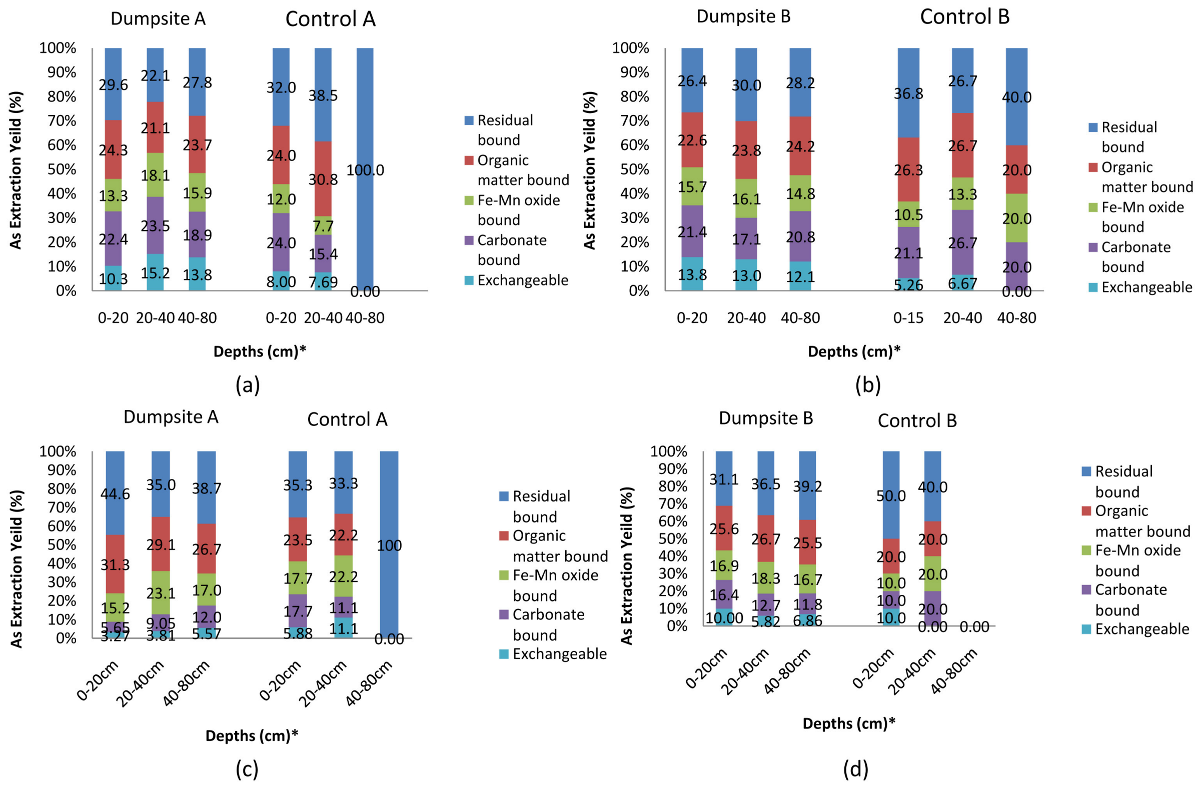

Figure 4. Arsenic extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NSM waste dumpsites.

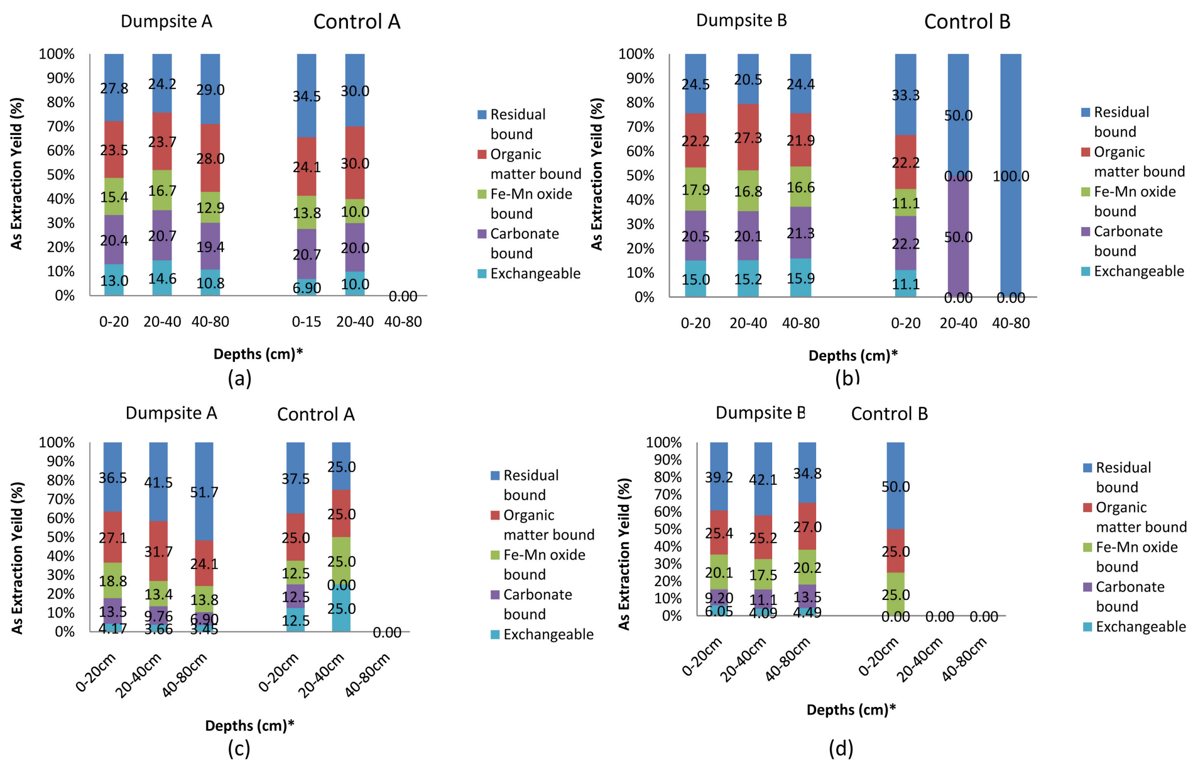

Figure 5. Arsenic extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NPS waste dumpsites.

