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Full Length Research Paper

Soil Profile Quality of a Contaminated Dumpsite in Ibadan, Nigeria

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ABSTRACT

Solid waste disposal may result in soil pollution with implications for groundwater quality. The impact of waste disposal on soil quality of the Aba-Eku dumpsite, Ibadan, Nigeria was studied at five depths in the profile. Soil samples were collected bi-monthly over a 21-month period at three sub-sites: - Waste Dump Area (WDA), Leachate Lagoon Area (LLA) 250m down-gradient of WDA; and control (600m away from WDA and LLA); using an auger and analyzed for various physico-chemical parameters. Data were analyzed using Principal Component Analysis (PCA) and ANOVA. Contamination factors were also computed using relevant formulas. Seven, five and four factors were extracted by PCA, explaining 83%, 86% and 80% variation in WDA, LLA and control respectively. Positive loadings for percent gravel (0.941) and permeability (0.596) and negative loadings from percent sand (-0.912) on the first PC for WDA suggested increases in the coarse fraction and decreases in the fine fraction were associated with moderate increases in permeability at the site. Except iron and potassium, other parameters were significantly elevated ($p<0.05$) in WDA profiles compared to LLA and control. Cadmium reduced significantly ($p<0.05$) with depth from 23.7±5.3; (0-15cm) to 12.7±3.0 mg/kg; (75-100cm) suggestive of gradual leaching into groundwater. Zinc, copper and cadmium had contamination factors of 56.84, 21.30 and 19.29 respectively in WDA which reduced to 3.28, 3.71 and 1.09 in LLA down-gradient. Two plants, *Chromoleana odorata* and *Pennisetum pupureum* found between WDA and LLA sites may have contributed to contaminant reduction and may be exploited for further remediation of the site.

Keywords: Soil, contaminants, wastes, Aba-Eku, groundwater, phytoremediation

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INTRODUCTION

Despite the complexity of wastes produced, the standards of landfills in developing countries is still poor (Ismail and Manaf, 2013). The expensive nature of sanitary landfills (Diaz and Savage, 2002) makes many developing countries to use unlined landfills with attendant effects on soil and underlying groundwater quality. Soil quality influences basic functions such as nutrient storage and cycling, buffering and immobilization reactions, contaminant filtration amongst other functions (Shukla *et al*, 2006). Soil and groundwater pollution from landfill leachate is a major problem (Aluko *et al.*, 2003; Yenigul *et al*, 2005; Rapti-Caputo and Vaccaro, 2006; Adnan *et al*, 2013; Gworek *et al*, 2015). The Aba-Eku dumpsite is a major municipal solid waste dumpsite in Ibadan, Nigeria. Inhabitants within a kilometer of the dumpsite rely on groundwater for their domestic needs. Considering the soil's ability to serve as a contaminant sink, and the implications of this for underlying groundwater quality, the impact of waste disposal on soil quality at various depths in the profile will be valuable. This study therefore evaluated the physico-chemical quality of the soil of the dumpsite at a maximum of five depth levels in the profile.

MATERIALS AND METHODS

Study Area: The Aba-Eku dumpsite is located in Ona-Ara local government area of Oyo state, Nigeria. Plants in the vicinity of the study area were collected for identification at the Herbarium of the Department of Botany, University of Ibadan, Ibadan, Nigeria.

Samples and Sampling procedures: Soil samples were obtained bimonthly (every two months) using a soil auger over a 21-month period at the following depths: top-soils (0-15cm); sub-soils, 15-30cm; 30-60cm; 60-75cm; and 75-100cm. However, it was not always possible to go beyond 75cm. Two additional sites: **(**LLA) and a control (CON) approximately 600m away from the WDA were located using a GPS 76 garnier model. Geographical coordinates are shown in Fig. 1. The LLA is located about 250m down-gradient of the dumpsite. Ten cores were obtained from WDA, while five cores were obtained from LLA and CON respectively. Core samples of similar depths within each site were bulked to form a composite at each sampling period. The soil samples were collected in labelled polyethylene bags and taken to the laboratory for processing and analysis.

