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Vertical Distribution of Cadmium and Lead on Soils Affected by Metropolitan Refuse Disposal in Owerri, Southeastern Nigeria

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Abstract: The authors investigated distribution of cadmium (Cd) and lead (Pb) in soil profile pits affected by municipal solid wastes in Avu dumpsite in Owerri, Southeastern Nigeria in 2010. Transect soil survey technique was used in aligning profile pits for field studies and sampling. Standard procedures were used in digging, describing and sampling from profile pits. Sieved soil samples were subjected to laboratory analyses and data were analyzed statistically using coefficient of variation measured in percentages. Results showed higher values of % CV in silt and clay contents. Variability of clay increased from dumpsite (CV=43.77 %) to moderately dumped site (CV=62.73%) decreased in slightly dumped side (20.98%). Highest mean values of organic matter (26.8 g/kg) and pH water (5.7) were reported in heavily dumped site. Organic Matter showed very significant positive relationship with Cd ($r = 0.92$; $p = 0.01$) and Pb ($r=0.97$; $P = 0.97$). There is need to include more soil attributes; results of which should be subjected to multi-variate techniques for more reliability and confidence especially in field applications.

Key words: Biotoxicity % Profile pit % Urban wastes % Waste disposal % Tropical soils

INTRODUCTION

Soil properties vary in space and time [1] as well as with depth. Variability in pedon characteristics is both continuous and scale-dependent and this understanding helps in the development of vertically and spatially distributed models on a range of environmental issues [2]. Extensive changes on soils and soil-related natural resources are common today in the environment resulting from anthropogenic activities which are intensified with urbanization and attendant waste accumulation. High rates of soil erosion, loss of organic matter, reduction in soil fertility and productivity, chemical and heavy metal contamination, degradation of waste and air quality have sparked interest in soil quality and its assessment [3]. Soil quality denotes the capacity of a soil to function [4], including buffering and filtering of potentially toxic materials [5]. Thus, concept of soil quality is often used in taxonomy as a foundation [6].

Owerri is a metropolitan city generating all forms of wastes, with refuse dumped principally at Avu lying at the outskirts of the city. Solid waste is heterogeneous compressing plastics, metals, old clothes, syringes, needles, papers and organic materials. The assumption is that these refuse types influence agriculture, air and water quality. It is on the background that solid wastes reduce bulk density, promotes aeration and infiltration , reduces crusting, erosion and nutrient loss by leaching; although over application can increase potential for leaching [7]. Refuse increases soil organic matter content [8], soil nutrients [9], influences soil pH [10], increase or decrease metal mobility in soils [11]; and has profound effect on microbial and enzymatic activities [12].

Solid wastes when transformed to organic matter may absorb heavy metals in dumpsites by complexation [13] although metals concentration vary with season [14,15].

Owerri is the capital of Imo State and is associated with teeming population and increasing human activity leading varying forms of wastes. Wastes are dumped on open sites including waterways. The municipal solid wastes are burnt as typical in most megacities of using air pollution via particulates [16]. Soils receiving these

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wastes are not characterized especially as it affects quality, yet they are used for vegetable, arable and tree crop production. It becomes necessary to investigate soils of Avu dumpsite in terms of concentration of biotoxic heavy metals, as they affect soil properties and human health. Based on this, the authors studied the distribution of cadmium and lead on soils of an open dumpsite proximal to Owerri municipality in central southeastern Nigeria.

MATERIALS AND METHODS

Study Area: We conducted the study at Avu Dumpsite Owerri Southeastern Nigeria, lying between latitude 5°10' and 5° 30' North and longitude 7° 15' to 7°45' East. Soils are acid sands and form over coastal plains sands (Benin formation). The plain is a dominant feature in the area and resulted from alternating denudational and aggradational activities [17]. The area lies within the humid tropics characterized by 9 months of rainfall and 3 months of dryness. Rainfall distribution is bimodal and averages about 2500 mm per annum, while the mean annual temperature ranges from 28 to 31°C. Otamiri River governs the hydrology of the study area but joins the lower course of the Imo River at Rivers State, Nigeria. Sand mining, gravel exploration, hunting, dry season vegetable production and arable farming are major socio-economic activities. Metropolitan services such as automobile activities, agro industries, food vending, packaging activities and others are prominent.

