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Ecological Risk Assessment of Heavy Metals in Contaminated Soil from a Point Source

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***Abstract*—**The study assessed the levels of some heavy metals in the contaminated soil from a point source using pollution indices to measure the extent of pollution. The soil used was sandy-loam in texture. The contaminant used was landfill leachate, introduced as a point source through an entry point positioned at the center of top layer of the soil tank. Samples were collected after 50 days and analyzed for heavy metal (Zn, Ni, Cu and Cd) using standard methods. The mean concentration of Ni ranged from 5.55-2.65 mg/kg, Zn 3.67-0.85 mg/kg, Cu 1.60-0.93 mg/kg and Cd 1.60-0.15 mg/kg. The richness of metals was in decreasing order: Ni > Zn > Cu > Cd. The metals concentration was found to be maximum at 0.25 m radial distance from the point of leachate application. The geo-accumulation index (Igeo) studied revealed that all the metals recovered at 0.25 and 0.50 m radial distance and at 0.15, 0.30, 0.45 and 0.60 m depth from the point of application of leachate fall under unpolluted to moderately polluted range. Ecological risk assessment showed high ecological risk index with values higher than RI > 300. The RI shows that the ecological risk in this study was mostly contributed by Cd ranging from 9-96.

***Keywords*—**Ecological risk, assessment, heavy metals, test soils, landfill leachate.

I. Introduction

THE illogical discarding of waste is a main source of soil pollution. Soil pollution gives rise to alteration of the physical, chemical and biological properties of soil. It limits the use of soil in many applications. Leachate from an unlined landfill contributes to an extensive contamination of soil beneath and nearby to the dump site. Landfill leachate is polluted liquid coming from solid waste. It holds soluble organic and inorganic compounds and also suspended particles. Organic compounds are bio-degradable and prone to biologic attacks. Many organic contaminants are lipophilic with low water solubility. It suggests that they are strongly adsorbed to soil particles and have a low bioavailability. Alternatively, inorganic contaminants cannot be degraded. But their distribution, speciation etc. depends on the environmental factors such as pH and redox potential [1]-[3].

Ecological risk assessment is a process that evaluates the chances of adverse ecological effects arising as a result of exposure to physical or chemical stressors. The process is used scientifically to assess and bring together data, information, assumptions, and doubts in order to help comprehend and predict the relationships between stressors and ecological effects in a way that is useful for environmental decision making. This assessment could include physical, chemical, or biological stressors, and one stressor or many stressors may be considered. These stressors are defined as any physical, chemical and biological factors that cause adverse responses in the environment. Ecological risk factor (E^i_r) is used for evaluation of anthropogenic influence on soil and sediment; a study has been done using this method [4]. Health risk assessment of heavy metals would make known the pollution level of soil and planning the management strategy accordingly. Reference [5] reported that geo-accumulation and potential ecological risk index are used to assess the risk posed by heavy metals on soils.

This study aims to assess the levels of some heavy metals in contaminated soil from point source with a view of providing information on the level of the pollution and total ecological risk of metals in the soil.

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II. Materials and Methods

A. Soil

The soil used in this work was a sandy loam soil and acidic in nature. It was collected at a depth of 0.9 m. According to [6], analysis of the upper layers is important in understanding soil interactions with other environmental compartments and the pathways of pollutants between them.

B. Municipal Solid Waste Leachate

The leachate used in this study was collected from Uyo main refuse dump site. The leachate was collected from a hole dug 10 m away from the waste dump site. The sample was taken to the laboratory and kept in the refrigerator at 4 ^oC prior to using in the study.

C. Test Set-Up

A rectangular intermediate bulk container (IBC) test tank was used for the experiment. An overhead tank was provided to supply leachate to the soil through a PVC tap system where rate of flow can be controlled. From the overhead tank the leachate is supplied through a PVC perforated pipe, from which it percolates to the soil.

D. Experimental Procedure

The experiment was conducted in the developed laboratory set-up to study the leaching process. Test soil was air dried for 28 days and filled in the IBC test tank. At the center of the tank, above the filled soil, a circular pit of 60 mm diameter and 50 mm depth was prepared. This pit resembles the solid waste dump site. A circular PVC pipe of 60 mm diameter and 400 mm length was placed at this pit. Perforations were made on the portion of the PVC 50 mm where it is having contact with the soil. Leachate was transferred to the soil through this perforated container. Perforations facilitate the uniform passage of the leachate to surrounding soil. The entire leachate (4.76 litres, approximately 5 litres) was transferred to the soil from the overhead leachate tank to the perforated PVC pipe at a constant rate so as to achieve 50% saturation in 50 days (Fig. 1).

At the beginning of any test, unpolluted water was first allowed through the tank to ensure steady state conditions before the leachate was introduced. This allows for the establishment of a proper outflow condition at the port so that a constant velocity is maintained. A discharge velocity of about 1.157×10^{-6} l/sec was used in the experiments. The leachate treated soils were collected from the positions corresponding to 0.25 m and 0.50 m radial distances from the point of application of leachate. The samples were collected after 50 days, i.e., the day at which the application of leachate ends.