Sample processing / Analysis: Soil samples were air-dried for 48-72 hours in the laboratory pulverized using a porcelain mortar and sieved using a 2mm sieve. pH and Soil Organic Matter (SOM) was determined according to (ASTM, 1995) and Lu, (1999) method. Cation Exchange Capacity (CEC) was determined using the method of (Madeira *et al.,* 2003). Exchangeable cations and metals were determined on an ICP-OES Perkin Elmer Optima 3000 after Hydrofluoric-perchloric-nitric acid digestion (Lu, 1999). A metal standard (lead) was purchased from the manufacturer, digested and analyzed as above. The recovery rate was 94%. Grain size distribution was determined according to Tucker (1991) at the Department of Geology, University of Ibadan, Ibadan, Nigeria. Permeability was estimated from the results of Grain size distribution using Hazen's empirical formula (Odong, 2007). All analytical procedures, except for grain size and permeability were carried out at the Shenyang Institute of Applied Ecology, Shenyang, China.
Contamination factor for each metal was determined according to Hakanson (1980) using the expression

$$c^i_f = c^i_{0-1} / c^i_n$$

where

c^i_f = contamination factor,

c^i_{0-1} = Mean concentration of individual metal from top-soil of the test sites, and

c^i_n = baseline or background concentration of the individual metal from top-soils of the reference site. Analysis of variance (ANOVA) and Principal Component Analysis (PCA) was used for data analysis

RESULTS

Results of the physicochemical parameters and ANOVA for the three sites are summarized and presented in Tables 1-3. Except for top-soils of LLA, pH in WDA was statistically similar to that of LLA but significantly higher than control ($p<0.05$). Organic matter, CEC, calcium, copper, zinc, lead and cadmium were significantly higher ($p<0.05$) in all WDA profiles than in profiles of both LLA and control sites (Tables 1-3). Organic matter levels were highest in top-soils of LLA and control, while WDA had higher levels of SOM within the profile, compared to top-soil (Tables 1-3). Magnesium levels were significantly elevated ($p<0.05$) in WDA profiles compared to LLA and control except for the 15-30cm depth, which was statistically similar with LLA at this depth. Potassium and iron showed predominant declines down WDA profiles (Table 1), with both elements showing the highest levels in LLA down-gradient of the dumpsite. Potassium was significantly elevated ($p<0.05$) in LLA profiles, while iron levels were higher but not significant at $p<0.05$, except at the 15-30cm depth in LLA. As expected, values for potassium and iron in the control were the lowest and differed statistically from WDA and LLA profiles except at the highest depths (Tables 1-3).

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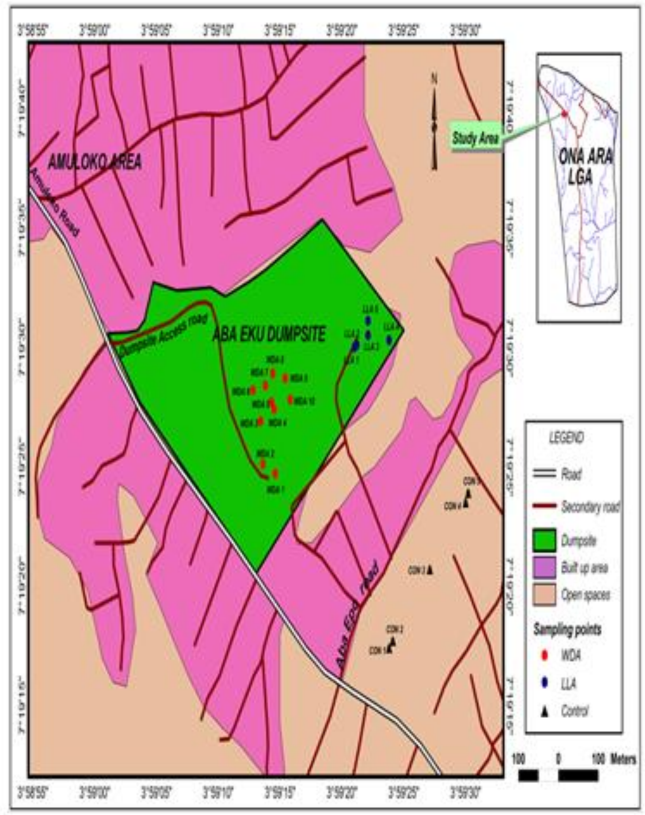

Plate 1:
Map of the dumpsite showing the sampling points

Manganese was significantly higher ($p<0.05$) in WDA profiles up to 30cm depth when compared to LLA and control.

