

STATUS OF MINERALS AND HEAVY METALS IN THE SUBSTANCE SEDIMENTS AROUND A LANDFILL IN BOTSWANA

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ABSTRACT

The minerals and heavy metals in subsurface soil samples from around Gaborone Landfill in Botswana were characterized using laboratory analytical techniques and complemented with multivariate statistical analyses to determine whether landfilling of waste has had any impact on their composition and concentrations respectively. Physico-chemical properties such as texture, bulk density (D_b), porosity, moisture content, pH, electrical conductivity (EC), cation exchange capacity (CEC), as well as heavy metals including cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn), and minerals in the soil samples were determined. The soil texture was identified as sandy loam, silty loam, and silt. Whereas the values obtained for D_b and porosity were reflective of the textural classes of the different samples, values obtained for moisture content of the studied samples were characteristic of soils in semi-arid environments. The soils were mainly brownish in color and basic in pH. Significant amounts of total dissolved salts (TDS) were present in the soil samples especially those collected from along the eastern corner of the landfill. Minerals identified included quartz, microcline, muscovite and kaolinite in bulk subsurface samples, and kaolinite, smectite and illite in the clay fractions. Metal concentrations were higher between depths of 100 and 250 cm along profiles with the eastern corner of the landfill having higher values for heavy metal concentration than the other corners. Principal component analyses suggested an anthropogenic interference in the distribution of metals around the landfill whereas along the control profile, associations were mainly of geochemical origin.

KEYWORDS: Clay minerals, Landfill, multivariate analyses, X-ray diffraction

INTRODUCTION

The impacts of heavy metals on soils have been documented by McBride (1995) and Alloway (1995). The extent of heavy metal contamination in the subsurface environment around landfills is determined by the chemical and physical properties of the subsurface soil stratum, its clay mineral composition and the chemistry of the leachate migrating from the landfill (Thomson et al., 2000). Several studies have documented the role of soil characteristics in the mobility of heavy metals within the soil environment. Alloway (1995) identified pH, organic matter (OM) content and cation exchange capacity (CEC) as some soil properties that influence the retention of Cd, Cu and Zn in soils. Soil mineralogy especially the clay fraction influences metal retention through its effect on CEC (Sparks, 1995).

Landfilling of waste is one of the sources of heavy metals to the soil environment (Alloway, 1995). The concentrations of heavy metals in leachate generated within the landfill is determined by the composition of the waste that is deposited in the landfill. Gaborone landfill was designed as a municipal

solid waste landfill. Unfortunately, there are no waste sorting facilities at the site. In this regard some industrial waste that may be deposited in the landfill could result in an increase in the level of contaminants in the leachate generated. Contaminant plumes were identified at different points around the Gaborone landfill by Bogatsu et al., (2000) but the heavy metal concentration in the plume is not known. It is also not known whether landfilling activities have had any impact on the heavy metal concentrations in the soils around the area. The mineralogy of the soil stratum around the landfill and the role it may play as a filter of contaminants contained in the plume is not understood. This study, therefore aimed at establishing the status of heavy metal concentrations, and mineralogy of the soils around the Gaborone landfill. A multivariate statistical approach as employed by Davies (1997), Armanino et al., (1996) and Danielsson et al., (1999) was used to characterize the distribution of metals.

Study area

Gaborone landfill is located south east of Gaborone city (Figure 1) the capital of Botswana.