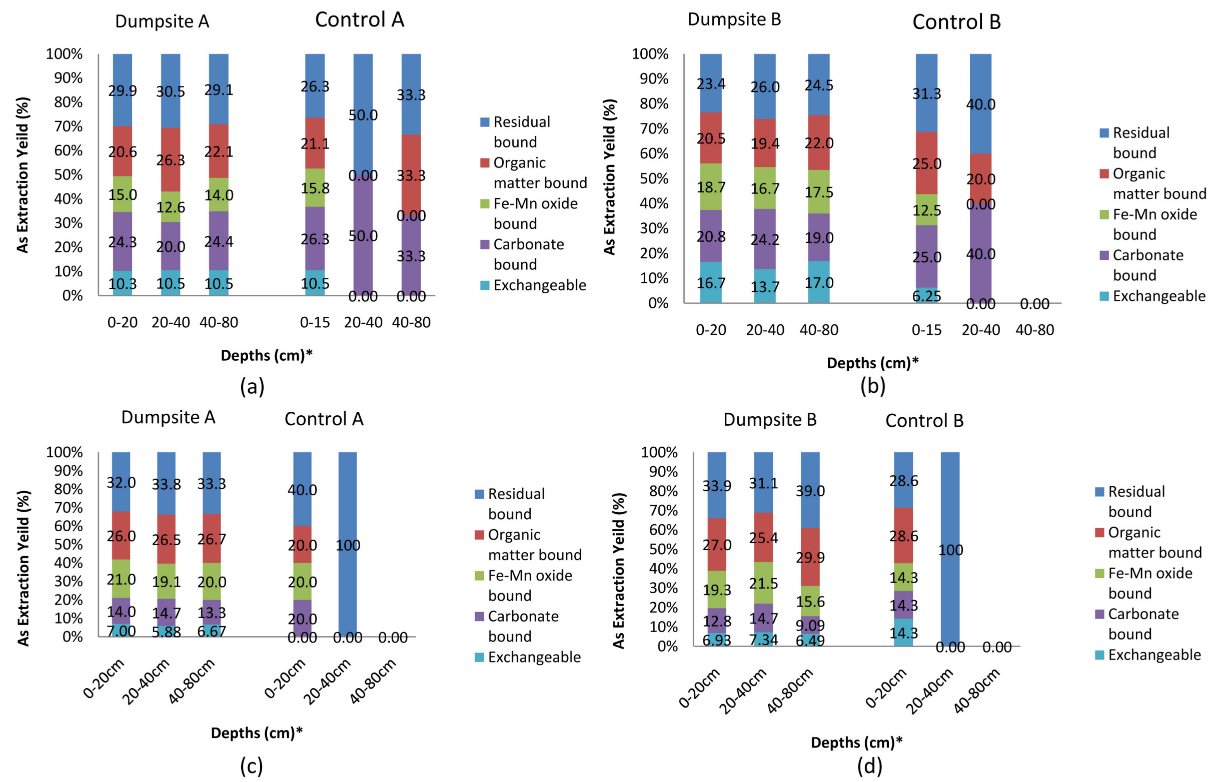

Figure 6. Arsenic extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at SFB waste dumpsites.