Principal Component Analysis for WDA extracted seven factors which explained 83% of the total variance. Principal components 1-7 explained 16%, 15%, 13%, 11%, 11%, 10% and 8% of total variance respectively. Percent gravel, permeability and percent sand contributed most to the variance on principal components (PC) 1 for WDA and PC 2 for LLA; with percent sand loading negatively on both PCs (Tables 4-5). Calcium, magnesium and cadmium accounted for most of the variance on PC 2 in WDA; manganese, zinc and soil organic matter on PC 3 in WDA; CEC and potassium on PC 4; iron on PC 5; while pH and lead contributed most of the variance on PC 6 with lead showing a negative loading on this principal component. Copper contributed much of the variance on PC 7 (Table 4).

Table 1:
Summary of some physico-chemical parameters of WDA soils over the study period.

SAMPLE	pH	SOM (%)	CEC (Cmol/kg)	Ca	Mg	K	Fe	Mn	Cu	Zn	Pb	Cd	% GRAVEL	% SAND	% SILT/CLAY	K (PERM.)
0-15 Min	7.02	4.53	521.1	18782.6	2303.79	8160.01	14821.87	706.01	430.69	1213.5	161.47	17.22	40.24	37.34	1.15	0.000065
Max	8.65	11.69	294.9	42663.85	6485.47	14897.29	69641.05	1548.03	883.56	2956.21	570.14	34.81	58	57.53	6.41	0.000116
Mean (9)	7.76b	7.44b	377.33b	29617.73bc	3889.33bc	9584.04a	35415.55b	1094.90bd	608.45b	1884.33b	271.73b	23.73d	46.40d	50.33c	3.27a	0.000099a
SD	0.44	1.93	68.47	7108.51	1442.52	2117.12	16646.08	259.58	172.93	650.14	118.21	5.25	7.07	7.32	1.75	0.000018
15-30 Min	7.15	6.63	299.2	16745.06	2179.16	8094.87	27708.79	794.08	398.75	1250.69	156.65	6.15	27.75	37.2	0.97	0.000057
Max	7.98	9.41	368.7	28610.85	3657.06	9679.72	46357.39	1502.51	1235.51	2199.45	356.8	21.51	61.5	65.38	7.16	0.00018
Mean (9)	7.63b	8.06b	332.88b	22065.51c	2860.88bc	8922.54a	33593.89ac	1119.76bd	615.84b	1540.84b	253.01b	15.13c	43.81df	52.96c	3.23a	0.000110a
SD	0.28	0.94	29.19	3971.24	473.99	522.69	6600.46	226.29	282.07	337.59	67.61	4.63	10.14	8.97	2.53	0.000046
30-60 Min	7.57	6.15	396.4	17756.94	2277.68	7249.52	22008.88	744.41	370.59	956.04	173.04	11.26	31.5	45.26	1.32	0.000051
Max	7.97	11.69	198.4	48226.28	4953.6	9978.09	41857.27	1905.51	1367.51	2375.6	281.32	23.59	52	61.21	7.29	0.000635
Mean (8)	7.78b	8.24b	317.01b	27729.07b	3247.16bc	8702.63a	28329.70ac	1200.54de	674.88b	1617.35b	207.82b	17.13cd	42.97df	54.31c	2.72a	0.000169a
SD	0.15	1.73	66.43	8934.33	847.46	945.58	6115.66	439.92	342.21	483.53	32.65	4.76	6.44	5.11	1.97	0.000192
60-75 Min	7.83	5.82	290	27760.97	3285.4	7780.88	22242.04	919.34	389.4	839.96	152.08	15.91	41	52.68	2.32	0.000084
Max	8.07	11.69	307.8	46886.86	4976.36	8003.24	36108.74	2783.73	611.91	3030.55	208.63	21.43	45	56.01	2.99	0.000153
Mean (2)	7.95b	8.76b	298.90b	37323.9b	4130.88b	7892.06a	29175.39ce	1851.53f	500.65b	1935.26b	180.35b	18.67cd	42.99df	54.35c	2.66a	0.000119a
SD	0.17	4.15	12.59	13524.05	1195.69	157.23	9805.23	1318.32	157.34	1548.98	39.99	3.9	2.83	2.35	0.47	0.000049
75-100 Min	7.76	8.61	361.7	17749.88	2213.78	8501.57	21425.73	1020.38	410.59	1094.36	137.82	10.63	31	57.6	7.02	0.000046
Max	7.96	8.61	379.5	18156.6	2303.8	9339.78	27825.61	1117.22	2273.05	2071.81	144.23	14.81	33.5	61.98	8.9	0.000057
Mean (2)	7.86l	8.61b	370.60b	17953.24c	2258.79cd	8920.67a	24625.67c	1068.80d	1341.82c	1583.09b	141.02b	12.72c	32.25f	59.79c	7.96b	0.000052
SD	0.14	0	12.59	287.59	63.65	592.7	4525.4	68.48	1316.96	691.16	4.54	2.95	1.77	3.1	1.33	0.000008