Figure 1: Location of Gaborone City

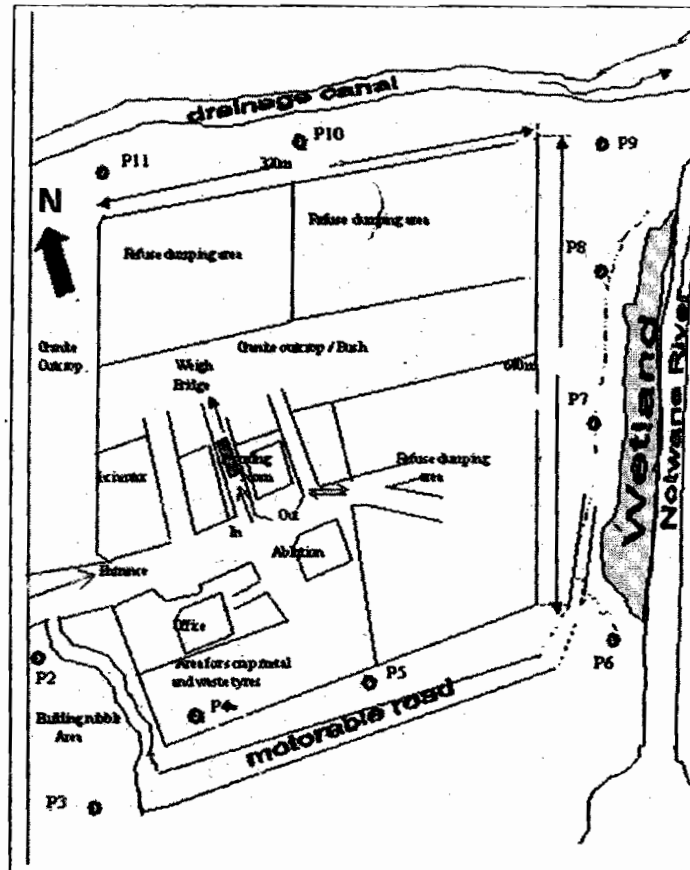
The landfill covers an area of 204 800 m² with a topographic gradient of 1.77 from west to east and slopes toward a river (Notwane River) which flows northeast of the landfill. The landfill area is overlain by the Thamaga Granite which constitutes part of the Gaborone Granite Complex. The soil stratum around the landfill is 1 m – 2 m thick and becomes thicker in the northeastern corner being 3 m – 4 m below the surface (Arup, 1994). The shallow to moderately deep well drained soils around the area are derived from a granitic bedrock and consists of coarse-grained sands covered by a thin layer of recently transported soil of mixed origin. Pre-construction investigations carried out by Arup (1994) indicated a permeability range of 2.3×10^{-8} ms⁻² to 5.7×10^{-7} ms⁻² at depths between 1.3 m and 4.0 m. According to the

same investigations, the water table around the site varies from 4.48m to 7.86 m below the ground surface.

METHODS AND ANALYTICAL TECHNIQUES

Determination of the physico-chemical properties of the soil samples

Fifty samples were collected from eleven profiles (P 1 – P 11). Ten of these (P 2 – P 11) were spread around the landfill vicinity as indicated in Figure 2 whereas P 1 (the control profile) was located 6 km northeast of the landfill in an area with the same geologic formation and lithology as the landfill subsurface terrain.



● Indicates sampling profiles

Figure 2: Location of sampling points around the landfill.

Samples were collected at depths of 50 cm – 300 cm, with regular intervals of 50 cm along each profile. Due to the variation in thickness of soil stratum around the landfill, the number of samples per profile varied. Six samples were collected from each of the profiles: 1, 2, 3, 6, 8, and 9; adding up to 36 samples. Four samples were collected from along profile 5, three from each of profiles 4 and 11, and two from each of profiles 7 and 10; adding up to 14 samples.

Basic physico-chemical analyses including texture, bulk density (D_b), moisture content, percentage pore space and particle size analyses were carried out on samples according to methods described in Song et al (1999), and van Reeuwijk, (1993). The Standard Munsell Soil Color Chart (1992) was used to observe the color of each sample in the laboratory while 10 % HCl was used to detect the presence of calcium carbonates in the samples. Soil pH was determined both in a 1:2.5 soil: water and soil : 1 M KCl mixture as described by van Reeuwijk, (1993) and Palumbo et al., (2000) whereas the EC of samples was determined in the same 1 : 2.5 soil : water suspension used for pH determination (Sheppard et al., 2000).

The barium chloride–triethanolamine ($BaCl_2 - (CH_3-CH_2OH)_3N$) method as described by Inglethorpe et al. (1993) was used to determine the CEC of the samples.

Minerals identification and heavy metal analyses of soil samples

Minerals contained in the samples were identified with a Philips PW 3710 XRPD unit operated at 40 kV and 45 mA with a Cu-K α radiation and a graphite monochromator (Ekosse, 2000; Melkerud et al., 2000). To extract heavy metals from samples, 0.5 gm of the < 50 μ m fraction of each sample was weighed into Teflon beakers and digested with concentrated HNO₃ in an ultra sonic bath for about 7 hours at 50 °C (Singh et al. 1999). Whereas a PC-controlled Varian SpectraAA 400 Plus Zeeman Atomic Absorption Spectrometer with a Varian Zeeman GTA 96 Plus Graphite Furnace was used in the determination of Cd, Cr, Co, Cu, Mn, Ni, and Pb, a Varian SpectraAA 10 Flame AAS was employed in the determination of Fe and Zn. All samples were analyzed in duplicate and the mean of two values taken as elemental concentration.