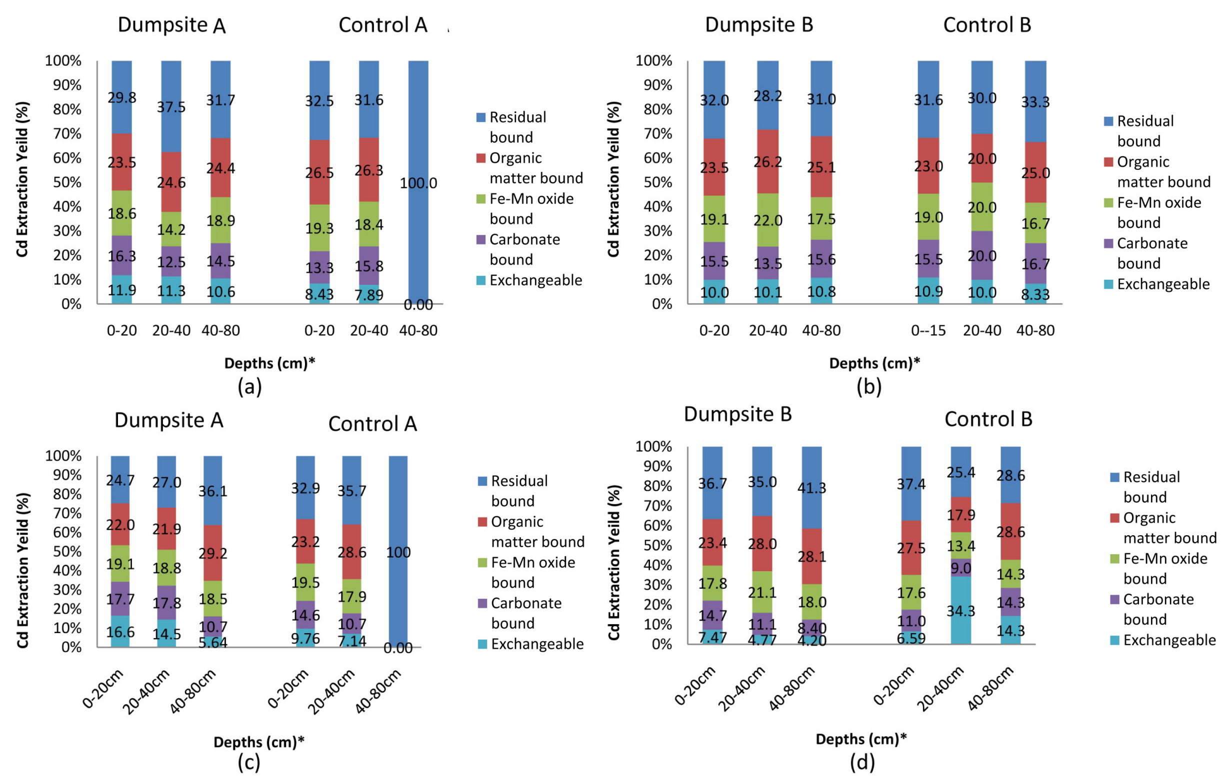

Figure 7. Cadmium extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NFB waste dumpsites.

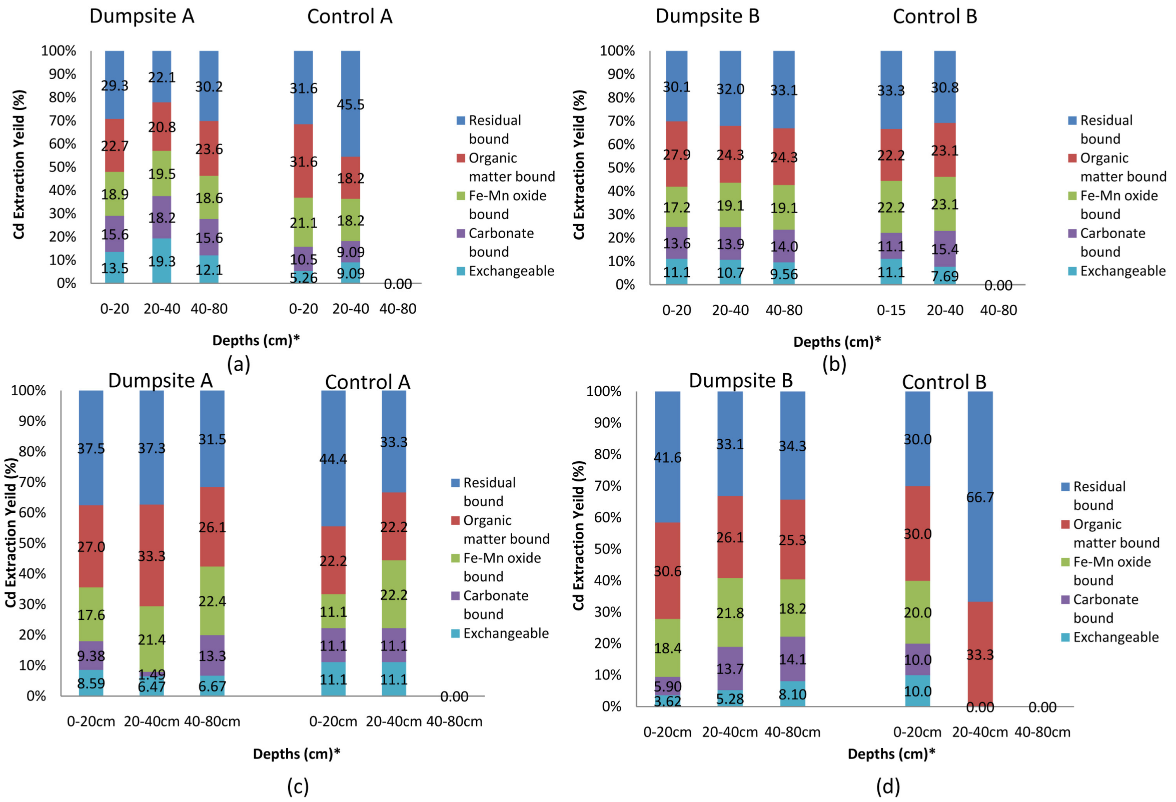

Figure 8. Cadmium extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NSM waste dumpsites.