[1]*Means with similar letters are not significantly different at $p < 0.05$*

Table 2:
Summary of some physico-chemical parameters of LLA soils over the study period

SAMPLE	pH	SOM (%)	CEC (Cmol/kg)	Ca	Mg	K	Fe	Mn	Cu	Zn	Pb	Cd	% GRAVEL	% SAND	% SILT/CLAY	K (PERM.)
0-15 Min	6.59	1.14	51.4	2458.33	1308.33	10420.28	18129.17	211.33	55.58	35.56	0.00	0.00	22.50	49.65	2.26	0.000051
Max	7.51	2.41	92.1	12359.22	4146.46	33804.95	62223.25	1256.61	160.40	222.15	163.06	4.31	47.25	71.17	9.37	0.000094
Mean (9)	7.15a	1.87a	74.46a	8066.73ad	2158.58a	16606.63b	37024.41bd	589.18a	105.88a	108.88a	92.77a	1.34a	30.72ef	64.91bc	4.37a	0.000076a
SD	0.37	0.43	12.13	2782.57	892.18	8236.57	11831.13	348.08	38.31	53.99	64.49	1.68	7.20	6.46	2.32	0.000015
15-30 Min	6.94	0.79	53.1	4277.78	1112.50	9253.61	22136.11	316.61	58.75	43.06	0.00	0.00	25.74	61.63	1.08	0.000057
Max	7.90	1.74	92.1	11359.24	3167.39	29180.43	79512.86	1483.34	216.23	226.73	140.81	2.19	36.25	72.21	4.37	0.000131
Mean (9)	7.51ab	1.33a	70.30a	7471.63bd	2335.33ac	20227.57b	48532.75bd	635.51a	129.10a	133.26a	44.08a	0.79a	29.25e	68.24c	2.51a	0.000089a
SD	0.33	0.29	14.88	2910.80	852.10	7794.77	22187.69	359.53	65.65	74.81	50.74	0.75	3.58	3.19	0.98	0.000023
30-60Min	6.84	0.99	3.15	1013.89	929.17	11003.61	1077.50	195.70	69.42	23.28	0.00	0.00	33.00	46.52	1.51	0.000061
Max	8.24	2.57	133.8	18775.22	4021.47	32513.36	63056.54	1891.61	257.47	363.38	133.06	6.90	51.50	66.52	5.60	0.000760
Mean (9)	7.63ab	1.35a	75.21a	7824.30ad	2005.35a	17066.00b	35192.31ad	601.82ae	136.46a	116.09a	60.29a	1.88a	37.09f	59.91b	3.00a	0.000195a
SD	0.41	0.53	40.15	6880.07	1277.71	8989.57	18633.15	612.79	78.52	131.26	46.41	2.42	6.88	6.49	1.26	0.000231
60-75 Min	7.13	0.89	51.8	2166.67	934.72	10781.39	33302.78	217.72	69.08	17.50	5.36	0.00	27.52	63.76	2.10	0.000074
Max	8.17	1.95	143.8	11151.16	2446.63	22347.78	73722.07	515.92	258.73	331.71	78.61	1.52	32.50	70.28	3.74	0.000105
Mean (3)	7.75b	1.42a	104.20a	6478.65de	1905.18af	17464.75ab	52402.71de	399.57af	189.82a	214.76a	38.45a	0.58a	29.67e	67.65c	2.68a	0.000091a
SD	0.55	0.53	47.32	4503.08	842.32	5989.68	20300.84	159.53	104.91	171.81	37.13	0.82	2.56	3.44	0.92	0.000016

[1]*Means with similar letters are not significantly different at $p < 0.05$*

Table 3:
Summary of some physico-chemical parameters of Control (CON) soils over the study period.