Multivariate analyses

Cluster analyses and principal component analyses (PCA) multivariate techniques were used to characterize the distribution of metals in the sediments as described by Danielsson et al., (1999); Facchinelli et al., (2001); Davies, (1997). Whereas principal component analyses (PCA) was used to characterize elemental composition, cluster analyses was employed for the spatial distribution of metals along the different profiles. Pearson's correlation was also carried out on metal concentrations, and on the wt % sand, silt and clay fraction of the sediments to find out any inherent association. The correlation of metals along the control profile and along

profiles around the landfill was compared to ascertain anthropogenic or natural sources of heavy metals.

RESULTS AND DISCUSSIONS**Physicochemical properties of subsurface sediments**

The EC of samples varied with depth around the landfill but the highest EC values were recorded along P 5, P 7, P 8, all located on the eastern corner of the landfill where previous studies had identified contaminant plumes (Table 1). The high EC values indicate the presence of dissolved salts (Ekosse, 2000) which might have arisen as a result of the seepage of landfill leachate through the sediments.

Table 1: Physico-chemical properties of the soil samples from the subsurface environment around the landfill

Depth (cm)	Profile	EC (\square /Scm)	pH (KCl)	pH (H ₂ O)	CEC (Meq/100 g soil)	Surface area (g/cm ²)	wt % sand	wt % silt	wt % clay
50	CP	36.67	6.02	6.68	17.32	0.53	75.60	21.86	2.54
	LP	423.80	7.21	7.97	27.49	0.27	50.65	47.47	1.78
100	CP	38.33	6.21	6.81	21.97	0.67	66.20	28.97	4.83
	LP	578.21	7.53	8.39	26.04	0.25	50.16	48.42	1.42
150	CP	97.17	6.18	6.56	18.93	0.73	62.66	31.33	6.01
	LP	818.98	7.53	8.58	26.23	0.27	48.11	50.36	1.53
200	CP	80.97	6.98	7.29	23.72	0.66	54.62	38.44	6.94
	LP	1087.33	7.95	8.94	25.79	0.31	43.51	54.23	2.27
250	CP	162.27	7.95	8.57	22.39	0.28	78.00	21.38	0.62
	LP	1198.10	7.76	9.03	25.30	0.21	40.01	59.03	0.96
300	CP	291.00	7.43	8.18	21.78	0.20	79.20	20.40	0.40
	LP	1070.64	8.12	9.19	19.13	0.18	52.93	46.73	0.34
Mean	CP	122.32	6.97	7.54	21.36	0.46	71.56	25.97	2.47
	LP	673.70	7.54	8.50	25.47	0.26	48.94	49.63	1.43

CP = control profile, LP = landfill profile

According to studies carried out by Christensen et al. (1994), leachate from decomposing wastes is usually rich in CO₃²⁻, Cl⁻, SO₄²⁻, HCO₃⁻ and PO₄³⁻ which are likely to be detected in any plume from the landfill. In addition the pH of a leachate plume is capable of influencing the pH of the subsurface sediments contained in the plume depending on the buffering capacity of the soils. Profiles along the eastern corner had pH values which were more basic than values along other profiles especially between depths of 100 – 250 cm down the profiles. The higher values of pH and EC at a particular depth in the landfill subsurface environment could be an indication of the depth at which the plume from the landfill is migrating. The textural classes of the sediments were sandy loam, silty loam and silt as reported by Ngole et al., (2002) with profiles along the eastern corner having more clay and silt than the other profiles. There was no pattern in the vertical distribution of silt and clay particles in samples but wt % sand increased with depth along all except P 4 and P 8 where it decreased with depth. Values for CEC along profiles decreased with depth along P 1 and P 10 and fluctuated along other profiles. According to Tan, (1998) and Palumbo et al. (2000), the clay fraction of soil determines its surface area and consequently its CEC. As can be observed from Table 1, these sediments had very low wt % clay accounting for their surface area and CEC. In addition to texture, the mineralogical composition of soils also affects their CEC.