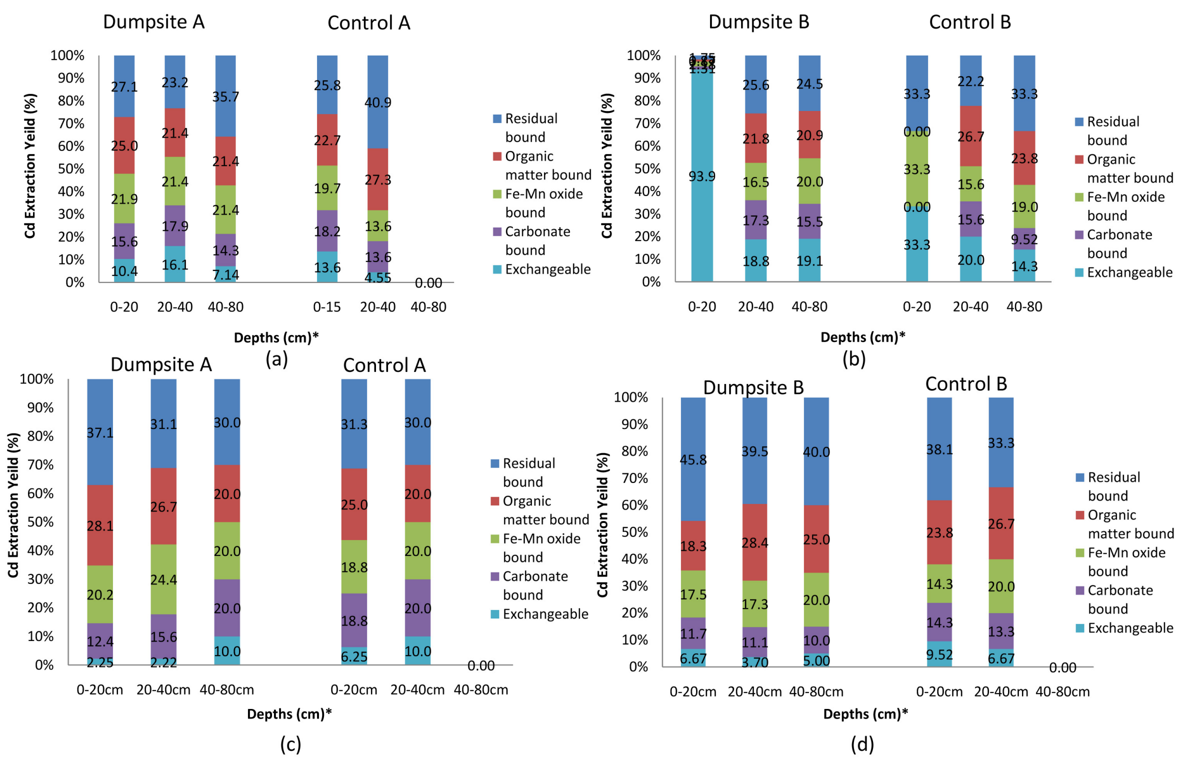

Figure 9. Cadmium extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NPS waste dumpsites.

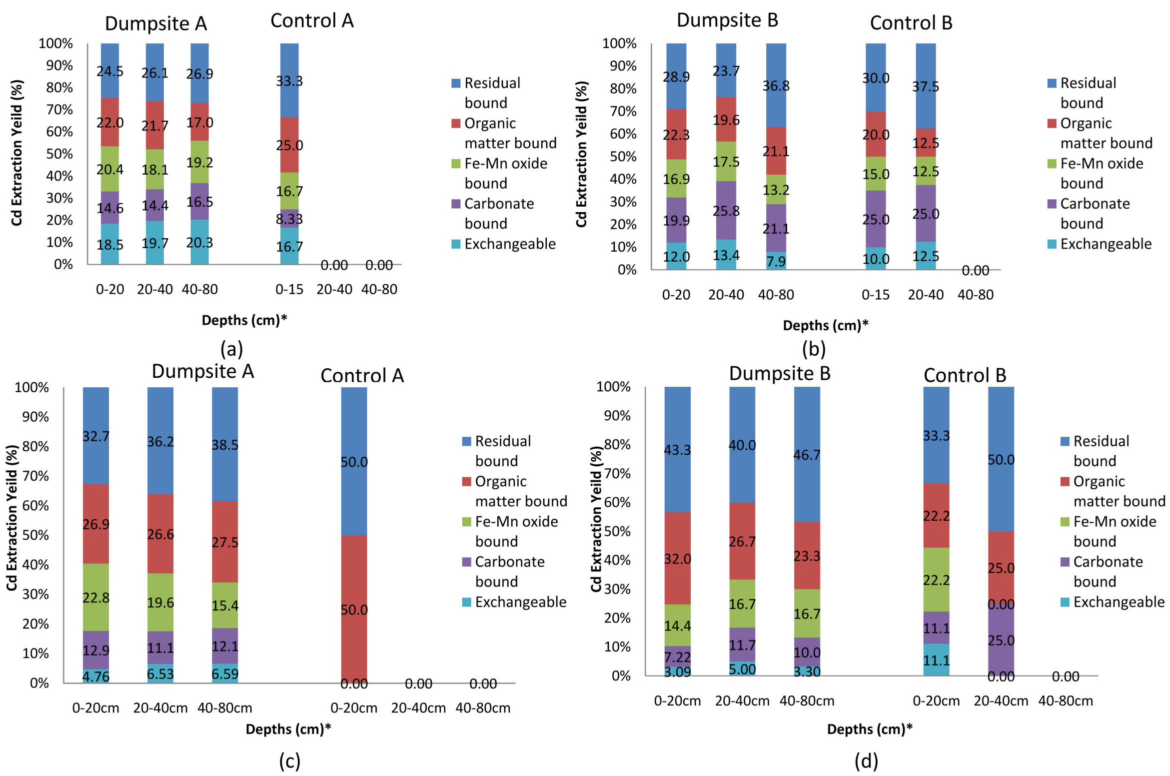

Figure 10. Cadmium extraction yields (%) in Soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at SFB waste dumpsites.