Sample	pH	SOM (%)	CEC (Cmol/kg)	Ca	Mg	K	Fe	Mn	Cu	Zn	Pb	Cd	GRAVEL	% SAND	% SILT/CLAY	K (PERM.)
0-15Min	6.56	1.80	50.30	8750.00	1541.67	9892.50	11941.67	423.28	17.83	8.04	30.56	0.00	20.00	63.35	2.88	0.000054
Max	7.25	3.27	74.30	13626.82	1908.71	13114.72	29636.11	824.39	51.19	154.58	101.65	2.55	31.00	74.54	7.07	0.000196
Mean (9)	6.91a	2.13a	61.82a	10367.49a	1746.65a	11552.08a	19509.54a	549.90a	28.57a	33.15a	63.69a	1.23a	25.74e	69.67c	4.61a	0.000093a
SD	0.24	0.48	8.14	1472.40	144.35	1100.99	4956.08	116.44	10.57	46.34	21.49	0.92	3.21	2.32	1.63	0.000045
15-30 Min	6.33	1.02	42.50	8472.22	1462.50	10336.94	15552.78	424.94	24.78	12.36	27.78	0.00	21.00	67.41	2.51	0.000060
Max	7.20	3.08	89.01	14987.88	2297.54	12753.61	38719.44	912.17	80.06	225.42	126.10	4.34	30.00	76.49	4.34	0.000227
Mean (9)	6.86a	1.71a	62.10a	10630.05a	1811.03a	11839.75a	24487.75a	563.43a	39.56a	54.68a	60.71a	2.00a	26.17e	70.41c	3.42ab	0.000103a
SD	0.33	0.63	16.40	2163.04	262.19	772.86	6955.07	150.56	18.11	71.09	36.38	1.38	2.61	2.78	0.66	0.000060
30-60 Min	6.45	0.82	38.80	5583.33	1248.61	7836.94	16663.89	445.50	20.97	5.14	30.56	0.00	21.00	49.93	1.07	0.000065
Max	7.35	1.94	82.41	11182.92	1908.72	13031.39	50450.29	1458.15	62.37	87.71	101.38	2.00	49.00	75.19	5.28	0.000668
Mean (8)	6.98a	1.26a	52.56a	8413.26a	1555.36ae	10805.31a	30971.98a	850.18ae	45.76a	31.03a	60.70a	0.83a	30.87e	65.59c	3.54ab	0.000221ab
SD	0.34	0.40	17.27	1835.64	206.66	1746.02	14199.57	372.43	12.63	29.30	26.37	0.95	9.33	8.32	1.66	0.000266
60-75 Min	6.90	1.46	41.84	4027.78	1020.83	7542.50	37191.67	855.78	58.89	25.22	45.28	0.00	41.50	40.59	1.91	0.000181
Max	6.45	1.53	51.18	6027.78	1495.83	12142.50	65441.66	2170.50	68.81	35.03	46.39	0.00	57.50	55.16	3.34	0.000760
Mean (3)	6.68a	1.51a	45.43a	5175.93e	1314.35ef	10507.31a	51487.96e	1310.96f	63.84a	31.08a	45.56a	0.00a	47.83f	49.68d	2.49b	0.000389b
SD	0.23	0.04	5.03	1032.40	256.55	2572.15	14128.12	744.81	4.96	5.18	0.74	0.00	8.50	7.93	0.75	0.000322

[1]*Means with similar letters are not significantly different at $p < 0.05$*

Table 4:
Principal Component Analysis (PCA) for the Waste Dump Area (WDA)

Rotated Component Matrix for site WDA							
	Principal Component						
	1	**2**	**3**	**4**	**5**	**6**	**7**
pH	.069	.200	-.072	.242	.107	.858	-.092
som	-.166	-.388	.633	.010	-.164	-.417	-.111
cec	.011	-.019	-.042	.893	.015	-.099	-.101
ca	-.027	.793	-.209	-.004	.122	.199	-.237
mg	.013	.765	-.219	.344	.140	.289	-.187
k	.094	.129	-.089	.857	.125	.178	.010
fe	.160	.163	.004	.118	.888	.076	-.029
mn	-.056	-.161	.929	-.121	.083	.051	-.069
cu	-.193	-.092	.080	-.096	.000	-.011	.905
zn	.211	.063	.774	-.041	.035	-.040	.467
pb	.529	-.031	.001	.239	-.007	-.687	-.024
cd	.211	.720	-.002	.105	-.217	-.197	.298
pctgrl	.941	.200	.011	.064	.098	-.049	-.111
pctsd	-.912	-.054	-.014	-.159	-.171	.103	.104
pctsc	-.496	-.543	-.016	.267	.126	-.131	.052
perm	.596	-.151	-.037	-.341	-.158	.454	.192
% V.	16%	15%	13%	11%	11%	10%	8%
CV.	16%	31%	43%	54%	65%	75%	83%