Minerals identified and heavy metal concentrations in subsurface sediment

The main minerals identified in the samples included quartz, the feldspars, kaolinite, illite, calcite and smectite (Figure 3). The XRPD patterns showed marked variations between the whole soil and the clay fractions. Whereas quartz was identified in all fractions of all samples, hornblende, microcline,

albite, and hematite were identified in the saprolite only, albite in the 50 - 2000 μ m fraction, kaolinite, illite, and smectite in the > 2 μ m fraction (Figure 3 a, b, c, d, e). These mineral patterns were a reflection of the granitic parent material from which the soils were derived. Granite which forms the bedrock around the landfill area weathers to kaolinite under good drainage conditions and to smectites under poor drainage conditions. The presence of these minerals in the sediments from the landfill's subsurface environment therefore reflects natural alteration processes. However, the migration of leachate within the subsurface could also play a contributory role as a result of its ability to increase soil moisture content and provide additional ions which may be sorbed onto the exchange complex.

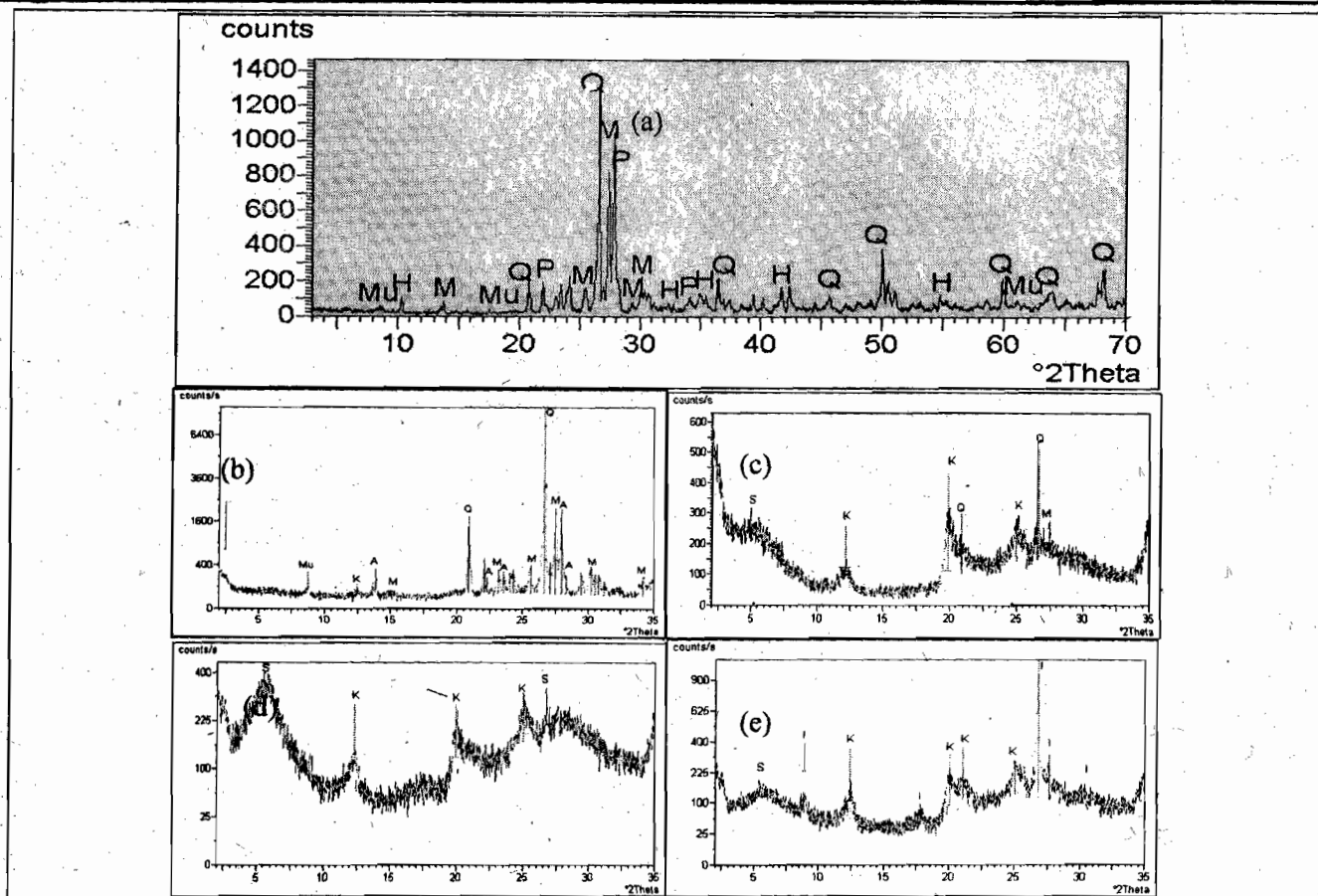


Figure 3: XRPD diffraction patterns of a representative saprolite (a), whole soil (b), and clay fractions (c, d, and e) of soil samples. (Q = quartz, H= hematite, Mu = muscovite, P = plagioclase, M = microcline, A = albite, K = kaolinite, S = smectite, I = illite).

Besides the silicate minerals, calcite also occurred in some sediment especially along the eastern corner. Interactions of

landfill leachate and soil moisture are likely to have resulted in the precipitation of CaCO₃ along these profiles (Spark, 1995).

The concentrations of the different metals along the different profiles also varied like all the other properties (Tables 2 & 3). Most profiles had a higher metal concentration than the control profile (P 1) as indicated in Tables 2 and 3. Results obtained from chemical analyses compare well with those obtained by Sheppard *et al.*, (2000), and Melkerud, (2000).