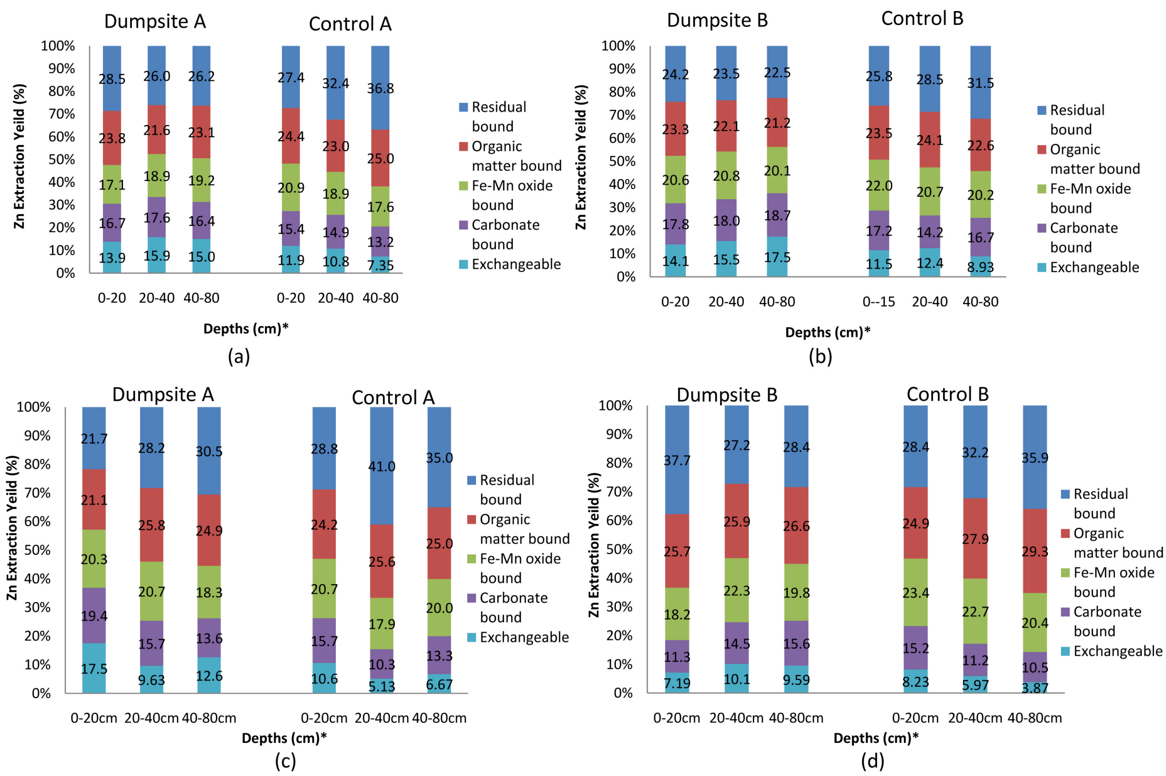

Figure 11. Zinc extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NFB waste dumpsites.

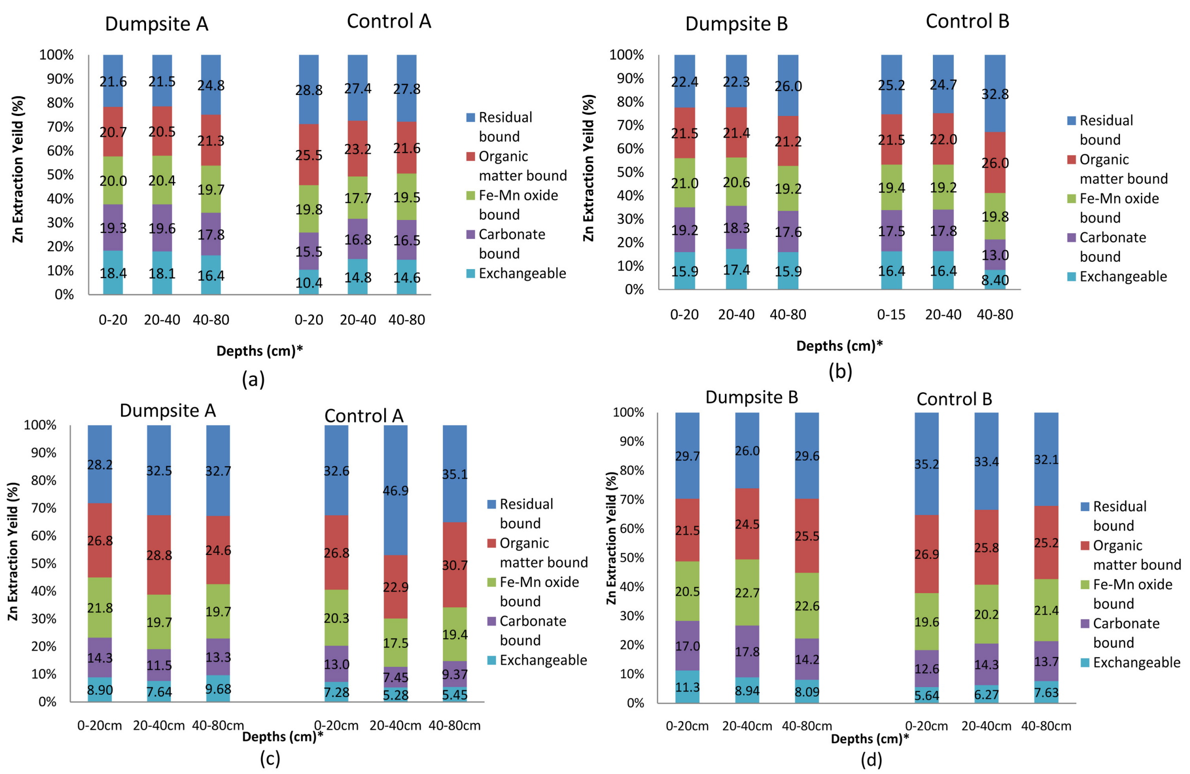

Figure 12. Zinc extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NSM waste dumpsites.