Abbreviations- SOM: Soil organic matter; CEC: Cation exchange capacity; Ca: Calcium; Mg: Magnesium; K: Potassium; Fe: Iron; Mn: Manganese; Cu: Copper; Zn: Zinc; Pb: lead; Cd: Cadmium; Ni: Nickel; Cr: Chromium; Pctgrvl: Percent gravel; Pctsd: Percent sand; Pctsc: Percent silt/clay; Perm: Permeability; % V: Percentage variance; CV: Cumulative Variance.

Table 5:
Principal Component Analysis (PCA) for the Leachate Lagoon Area (LLA)

Rotated Component Matrix for the Leachate Lagoon Area					
	Principal Component				
	1	2	3	4	5
pH	.329	.181	-.271	.779	-.010
som	-.085	.108	.881	.039	.192
cec	.204	.339	.386	.746	.160
ca	.539	.361	.634	.073	.146
mg	.903	.171	.210	-.027	.227
k	.957	.113	-.005	-.039	.129
fe	.914	-.078	.172	.226	-.135
mn	.356	.282	.752	-.024	-.134
cu	.726	.070	.265	.560	.104
zn	.737	.165	.458	.397	-.005
pb	-.851	-.059	.254	-.076	-.007
cd	.454	.351	.115	-.267	.578
pctgvl	-.040	.949	.092	.127	-.140
pctsd	.072	-.920	-.119	-.188	-.084
pctsltcl	-.109	-.281	.081	.197	.836
perm	.225	.734	.395	.060	-.137
%V.	37%	16%	15%	11%	7%
CV.	37%	53%	68%	79%	86%

Abbreviations- SOM: Soil organic matter; CEC: Cation exchange capacity; Ca: Calcium; Mg: Magnesium; K: Potassium; Fe: Iron; Mn: Manganese; Cu: Copper; Zn: Zinc; Pb: lead; Cd: Cadmium; Ni: Nickel; Cr: Chromium; Pctgrvl: Percent gravel; Pctsd: Percent sand; Pctsc: Percent silt/clay; Perm: Permeability; % V. :Percentage Variance; CV: Cumulative Variance.

Results of PCA for LLA showed that five factors were extracted which explained 86% of the variance. Principal Components 1-5 explained 37%, 16%, 15%, 11% and 7% of the total variance respectively (Table 5). Potassium, iron, zinc, lead copper and calcium contributed most to the variance on PC 1 in LLA; percent gravel, percent sand and permeability on PC 2; soil organic matter, manganese and calcium on PC 3; pH, CEC and copper on PC 4; while percent silt and clay and cadmium contributed most to the variance on PC 5 in LLA (Table 5).

Four factors were extracted in control explaining a total of 80% of total variance, with percentage contributions of 37%, 17%, 15% and 11% on PC 1-4 respectively (Table 6). Iron, manganese, percent sand, percent gravel, copper and cadmium contributed most of the variance on PC 1 of the control, with percent sand and cadmium loading negatively on that PC. Calcium and magnesium, as well as lead and pH contributed much of the variance on PC 2 of the control; while zinc, CEC and potassium contributed most to the variance on PC 3 and soil organic matter on PC 4 of the control (Table 6).

Table 6:
Principal Component Analysis (PCA) for the Control Area (CON)

Rotated Component Matrix for CON				
	Principal Component			
	1	**2**	**3**	**4**
pH	.187	**.608**	.445	-.038
som	-.144	-.160	.132	**.829**
cec	-.211	.109	**.753**	.317
ca	-.297	**.903**	.051	.027
mg	-.275	**.848**	.053	-.012
k	-.419	.000	**.635**	.057
fe	**.933**	-.074	-.014	-.247
mn	**.916**	-.141	-.169	-.164
cu	**.719**	-.181	.561	-.151
zn	.100	-.088	**.897**	.004
pb	.073	**.857**	-.372	-.135
cd	**-.605**	.447	-.114	-.184
pctgrvl	**.787**	-.152	-.175	-.411
pctsd	**-.794**	.167	.185	.310
pctsltcl	-.340	-.012	.025	**.771**
perm	**.730**	-.031	-.289	-.344
%V.	37%	17%	15%	11%
CV	37%	54%	69%	80%