Table 2: Concentration of Cd, Co, Cr, Cu and Fe along the different profiles

Depth (cm)	Cadmium (mg/kg)										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	0.57	0.64	0.93	2.22	0.13	0.65	1.81	0.90	0.56	0.52	0.86
100	0.51	1.38	1.11	1.95	0.45	0.74	2.59	1.26	0.43	0.75	1.22
150	0.54	2.12	1.28	1.67	0.61	0.82		2.01	0.29		1.58
200	0.58	1.57	1.09		0.45	0.89		2.76	0.77		
250	1.03	1.14	0.89			0.96		3.51	1.26		
300	1.48	0.47	0.70			1.03		4.26	1.74		
Depth (cm)	Cobalt (mg/Kg)										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	1.08	1.66	1.34	1.18	1.12	2.20	1.90	2.26	3.28	1.74	0.94
100	1.11	1.43	1.35	1.51	1.48	2.36	2.62	2.22	2.18	0.54	0.79
150	1.14	1.20	1.36	1.84	1.66	2.51		2.23	1.08		0.64
200	1.17	1.23	1.33		2.32	1.95		2.24	1.32		
250	1.52	1.30	1.30			1.40		2.25	1.56		
300	1.86	1.30	1.27			0.84		2.26	1.80		

Chromium (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	4.08	3.33	4.45	4.70	1.12	5.96	4.59	8.69	6.44	4.47	5.19
100	4.25	1.95	4.90	5.08	2.78	5.28	4.76	9.16	7.77	2.70	3.65
150	4.42	6.56	5.34	5.46	3.61	4.59		8.52	9.09		2.11
200	4.59	5.63	4.49		3.79	5.11		7.89	8.50		
250	5.58	4.84	3.65			5.63		7.25	7.91		
300	6.57	3.78	2.80			6.15		6.61	7.32		

Copper (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	7.07	15.74	19.98	15.98	41.32	9.28	8.52	10.08	24.52	6.22	3.38
100	7.78	18.57	21.85	20.61	23.20	10.93	5.62	10.05	16.39	4.95	6.66
150	8.49	21.40	23.71	25.24	14.14	12.58		8.95	8.25		9.94
200	9.20	25.03	21.45		3.28	10.74		7.86	6.61		
250	11.26	21.66	19.19			8.90		6.76	5.38		
300	13.32	32.28	16.92			7.06		5.66	3.94		

Iron (%)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	14.74	13.86	17.38	14.58	10.01	9.19	16.31	30.81	18.97	11.09	7.56
100	14.92	17.33	14.96	15.21	12.88	9.47	13.92	16.61	13.82	11.51	8.51
150	15.1	20.80	12.54	15.84	14.32	9.74		16.03	8.68		9.47
200	15.28	20.15	10.52		14.08	14.86		15.44	10.96		
250	14.78	18.30	8.49			19.97		14.85	13.24		
300	14.28	18.84	6.47			25.08		14.27	15.52		