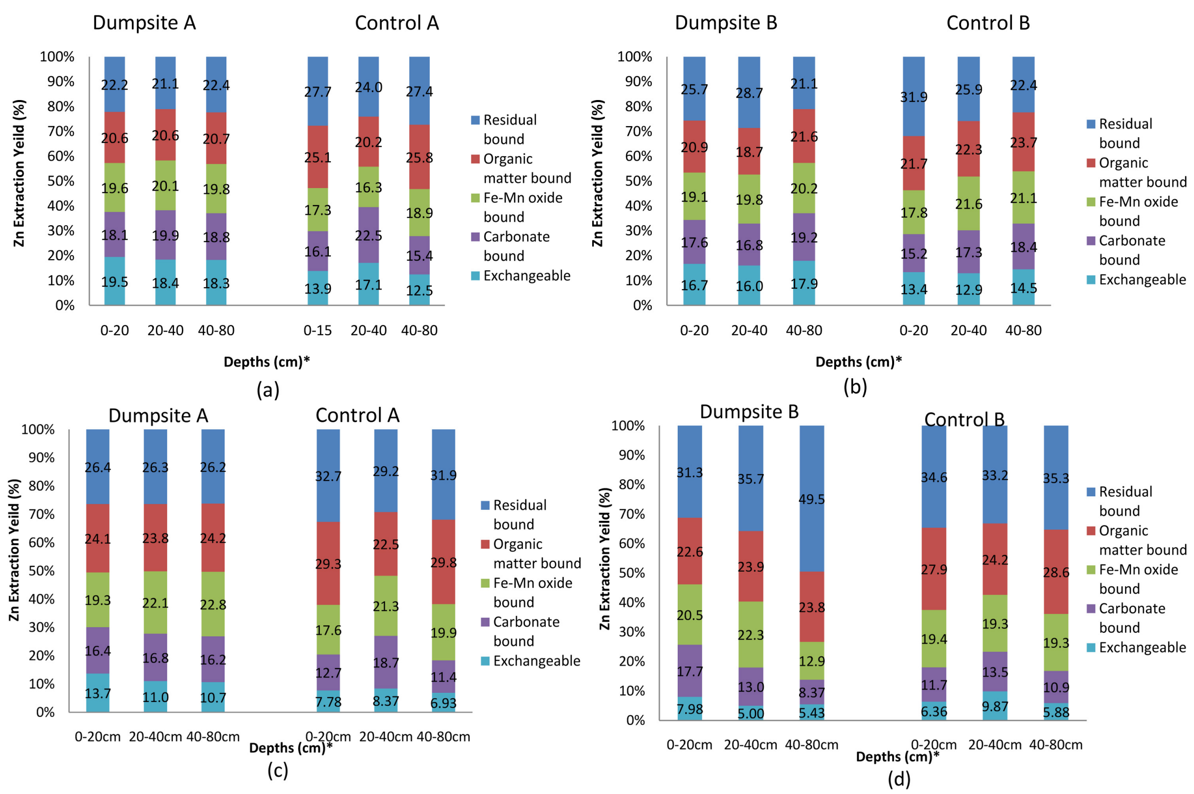

Figure 13. Zinc extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at NPS waste dumpsites.

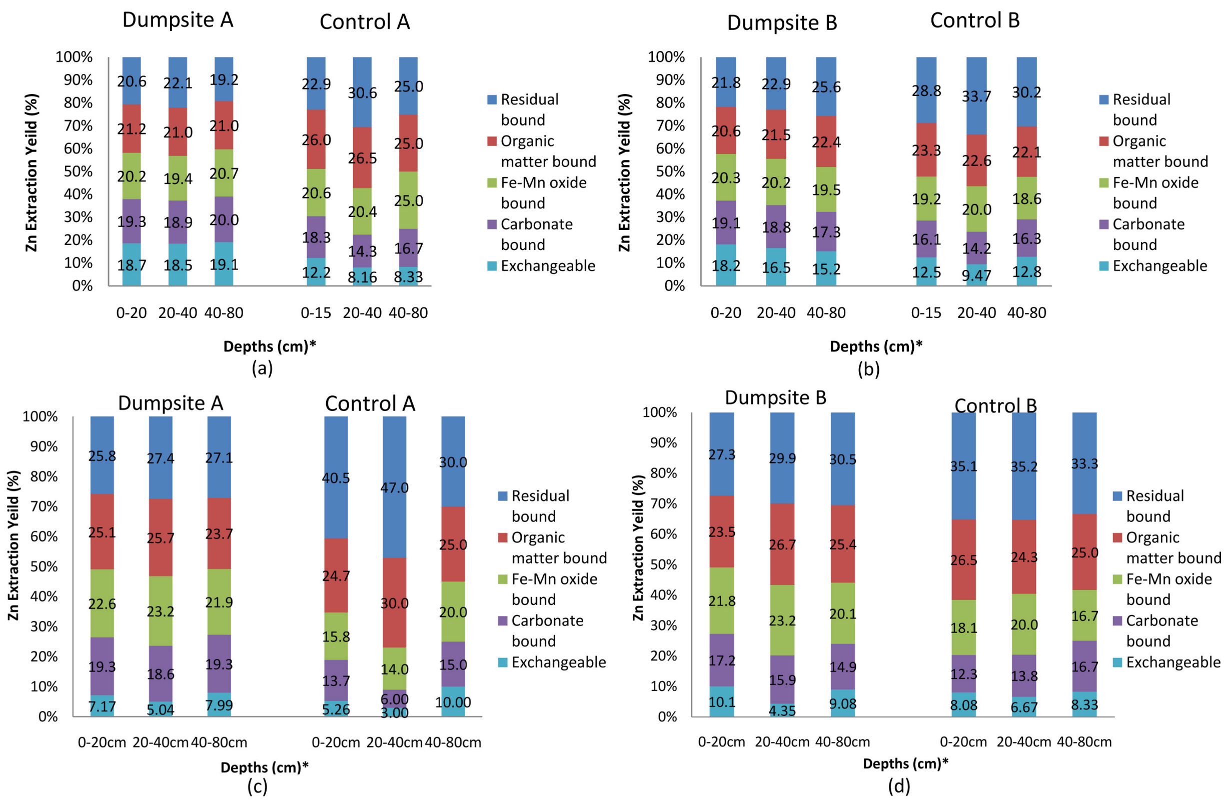

Figure 14. Zinc extraction yields (%) in soil samples from various profiles in dry season (a) & (b) and wet season (c) & (d) at SFB waste dumpsites.

3.2. Heavy Metal Contamination and Potential Ecological Risks

Modified Degree of Contamination

The results of the modified degree of contamination of the study area by heavy metals are presented in Table 1 and Table 2 for dry and wet seasons, respectively. The classification of the contamination status using the mC_d index was based on established reference values [23].