Field Studies: A transect soil survey technique was used to guide soil sampling. A transverse was cut from the centre (origin) of the dumpsite outwards. Four outstanding land units were identified for the study. They include dumpsite (heavily dumped), 10 metres away from dumpsite (moderately dumped), 20 metres away from dumpsite (slightly dumped) and 5 kilometres away from dumpsite (control). A soil profile pit was sunk in each land unit giving a total of four profile pits. Each profile pit was described according to FAO guidelines [18] and soil samples were collected based on horizon differentiation. Core samples were collected from each horizon for bulk density determination. Soil samples were air-dried and sieved using 2-mm sieve.

Laboratory Analysis: Particle size distribution was measured by hydrometer meter [19] while bulk density was determined by core procedure [20]. Soil pH was measured electrometrically in distilled water using soil: liquid ratio of 1:2.5. Soil organic carbon was estimated by wet digestion [21]. Soil organic matter, was derived using van Bermelen factor of 1.724. Available P was estimated by Bray 2 method [22].Total nitrogen was determined according to the procedure of Bremner and Mulvaney [23]. Exchangeable cations (Al, H,) and (Ca, Mg, K and Na) were determined titrimetrically. Calcium-magnesium ratios were calculated. Cation exchange capacity (CEC) were extracted with $BaCl_2$ 0.1M method [24] and this analyzed with atomic absorption spectrophotometer (Perkin Elmer Model 2280/2380). Cadmium and lead concentrations were determined using atomic absorption spectrophotometer after extraction of cations with dithionite-citrate carbonate according to Hesser [25].

Data Analysis: Soil data were subjected to coefficient of variation calculated in percentage while relationship between cadmium and lead was determined by correlation analysis.

RESULTS AND DISCUSSION

Physical properties of soil units are presented in Table 1, indicating weak argillic horizons in dumpsites compared with pronounced argillation in control soil unit. Soils were generally sandy which could be a result of combined interaction of geological material climate and land use history on soils.

Weak argillation in dumped sites could be attributed to interaction of heavy metals with colloidal clays which might have led to mobility and redistribution of clay-sized fractions within the pedon. Bulk density increased spatially and vertically with least values obtained at heavily dumped and surface horizons, respectively. This was in response to spatial and vertical organic matter distribution in the soil units (Table 2).

There was no clear trend in the distribution of soil pH and available phosphorus while highest mean value of ECEC was recorded in heavily dumped soil unit. Despite high organic matter content of heavily dumped soil, it recorded least Ca:Mg value of 1.78 while control soil unit had the highest value of 2.73. Calcium-magnesium ratio is an index of soil fertility [26], suggesting poor Ca:Mg interaction in dumped sites. The Ca:Mg ratio was more stable in control site (%CV = 10.06) compared to 33.92%, 32.35% and 39.99% obtained in heavily dumped, moderately dumped and slightly dumped soil units, respectively (Table 2).