Abbreviations- SOM: Soil organic matter; CEC: Cation exchange capacity; Ca: Calcium; Mg: Magnesium; K: Potassium; Fe: Iron; Mn: Manganese; Cu: Copper; Zn: Zinc; Pb: lead; Cd: Cadmium; Ni: Nickel; Cr: Chromium; Pctgrvl: Percent gravel; Pctsd: Percent sand; Pctsc: Percent silt/clay; Perm: Permeability; % V. :Percentage Variance; CV: Cumulative Variance.

DISCUSSION

The similarity in pH between WDA and LLA shows a trend of increased alkalinity in the dumpsite soil profile occasioned by leachate percolation into it. The higher levels of Soil Organic Matter (SOM) within WDA profiles compared to the top-soil (Table 1) may be due to intense leaching in WDA, which probably resulted in the translocation of soluble organics and subsequent loss of SOM from the surface of the soil pedon (Daniels and Galbraith, 2007). The increased CEC values in WDA imply that there will be increased competition at uptake sites on the soil surface (Nahmani *et al,* 2007a) which may reduce the amounts of metal ions that may be absorbed. Calcium and magnesium showed a similar leaching pattern in soil profiles of the three sites, probably suggestive of similar anthropogenic and/or geogenic origin and behavior (Tables 1-3).

Contamination factors for potassium in WDA and LLA were 0.83 and 1.44 respectively, suggestive of the downward leaching of potassium from WDA and its subsequent accumulation in LLA down-gradient of the dumpsite. Similar results were obtained by Ahmed & Suleiman (2001) on a Malaysian landfill. Furthermore, the humid regions of southern Nigeria are known to have a high leaching intensity which often results in potassium deficiency in some soils in this region, particularly sandy soils (Ideriah *et al.,* 2006). WDA soils had high sand content (Table 1), thus the high leaching intensity coupled with leachate percolation through soil may have resulted in potassium deficiency in WDA and its subsequent accumulation down-gradient. This may explain the low levels of potassium in WDA soils compared to control. Iron levels were highest in LLA down-gradient, also suggestive of downward leaching of iron from WDA (Tables I-III). High levels of iron in the control may suggest high natural background concentrations in soils adjoining the dumpsite. Natural soils may contain high concentrations of iron (Ademoroti, 1996; Agunbiade and Fawale, 2009). The computed contamination factors for metals in WDA were zinc (56.84), copper (21.30), cadmium (19.29), lead (4.27), manganese (1.99) and iron (1.83). The site LLA down-gradient had much lower contamination factors of 3.71 (copper), zinc (3.28), iron (1.90), lead (1.46), cadmium (1.09) and manganese (1.07). Thus, contamination factors in WDA top-soils were in the order Zn > Cu > Cd (very high contamination factor of ≥6) > Pb (considerable contamination factor of 3-6 > Mn > Fe (moderate contamination factors of 1-3).

Furthermore, copper, zinc and cadmium in WDA exceeded local regulatory standards at all depths in the profile. Lead exceeded the standards at all depths except the 75-100cm depth, while chromium exceeded the standards at 0-15; 15-30cm depths and 75-100cm depths. Copper exceeded the limits in LLA at all depths, while other metals were within the limits. Metals in the control were all within regulatory limits (Tables 1-3). These results clearly illustrate the effects of the wastes dumped on metal levels in soils. High metal levels in the soils are reflective of the high proportion of metal wastes at the dumpsite (about 25%) (Oni, 2010). The LLA had contamination factors ranged from considerable for copper and zinc to moderate for iron, lead, cadmium and manganese respectively. Two plants *(Chromoleana odorata* (L. King & Robinson) (Siam weed) and *Pennisetum purpureum* (Elephant grass) were found growing abundantly in vegetated areas adjacent to WDA. The hyper-accumulation potentials of *C. odorata* for heavy metals such as copper, mercury (Alisung, 2005; Alinsug *et al,* 2005), lead, cadmium (Tanhan *et al,* 2007; Agunbiade and Fawale, 2009; Aziz, 2011) and zinc (Aziz, 2011) are well known and reported in literature. *Pennisetum pupureum* is known to be heavy metal tolerant (Chen *et al,* 2011) and also has potential for the phyto-extraction of cadmium and zinc polluted sites (Zhang *et al,* 2010). Thus, the presence of these plants in the vicinity of the study area may perhaps explain the considerably reduced contaminant levels in the down-gradient area of the dump site. These metals also exceeded local regulatory limits highlighting the need for remediation. The potential of *C. odorata* and *Pennisetum pupureum* may be further exploited for site remediation. Soils of WDA had high percentages of sand and gravel with little amounts of silt and clay (Tables 1-3). Consequently, the soils' permeabilities were higher than the stipulated minimum value of 1 x 10^{-6} cm/sec (Diaz and Savage, 2002) for landfill soils. Although LLA soils had higher percentages of sand, their permeabilities were still higher than the stipulated minimum for landfill soils. Significantly increased levels of gravel at higher depths (60-75cm depth) in the control resulted in a significant increase in permeability at that depth. The high permeabilities imply that contaminants may move rapidly through the soil, receiving very little filtration along the way (Lindorff, 1979), thus resulting in groundwater contamination. Groundwater analysis over a similar time-frame showed elevated metal levels (Oni, 2010).