Dry Season: The contamination status of NFB using the mC_d index was moderate at the surface soil (0 - 20 cm), low and nil to very low at 20 - 40 cm and 40 - 80 cm profiles respectively during the season and the highest among the four formations (Table 1). The contamination status of NSM, NPS and SFB stations varied from "nil to very low" status. The result of NFB was in agreement with previous investigation by Wuana *et al.* [17]. This indicates that the soil at the dumpsites is not heavily contaminated. Therefore, it would not pose immediate threat to man and the environment. However, to avoid heavy metal bioaccumulation at the waste dumps of the formations, efforts could be made to develop a remediation programme for wastedump soils.

Wet Season: The Modified Degree of Contamination of the heavy metals in the studied waste dump soils for wet season was also calculated and presented in Table 2. Generally, the contamination statues of dumpsites (NFB, NSM, NPS and SFB) using the mC_d index was between "nil and very low" at all the depths. This indicated that the soils at the dumpsites were not heavily contaminated and

Table 1. Modified degree of contamination and its status (dry season).

Locations	Depths	Contamination Factor					Contamination status
		As	Cd	Zn	C_d	mC_d	
NFB	0 - 20	1.00	13.3	0.45	16.3	2.33	Moderate
	20 - 40	0.80	11.3	0.39	13.6	1.94	Low
	40 - 80	0.35	4.26	0.31	5.60	0.80	Nil to Very Low
NSM	0 - 20	0.76	8.73	0.23	10.8	1.55	Low
	20 - 40	0.34	3.94	0.18	5.18	0.74	Nil to Very Low
	40 - 80	0.17	1.79	0.11	2.43	0.35	Nil to Very Low
NPS	0 - 20	0.40	0.10	0.15	1.23	0.18	Nil to Very Low
	20 - 40	0.30	0.96	0.12	1.89	0.27	Nil to Very Low
	40 - 80	0.14	0.66	0.08	1.07	0.15	Nil to Very Low
SFB	0 - 20	0.16	2.62	0.17	3.43	0.49	Nil to Very Low
	20 - 40	0.11	2.07	0.10	2.58	0.37	Nil to Very Low
	40 - 80	0.10	1.21	0.06	1.53	0.22	Nil to Very Low

Table 2. Modified degree of contamination and its status (wet season).

Locations	Depths	Contamination Factor					Contamination status
		As	Cd	Zn	C_d	mC_d	
NFB	0 - 20	0.46	7.84	0.32	9.70	1.39	Nil to very Low
	20 - 40	0.57	6.64	0.26	8.20	1.17	Nil to very Low
	40 - 80	0.25	2.50	0.17	3.49	0.50	Nil to very Low
NSM	0 - 20	0.24	5.14	0.17	6.36	0.91	Nil to very Low
	20 - 40	0.28	2.65	0.28	3.78	0.54	Nil to very Low
	40 - 80	0.16	1.36	0.16	1.97	0.28	Nil to very Low
NPS	0 - 20	0.18	1.12	0.13	1.93	0.28	Nil to very Low
	20 - 40	0.15	0.66	0.10	1.31	0.19	Nil to very Low
	40 - 80	0.04	0.16	0.05	0.48	0.07	Nil to very Low
SFB	0 - 20	0.13	2.10	0.16	2.81	0.40	Nil to very Low
	20 - 40	0.08	1.34	0.10	1.94	0.28	Nil to very Low
	40 - 80	0.03	0.65	0.06	0.87	0.12	Nil to very Low

therefore, would not pose immediate threat to man and the environment. This result was in agreement previous investigation [17] but differ from [16]. The difference could be due to a variation in the type of waste materials at individual study areas.

3.3. Pollution Index and Degree of Contamination

The degrees of contamination are shown in Table 3 and Table 4 for the two seasons.

Dry Season: The pollution index (Table 3) for all the studied dumpsites was

Table 3. Degree of contamination for dry season.

		Contamination Factor				
Locations	Depths	As	Cd	Zn	C_d	Degree of contamination
NFB	0 - 20	1.00	13.3	0.45	16.3	Considerable
	20 - 40	0.80	11.3	0.39	13.6	Moderate
	40 - 80	0.35	4.26	0.31	5.60	Low
NSM	0 - 20	0.76	8.73	0.23	10.8	Moderate
	20 - 40	0.34	3.94	0.18	5.18	Low
	40 - 80	0.17	1.79	0.11	2.43	Low
NPS	0 - 20	0.40	0.10	0.15	1.23	Low
	20 - 40	0.30	0.96	0.12	1.89	Low
	40 - 80	0.14	0.66	0.08	1.07	Low
SFB	0 - 20	0.16	2.62	0.17	3.43	Low
	20 - 40	0.11	2.07	0.10	2.58	Low
	40 - 80	0.10	1.21	0.06	1.53	Low

Table 4. Degree of contamination for the wet season.

Sample Location	Depths	Contamination factor				Degree of contamination
		As	Cd	Zn	C_d	
NFB	0 - 20	0.46	7.84	0.32	9.70	Moderate
	20 - 40	0.57	6.64	0.26	8.20	Moderate
	40 - 80	0.25	2.50	0.17	3.49	Low
NSM	0 - 20	0.24	5.14	0.17	6.36	Low
	20 - 40	0.28	2.65	0.28	3.78	Low
	40 - 80	0.16	1.36	0.16	1.97	Low
NPS	0 - 20	0.18	1.12	0.13	1.93	Low
	20 - 40	0.15	0.66	0.10	1.31	Low
	40 - 80	0.04	0.16	0.05	0.48	Low
SFB	0 - 20	0.13	2.10	0.16	2.81	Low
	20 - 40	0.08	1.34	0.10	1.94	Low
	40 - 80	0.03	0.65	0.06	0.87	Low

assessed by calculating the contamination factor (C_f) and the degree of contamination (C_d) using Equation (2). The degrees of contamination of NFB were considerable (0 - 20 cm), moderate (20 - 40 cm) and low at 40 - 80 cm. The degree of contamination of NSM was moderate at the surface (0 - 20 cm) and low at 20 - 80 cm while the other dumpsites had low degree of contamination at all the depths.