To collect samples at different depths, PVC pipe of 14 mm diameter and 0.7 m long was introduced at the center radial distances to enable the collection of the sample at the required depth. Eight samples were separated corresponding to different depth 0.15, 0.30, 0.45 and 0.60 m at 0.25 and 0.50 m radial distances as shown in Fig. 2 and analyzed for selected heavy metal.

Fig. 1 Laboratory Test Set-up

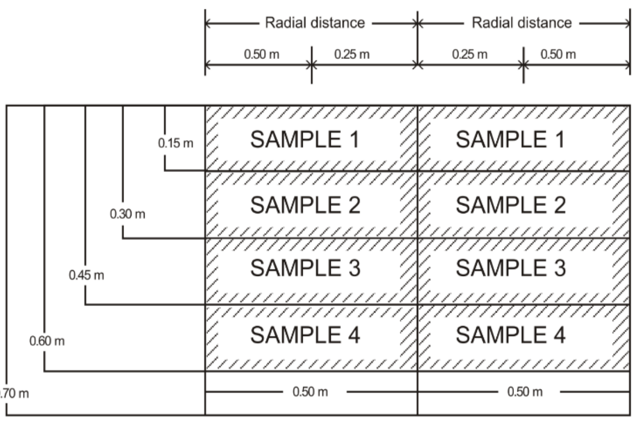

Fig. 2 Samples at Different Depths

E. Soil Analysis

The collected soil samples were air-dried. The air-dried samples were crushed and passed through a 2 mm sieve for metal analysis. The heavy metals were analyzed for Zn, Cu, Cd and Ni. The method Developed by [7] using DTPA extractant (Diethylene triamine penta acetic acid) was followed for the estimation of Zn, Cu, Cd and Ni.

III. Pollution Indices

Geo-accumulation index and ecological risk assessment were employed to measure the level of pollution.

A. Geo-Accumulation Index

Geo-accumulation Index was proposed by [8]. The method was to assess metal pollution in the contaminated soil from a point source as follows:

$$Igeo = \text{Log}_2 (C_n/1.5B_n) \quad (1)$$

where Cn is the measured concentration of the metal in the contaminated soil from a point source. Bn is the reference concentration of the metal in uncontaminated soil. The factor 1.5 is reference or control value [9]. The background value is reference value of metals by [10] were used, for maximum allowable concentration of metals in Nigeria soil (Cd = 0.8, Cu = 36 and Zn = 140) in mg/kg. Contamination classes are used to express the degree of metal pollutants in contaminated soils from a point source. These are describing as: Igeo < 0 uncontaminated soil; $0 \leq$ Igeo < 1 uncontaminated to moderately contaminated soil; $1 \leq$ Igeo < 2 moderately contaminated soil; $2 \leq$ Igeo < 3 moderately to strongly contaminated soil; $3 \leq$ Igeo < 4 strongly contaminated soil; $4 \leq$ Igeo < 5 strongly to very strongly contaminated soil; Igeo > 5 very strongly contaminated soil [11].

B. Ecological Risk Assessment

Ecological risk assessment consists of the assessment of the risk posed by the presence of substances released to the environment by human, in theory, on all living organisms in the variety of ecosystems which make up the environment. The ecological risk of metals in contaminated soil was determined as suggested by [12] and first reported [5], expressed as:

$$E^i_r = (C^i_s/C^i_n) \times T^i_r \quad (2)$$

where E^i_r is ecological risk factor, C^i_s is the present concentration of heavy metal in the contaminated soil and C^i_n is the reference value of heavy metal in the urban soil. The reference values of the average shale in the urban environment used in this work are from [13]. These values are: Cu = 35.1, Cd = 0.5, Ni = 13.2 and Zn = 59.9 mg kg^{-1}. T^i_r is the toxic-response factor for a single heavy metal contamination was taken as, Zn = 1, Cu = 5, Ni = 6 and Cd = 30 [14], [15]. The following expressions are used to defined the potential ecological risk factor, $E^i_R < 40$ designate low potential ecological risk, $40 \leq E^i_R < 80$ moderate potential ecological risk, $80 \leq E^i_R < 160$ considerable potential ecological risk, $160 \leq E^i_R < 320$ high potential ecological risk and $E^i_R \geq 320$ very high potential ecological risk [16] based on ecological risk classification introduced by [5].