Table 1: Soil physical properties of the study site

Horizon	Depth Cm	BD Mg/m^3	Sand	Silt	Clay	Texture
			----------	g/kg	----------	
Heavily Dumped (Dumpsite)						
A	0-18	1.04	812	100	88	Loamy sand
AB	18-48	1.12	832	130	38	Loamy sand
Bt_1	48-82	1.19	882	20	98	Loamy sand
Bt_2	82-150	1.30	842	100	68	Loamy sand
Mean		1.16	842	99.5	61	Loamy sand
CV (%)		9.48	3.50	47.41	43.37	-
Moderately Dumped (10 metres away from Dumpsite)						
A	0-15	1.15	942	30	28	Sand
AB	15-50	1.14	950	28	22	Sand
Sand Bt_1	50-95	1.18	938	14	48	Sand
Bt_2	95-170	1.30	945	36	19	Sand
Mean		1.19	944	35.5	20.8	Sand
CV (%)		6.19	0.54	26.22	62.73	-
Slightly Dumped (20 metres away from Dumpsite)						
A	0-13	1.22	810	70	120	Loamy sand
AB	13-47	1.25	790	50	160	Sandy loam
Bt_1	47-89	1.32	800	10	150	Sandy loam
Bt_2	89-148	1.35	780	20	200	Sandy loam
Mean		1.29	795	37.5	157.5	Sandy loam
CV (%)		4.69	1.62	73.43	20.98	-
Control Site (5 km away from Dumpsite)						
A	0-12	1.27	870	20	110	Loamy sand
AB	12-48	1.29	880	10	110	Loamy sand
Bt_1	48-96	1.33	790	20	190	Sandy loam
Bt_2	96-60	1.42	780	10	210	Sandy loam
Mean		1.33	830	15	155	Sandy loam
CV (%)		5.00	6.30	38.49	33.93	

BD = bulk density, MC = moisture content

Table 2: Soil chemical properties of studied site

Horizon	Depth Cm	pH Water	OM g/kg	TN g/kg	ECEC cmol/kg	Av.P mg/kg	Ca:Mg
Heavily Dumped (Dumpsite)							
A	0-18	6.2	35.3	2.4	5.67	13.21	2.2
AB	18-48	5.6	30.9	1.3	4.35	12.82	2.3
Bt_1	48-82	5.9	21.6	1.2	2.46	11.93	1.6
Bt_2	82-150	5.1	19.3	0.9	2.73	11.31	1.0
Mean		5.7	26.8	1.5	3.80	12.32	1.78
CV (%)		8.23	28.31	45.22	39.42	6.97	33.92
Moderately Dumped (10 metres away from Dumpsite)							
A	0-15	6.2	18.6	0.8	4.54	6.60	2.6
AB	15-50	4.7	12.2	0.5	4.19	6.40	2.5
Bt_1	50-95	4.6	5.5	0.3	3.10	5.12	1.8
Bt_2	95-170	4.6	4.1	0.2	2.74	4.61	1.2
Mean		5.03	10.1	0.45	3.64	5.68	2.03
CV (%)		15.62	66.13	58.79	23.59	17.07	32.35
Slightly Dumped (20 metres away from Dumpsite)							
A	0-13	5.8	15.9	0.7	5.91	7.36	2.8
AB	13-47	4.9	10.6	0.5	4.92	8.16	2.6
Bt_1	47-89	4.7	7.2	0.2	3.68	5.23	1.6
Bt_2	89-148	4.3	3.9	0.1	5.40	5.81	1.1
Mean		4.93	9.4	0.38	4.98	6.64	2.03
CV (%)		12.88	54.52	73.43	19.18	20.40	39.99
Control Site (5 km away from Dumpsite)							
A	0-12	5.3	12.9	0.8	7.62	6.96	2.4
AB	12-48	5.1	9.2	0.5	5.66	7.01	3.0
Bt_1	48-96	5.0	6.6	0.3	6.12	6.36	2.9
Bt_2	96-60	4.8	4.0	0.1	4.67	5.55	2.6
Mean		5.05	8.18	0.43	6.02	6.47	2.73
CV (%)		4.12	46.47	70.26	20.40	10.52	10.06

Table 3: Cadmium and lead concentration (mg/kg) (N=16)