Positive loadings from percent gravel and permeability and the negative loading from percent sand on the first PC for WDA and second PC for LLA, suggests that increases in the coarse soil fraction and decreases in the finer fraction are associated with moderate increases in permeability at both sites. Nahmani *et al,* (2007b) in their analysis of metal contaminated soils obtained similar results. Leachates may contain increased heavy metals, organic matter, ammonia-nitrogen, organic and inorganic salts (Renou *et al,* 2008). The loadings from potassium, iron, manganese, copper, zinc, calcium and magnesium on the first PC for LLA are probably indicative of similar anthropogenic origin from leachates washing out towards the down-gradient area. Strong positive loadings on the first PC from iron, manganese, copper and zinc in the control may likely indicate similar geo-genic origin; while the negative loading from cadmium may possibly indicate the influences of other metals on sorption and desorption of cadmium in control soil.

The positive loadings from zinc and SOM on the third PC in WDA may suggest the possible contribution of SOM to some of these micro- nutrients such as zinc (Gaskell *et al,* 2007). The results obtained for the fourth PC for WDA and LLA, and the third for control, probably indicates the influence of CEC on potassium, zinc and copper levels in these soils. The CEC is a very important soil property for nutrient retention and supply (Caravaca *et al,* 1999). It appears that cation exchange probably plays an important role in the levels of these elements in these soils. The sixth PC illustrates the probable role of increased pH in lead desorption from the soil, ultimately leading to increased mobility of this metal in WDA soils. This was corroborated by high lead levels in the groundwater adjoining the dumpsite which exceeded international and local regulatory standards (Oni, 2010). The association of manganese and SOM on PC three in sites WDA and LLA is probably indicative of possible occurrence as complexes with SOM (Riediker *et al,* 2000).

Percent silt and clay fraction and SOM loaded strongly on the fourth PC in LLA and may be due to the fact that organic matter in arable soils are mostly associated with the silt and clay fraction (Christensen 1992; Hassink, 1997). Furthermore, soil fraction of less than 6.3mm which constitutes the silt/clay fraction is a good source of organic matter (Jain *et al*, 2005) and perhaps explains this association. The high levels of the various contaminants have important implications for underlying groundwater. Metals such as lead, cadmium and iron in groundwater of Aba-Eku community have been confirmed to be above international aind local regulatory limits; while others such as zinc and copper were within the limits, illustrating the important role mobility in soil plays in determining contaminant levels in groundwater (Oni, 2010). Bioremediation strategies are thus necessary for soils of the dumpsite. Phyto-remediation, a common bioremediation strategy for heavy metal polluted soils may be considered in view of its cost effectiveness and environmentally acceptable nature.

The results showed elevated levels of heavy metals in depth profiles of Aba-Eku dumpsite. This has implications for underlying groundwater of the site. The high contaminant levels negatively impacts the ecosystem and may also affect human health. *C. odorata,* and *P. pupureum,* two plants found in the adjoining down-gradient areas of the dumpsite may have played an important role in hyper-accumulation of some heavy metals resulting in much lower contamination down-gradient. Elevated levels of some metals above intervention/regulatory guidelines make remediation of the dumpsite highly necessary. The potential of *C. odorata* and *P. pupureum* in remedation of the site needs to be further exploited.

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