The sum of potentially individual risks (E^i_r) is the potential ecological risk index (RI) was calculated using (3). The following expressions are used to defined the potential ecological risk index; RI < 50 low ecological risk, $50 \leq RI < 200$ moderate ecological risk, $200 \leq RI < 300$ considerable ecological risk, and $RI \geq 300$ very high ecological risk [16] based on ecological risk classification introduced by [5].

$$RI = \sum E^i_r \tag{3}$$

IV. Results and Discussion

A. Heavy Metal Concentration in the Contaminated Soil

Table I presents heavy metals content in the contaminated soils in mg kg^{-1} after 50 days recovered at 0.25 and 0.50 m radial distance and at 0.15, 0.30, 0.45 and 0.60 m depth from the point where application of leachate ends. The richness of metals was in decreasing order: Ni > Zn > Cu > Cd. The mean concentration of Ni ranged from 5.55-2.65 mg/kg, Zn 3.67-0.85 mg/kg, Cu 1.60-0.93 mg/kg and Cd 1.60-0.15 mg/kg. It can be detected that the presence of chemicals is found to be maximum at 0.25 m radial distance from the point of leachate application. This may be due to the pattern of flow path of the leachate through the soil that is, point or leaky source [17]. The effect was decreased with increase in distances and depth.

TABLE I
HEAVY METALS CONTENT IN THE CONTAMINATED SOILS (MG/KG) AFTER 50 DAYS

	0.25 m Radial Distance			
Depth (m)	0.15	0.30	0.45	0.60
Zn	3.67	3.14	2.73	1.70
Cu	1.60	1.54	1.39	1.24
Cd	1.60	0.84	0.65	0.31
Ni	5.55	4.75	4.60	4.20
	0.50 m Radial Distance			
Depth (m)	0.15	0.30	0.45	0.60
Zn	2.85	1.69	1.02	0.85
Cu	1.36	1.18	1.05	0.93
Cd	0.91	0.64	0.47	0.15
Ni	4.82	3.45	2.96	2.65

B. Pollution Indices

The results of the geo-accumulation index of the contaminated soils were presented in Table II. The result revealed that all the metals recovered at 0.25 and 0.50 m radial distance and at 0.15, 0.30, 0.45 and 0.60 m depth from the point of application of leachate fall under unpolluted to moderately polluted range. This means that there may be moderate health effects particularly among individuals in vulnerable population.

C. Ecological Risk Assessment

Potential ecological RI (E^i_r) of individual heavy metal and RI are presented in Table III. The potential ecological risk for Zn, Cu and Ni were below 40 at 0.25 and 0.50 m radial distance and at 0.15, 0.30, 0.45 and 0.60 m depth from the point of application of leachate, hence indicating low potential ecological risk ($E^i_R < 40$). The value for Cd at 0.25 radial distance and at 0.15 depth fall under considerable potential ecological risk ($80 \leq E^i_r < 160$). The RI ranged from 0.11-204 at 0.25 and 0.50 m radial distance and at 0.15, 0.30, 0.45 and 0.60 m depth from the point where application of leachate ends. The summation of RI values in all samples was above 300, indicating high RI. The RI shows that the ecological risk in this study was mostly contributed by Cd 9– 96.

TABLE II
GEO-ACCUMULATION INDEX, IGEO FOR HEAVY METALS OF THE CONTAMINATED SOILS

	0.25 m Radial Distance			
Depth (m)	0.15	0.30	0.45	0.60
Zn	-1.77	-.1.83	-1.89	-.2.09
Cu	-1.53	-1.54	-1.59	-1.64
Cd	0.12	-0.15	-0.27	-0.59
	0.50 m Radial Distance			
Depth (m)	0.15	0.30	0.45	0.60
Zn	-1.87	-2.09	-2.31	-2.39
Cu	-1.53	-1.66	-1.71	-1.76
Cd	-0.12	-0.27	-0.41	-0.90

TABLE III
POTENTIAL ECOLOGICAL RI (E^i_R) OF INDIVIDUAL HEAVY METAL AND RI (RI)

	0.25 m Radial Distance				
Depth (m)	0.15	0.30	0.45	0.60	$RI= \sum E^i_r$
Zn	0.06	0.05	0.05	0.03	0.19
Cu	0.23	0.22	0.20	0.18	0.83
Cd	96.0	50.4	39.0	18.6	204
Ni	2.52	2.16	2.09	1.91	8.68
$RI= \sum E^i_r$					213.7
	0.50 m Radial Distance				
Depth (m)	0.15	0.30	0.45	0.60	
Zn	0.05	0.03	0.02	0.01	0.11
Cu	0.19	0.17	0.15	0.13	0.64
Cd	54.6	38.4	28.2	9.0	130.2
Ni	2.19	1.57	1.35	1.21	6.32
$RI = \sum E^i_r$					137.27

V. Conclusion

Contaminated soil from a point source was examined for Zn, Cu, Cd and Ni. The results of the metals show that the richness of metals was in decreasing order: Ni > Zn > Cu > Cd. The result revealed that the concentration of the metals decrease with increase in distances and depth. Geo-accumulation index falls under unpolluted to moderately polluted range. Ecological risk assessment showed high ecological RI with values higher than RI > 300. The RI shows that the ecological risk in this study was mostly contributed by Cd 9 – 96. Further studied is recommended to make known the level of the pollution in the dump site soil and planning the management strategy accordingly.

Conflict of Interest

Author has declared that no competing interests exist.

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