Table 3: Concentration of Mn, Ni, Pb, and Zn along the different profiles

Manganese (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	16.76	21.00	19.39	18.00	11.32	21.84	31.48	23.54	24.00	21.75	15.81
100	33.20	16.18	18.16	21.25	16.06	16.99	30.29	19.91	22.91	26.44	13.74
150	49.65	10.76	16.93	23.90	18.43	12.14		20.22	21.73		11.66
200	66.09	10.23	15.57		19.12	14.45		20.54	20.91		
250	40.53	16.34	14.21			16.75		20.85	20.10		
300	14.97	9.16	12.84			19.06		21.16	19.28		

Nickel (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	6.38	3.92	6.08	5.54	9.68	6.42	3.78	4.72	6.26	2.54	1.86
100	5.98	3.73	5.24	5.90	6.88	5.38	3.40	11.56	4.85	2.65	1.41
150	5.57	3.54	4.40	6.26	5.48	4.34		9.85	4.94		0.96
200	2.17	4.91	4.03		4.18	4.01		8.13	4.51		
250	2.01	5.69	3.65			3.67		6.42	5.19		
300	1.84	7.64	3.28			3.34		4.70	5.06		

Lead (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	3.80	12.83	11.28	34.14	36.42	3.76	20.30	59.51	19.22	5.07	10.70
100	4.74	17.38	18.03	27.84	19.38	20.04	24.79	53.54	16.49	12.36	8.09
150	5.68	21.93	24.78	21.53	10.86	36.32		51.43	13.76		5.47
200	6.62	16.16	24.69		1.56	38.54		49.32	10.08		
250	8.29	12.91	24.60			40.76		47.20	8.41		
300	9.96	4.61	24.51			42.98		45.09	7.73		

Zinc (mg/Kg)											
Depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
50	5.80	5.60	9.00	10.20	4.80	10.91	14.85	28.30	16.38	15.54	16.70
100	5.33	5.70	8.10	9.80	9.20	11.95	13.45	20.18	15.50	15.08	16.12
150	4.87	5.80	7.20	9.40	11.40	12.99		18.79	14.61		15.54
200	4.40	5.93	7.65		11.60	13.22		17.40	14.61		
250	4.30	7.98	8.10			13.46		16.00	14.61		
300	4.20	6.20	8.55			13.69		14.61	14.61		

The values obtained for the concentration of the metals were within the range reported in soils though those along profiles 6, 7, 8, and 9 were slightly higher than values in the other profiles (Tables 2 and 3). Gaborone landfill is a municipal solid waste landfill and therefore receives few toxic wastes. This may explain the observed low values obtained for metal concentrations in the subsurface environment around the landfill compared to those reported by Christensen et al., (1994).

Statistical interpretation and environmental implication

Cluster analyses of heavy metal concentrations at different depths indicated four clusters of profiles (Table 4). Clustering of profiles at a depth of 50 cm could be explained as resulting from anthropogenic disturbances around the profiles including cattle grazing, road construction and burying of pipes.

Table 4: Clustering of profiles sampled

Depth (cm)	Cluster 1	Cluster 2	Cluster 3	Cluster 4
50	P1, P2, and P4	P3, P7, P9,	P6, P5, P10, P11	P8
100	P1, P3, P4, P5, P7, P9	P2	P6, P10, P11	P8
150	P1, P3, P4, P5	P2	P6, P9, P11	P8
200	P1	P2	P6, P9, P11	P8
250	P1, P9,	P2, P6	P3	P8
300	P1, P8, P9	P2	P3	P6

Cycling through vegetation, atmospheric deposition and adsorption by soil organic matter could also account for the distribution of metals in the surface horizons. Cluster 1 contains profiles with metal concentration similar to the control profile at the different depths. Cluster 2 consists of profiles located mainly at the south eastern corner of the landfill where building rubble is disposed with values for heavy metal concentration being slightly higher than those of profiles in cluster 1. Clusters 3 and 4 contained mainly P 6, P 8, P 10, and P 11 with high metal concentrations compared with the control profile as reflected in Tables 2 & 3. These profiles are located along the eastern and north eastern corners of the landfill where plumes were identified.

Using PCA to group the profiles according to heavy metal concentrations, two components with Eigen value greater than one were identified. Along the control profile, component 1 was explained by all except Fe and Mn which were explained by component 2 (Table 5). These two components account for 98.96 % of the variance along the control profile.