Horizon	Depth (cm)	Cd	Pb
Heavily Dumped (Dumpsite)			
A	0-18	1.51	15.09
AB	18-48	1.60	14.27
Bt_1	48-82	1.80	13.57
Bt_2	82-150	0.80	12.52
Mean		1.44	13.85
Moderately Dumped (10 metres away from Dumpsite			
A	0-15	1.29	14.11
AB	15-50	1.11	15.10
Bt_1	50-95	1.30	14.88
Bt_2	95-170	0.88	11.00
Mean		1.14	13.77
Slightly Dumped (20 metres away from Dumpsite)			
A	0-13	2.00	2.83
AB	13-47	0.99	3.11
Bt_1	47-89	0.89	2.68
Bt_2	89-148	0.26	3.09
Mean		1.03	2.93
Control Site (5 km away from Dump Site)			
A	0-12	0.02	1.17
AB	12-48	0.01	0.75
Bt_1	48-96	0.01	0.62
Bt_2	96-60	0.04	0.51
Mean		0.02	0.91

Cd = cadmium, Pb = lead

Table 4: Relationship between Cd and Pb with some soil properties (N=16)

Parameters correlated	R	R^2	Level of significance
Cd vs OM	0.92	0.84	**
Cd vs ECEC	0.63	0.40	*
Cd vs Avail. P	0.88	0.77	-*
Cd vs pH	- 0.89	0.79	*
Cd vs sand	0.10	0.01	Ns
Cd vs silt	0.28	0.08	Ns
Cd vs clay	0.69	0.47	*
Pb vs OM	0.97	0.94	**
Pb vs ECEC	-0.56	0.31	Ns
Pb vs Avail. P	-0.79	0.62	*
Pb vs pH	-0.82	0.67	*
Pb vs sand	-0.08	0.06	Ns
Pb vs silt	0.16	0.02	Ns
Pb vs clay	0.61	0.37	*

Cd = Cadmium, Pb = Lead, OM = Organic Matter, ECEC = Effective Cation Exchange Capacity, Avail. P = Available Phosphorus

** = Significant at P = 0.01, * = significant at P = 0.05, ns = non significant

Concentrations of Cd and Pb generally decreased away from the dumpsite. Higher values of lead were recorded in all the soil units. Mean values of Cd (0.18 - 1.44mg/kg) and Pb (0.91 - 3.85 mg/kg) were lower than reports of Onweremadu [15] on soils of an automobile dumpsite in Owerri, central southeastern Nigeria. This suggests that toxicity of dump sites depends on waste source. Concentrations of Cd and Pb exceeded critical limits of 0.01 mg/kg and 5.00 mg/kg, respectively using WHO [27]. In addition to this, values of Cd exceeded permissible limits in all dumped soil units while Pb had the same effect on only heavily and moderately dumped soil units using tolerance limits of 0.06 mg/kg (Cd) and 10 mg/kg (Pb) [28].

Relationship existing between these biotoxic metals and some soil properties are shown in Table 4, indicating that both heavy and metals had very high significant (p = 0.01) with organic matter. The above results suggest possible use of organic matter sources for remediation of these soil toxicants. Serkar *et al*. [29] used an activated carbon from coconut shell and seed hull to adsorb 26.5mg/g of lead from aqueous solution at 65°C while vermicompost adsorbed 123.5 µg/g lead at 50°C [30]. These heavy metals correlated significantly (p=0.05) with pH, clay, available phosphorus and ECEC (Table 4).

Strong correlation between cadmium and soil variables (pH, total carbon and clay) were reported by Gray *et al*. [31] and they used these attributes to describe kinetic transfer of ions from soil solution to solid phase. These findings are necessary in modelling for the purpose of accurate predictions.

CONCLUSIONS

The study revealed differences in concentrations of Cd and lead in soil units leading to negative changes in some soil properties especially in Ca : Mg ratios. There were significant (P = 0.01, P = 0.05) differences in Cd and Pb relationships with some soil properties. Soil organic matter exhibited strongest relationship with Cd (r = 0.92; P = 0.01) and Pb (r = 0.97' r = 0.01) in the dumpsite .Further studies should include more soil parameters and results therefore should be subjected to multiple correlation, multiple regression, principal component analysis, cluster analysis and root mean square error(RMSE) determinations to increase reliability and confidence of soil predictors.

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