Wet Season: The pollution index for heavy metals in all the dumpsites and across the profiles for wet season (Table 4) was also calculated using the contamination factor (C_f) and the degree of contamination (C_d). The degree of contamination (C_d) across the dumpsites indicated that with the exception of NFB which was moderately contaminated the rest of the dumpsites soils had low degree of contamination. However, there is need for remediation measures to prevent bioaccumulation of heavy metal beyond permissible limit.

3.4. Ecological Risk Indices

The calculated mobility factors for all the evaluated heavy metals in the dumpsites and control for dry and wet seasons are presented in Table 5 and Table 6. The major ecological risks methods used were the mC_d, Pollution index and C_d, potential ecological risk index and the mobility factor.

Dry Season: The values of Ecological Risk Factor for As, Cd Zn at various depths across the dumpsites are shown in Table 5. The results indicate that the soils, at the dumpsites, are not heavily contaminated by the metals and would not pose immediate threat to man and the environment. However, to avoid heavy metal bioaccumulation at waste dumps of the military formations, efforts should be made to develop a remediation programme for wastedump soils.

Wet Season: The potential ecological risk index (RI) of the heavy metals in the studied waste dump soils is shown in Table 6. This indicates that the soil at the dumpsites was not heavily contaminated. This result agreed with a previous investigation [17]. However, there was the need to develop a remediation programme for NFB and NSM to avoid heavy metal accumulation at the waste dumps. It was also observed that the values of RI for wet season were lower than those of the dry season perhaps due to wet season dilution and dry season concentration as a result of evaporation.

Table 5. Potential ecological risk index for the dry season.

Locations	Depths	Ecological Risk Factor			RI	Ecological Risk
		As	Cd	Zn		
NFB	0 - 20	10.0	400	0.45	417	Considerable
	20 - 40	7.95	340	0.39	353	Considerable
	40 - 80	3.48	128	0.31	135	Low
NSM	0 - 20	7.60	262	0.23	275	Moderate
	20 - 40	3.38	118	0.18	125	Low
	40 - 80	1.68	53.6	0.11	57.1	Low
NPS	0 - 20	4.04	3.00	0.15	9.97	Low
	20 - 40	3.01	28.8	0.12	34.5	Low
	40 - 80	1.42	9.7	0.08	22.1	Low
SFB	0 - 20	1.55	78.6	0.17	82.7	Low
	20 - 40	1.07	62.1	0.10	64.7	Low
	40 - 80	1.03	36.3	0.06	38.1	Low

Table 6. Potential ecological risk index for the wet season.

Locations	Depths	Ecological Risk Factor			RI	Ecological Risk
		As	Cd	Zn		
NFB	0 - 20	4.57	235	0.32	245	Moderate
	20 - 40	5.73	199	0.26	208	Moderate
	40 - 80	2.48	75.0	0.17	80.4	Low
NSM	0 - 20	2.41	154	0.17	160	Moderate
	20 - 40	2.78	79.5	0.28	85.4	Low
	40 - 80	1.57	40.8	0.16	44.0	Low
NPS	0 - 20	1.79	33.5	0.13	37.9	Low
	20 - 40	1.51	19.7	0.10	23.3	Low
	40 - 80	0.41	4.80	0.05	6.39	Low
SFB	0 - 20	1.32	62.9	0.16	67.9	Low
	20 - 40	0.80	40.1	0.10	49.0	Low
	40 - 80	0.33	19.5	0.06	20.9	Low

Table 7. Pattern of heavy metals concentration across the dumpsites.

Metal	Dry Season	Wet Season
As	NSM > SFB > NPS > NFB	NSM > SFB > NPS > NFB
Cd	NPS > NSM > SFB > NPS	NFB > NPS > NSM > SFB
Zn	SFB > NPS > NSM > NFB	NFB > NPS > NSM > SFB

Mobility Factors of Soils Samples

The Mobility Factor (M_f) of soils samples (%) from various profiles (0 - 80 cm) was calculated using Equation (5) for all heavy metals. The orders of their concentrations across the dumpsites for dry and wet seasons are presented in Table 7.

4. Conclusion

The chemical fractionation pattern of the toxic heavy metals in the wastedump soils was in the order $F_5 > F_4 > F_3 > F_2 > F_1$. This entails that a higher percentage of the toxic heavy metals was in the residual fraction and therefore, would not be bioavailable for plant uptake. The total metal concentration of the soil samples varied slightly across the eight (8) dumpsites under study. It was observed that the dumpsites at the NFB and NSM had higher values than those at NPS and SFB. There is therefore the need, for closer attention to be paid to NFB and NSM dumpsites. The statistical analysis of the levels of heavy metals using the 2-way ANOVA ($p < 0.05$) indicated significant variation between the soil profiles but no significant variation across the various dumpsites. The ecological risk index of waste dumpsites using the mC_d indicated that the NFB and NSM dumpsites were moderately contaminated while the contamination of the rest was generally low. It was also observed that M_f was higher during the dry season than in the wet season and the variation was basically attributed to dry season concentration due to evaporation and wet season dilution due to rainfall. The possible source of the toxic heavy metals was considered anthropogenic. The mobility of the metals in the dry and wet season was in the order Cd > As > Zn and Zn > Cd >As across the waste dumpsites, respectively. Although the waste dumpsites may not pose immediate risk to man and the ground water, there is need for immediate remediation measures to be put in place in order to checkmate accumulation of the metals at the sites, especially the NFB and NSM dumpsites.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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