Table 5: Factor loadings for the first two principal components around the landfill and control profile

Variable	Landfill		Control profile	
	PC1	PC2	PC1	PC2
Eigenvalues	4.152	2.508	6.795	2.110
Cd	0.150	0.113	.857	.514
Co	0.201	0.068	.860	.509
Cr	0.168	0.091	.899	.436
Cu	0.088	-0.373	.949	.310
Fe	0.236	-0.113	-.355	-.935
Mn	0.041	0.232	.121	-.991
Ni	0.235	-0.176	-.954	.128
Pb	0.216	0.011	.980	.193
Zn				
	0.020	0.344	-.972	.222

Loading of metals on the different components along the control profile showed natural association where Fe and Mn occurred together and the other metals determine the other component. Factor 2 could be describing the sesquioxides of the sediments while factor 1 could be for geochemical characteristics of the soil. These natural associations are also reflected in the correlation coefficients of parameters along the control profile where metals correlate strongly with soil particles (Table 6). In profiles around the landfill, the two components accounted for 73.99 % of the total variance in metal concentrations along profiles. Component 1 was described by Cd, Co, Cr, Fe, Ni and Pb whereas component 2 strongly depended on Cu, Mn, and Zn. The natural association observed along the control profile was absent in profiles around the landfill where Zn, Mn, and Cu load heavily on PC2 and the other metals load heavily on PC1. Absence of geochemical associations and the low correlation of metals around the landfill (Table 6) could be indicative of human interference in the distribution of metals in that area.

Table 6: Correlation matrix of metals along profiles

	Control profile											
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Sand	Silt	Clay
Cd	1.0											
Co	0.99	1.0										
Cr	0.99	0.99	1.0									
Cu	0.97	0.98	0.99	1.0								
Fe	-0.78	-0.78	-0.73	-0.63	1.0							
Mn	-0.40	-0.39	-0.32	-0.19	0.88	1.00						
Ni	-0.74	-0.76	-0.79	-0.86	0.23	-0.23	1.0					
Pb	0.94	0.94	0.97	0.99	-0.63	-0.07	-0.89	1.0				
Zn	-0.72	-0.73	-0.78	-0.86	0.13	-0.34	0.93	-0.91	1.0			
Sand	0.63	0.62	0.57	0.47	-0.89	-0.84	-0.12	0.37	-0.01	1.0		
Silt	0.57	-0.56	-0.51	-0.40	0.89	0.87	0.04	-0.30	-0.07	-1.0	1.0	
Clay	0.75	-0.74	-0.71	-0.62	0.89	0.75	0.34	-0.54	0.21	-0.97	0.95	1.0

	Profiles around the landfill											
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Sand	Silt	Clay
Cd	1.0											
Co	0.21	1.0										
Cr	0.29	0.40	1.0									
Cu	-0.26	-0.15	-0.39	1.0								
Fe	0.17	0.18	0.36	0.11	1.0							
Mn	0.21	0.43	0.34	-0.44	0.14	1.0						
Ni	0.06	0.38	0.33	0.36	0.20	0.03	1.0					
Pb	0.44	0.32	0.38	-0.04	0.41	0.08	0.42	1.0				
Zn	0.16	0.36	0.57	-0.67	0.21	0.46	0.02	0.39	1.0			
Sand	-0.11	-0.22	-0.62	0.49	0.03	-0.38	-0.04	-0.02	-0.52	1.0		
Silt	0.11	0.25	0.64	-0.51	-0.02	0.41	0.04	0.04	0.54	-0.99	1.0	
Clay	0.03	-0.32	-0.22	0.25	-0.09	-0.30	-0.02	-0.15	-0.24	0.06	-0.17	1.0

CONCLUSION

Like values for EC, values for metal concentrations were also highest between depths of 100 cm and 250 cm along the profiles. The minerals contained in the sediments around the landfill are not likely to have a significant effect on the retention of metals because they are dominated by quartz and kaolinite with relatively low CEC. Further to this, sand is the most abundant particle in the soils which also imparts a low CEC. Considering the different contributions of the different elements on the principal components along the control profile (76.5 % and 23.5 % respectively), it could be concluded that the geochemical component of the sediments play a more important role in the distribution of metal in the subsurface around the landfill. The absence of natural associations along profiles around the landfill and the elevated amounts of heavy metal concentration especially along the eastern corner suggests anthropogenic origin. The detection of contaminant plumes using geophysical investigations in a study carried out by Bogatsu et al., (2000) at this site further ascertains the findings of this research.

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