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Assessment of Toxic Levels of Some Heavy Metals in Road Deposited Sediments in Suleja, Nigeria

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Abstract Road deposited sediments contain toxic metals which can pollute terrestrial as well as aquatic environments when these pollutants are mobilized during storm run-off. Assessment of toxic metals in the road deposited sediments of Suleja streets was carried out. 30 samples were collected from seven selected streets. The road sediment samples were digested with a mixture of HNO_3 and $HClO_4$ (2:1 v/v), and analyzed for the metals Pb, Cu, Cr, Zn, Cd and Ni using Atomic Absorption Spectrophotometer. Results showed that metal concentrations were in the order Zn>Pb>Cu>Ni>Cd>Cr. Geo-accumulation Index indicated that the contamination degree ranged from unpolluted to moderately polluted areas. Potential Ecological Risk Index demonstrated that overall risk caused by metals ranges from moderate to low. Only Cd constitutes considerable risk and contributed 60.15% of the total risk.

Keywords Toxic Metals, Geo-Accumulation Index, Ecological Risk Index, Sediments

1. Introduction

Though a vital link for communication and transport, roads are also becoming a source of pollution. Harmful substances emitted by exhausts and wear from vehicles are deposited and accumulated daily on road pavements and surrounding soil, together with primary and secondary particles from other anthropogenic (demolition/construction, industrial activities, e.t.c) and natural sources (short and long range transport of suspended soils). These depositions on roads are commonly referred to as street/road deposited sediments (RDS/SDS)[1]. The natural fraction of RDS consists of soil materials, plant and leaf litter, and atmospheric deposition[2]. The anthropogenic fraction contains high concentrations of heavy metals originating from brake linings, the combustion of fuels and the wear and tear of pavements and tires and vehicle body[3,4], and also industrial activities, municipal solid waste incineration, metals smelting, e.t. c.

Interest in heavy metal pollutions in RDS has been rapidly increasing probably as a consequence of high levels of contamination measured in a number of cities, and the potential health risks associated with them. Roadways and automobiles now are considered to be one of the largest sources of heavy metals. Zinc, copper, and lead are three of the most common heavy metals released from road travel, accounting for at least 90 percent of the total metals in road runoff. Street sediments that accumulate along pavements in urban environments have the potential to provide considerable loading of heavy metals to receiving waters and water bodies[5].

One of the most important properties of these metals which differentiate them from other toxic pollutants is that they are not biodegradable in the environment[6]. Another problem associated with them is the potential for bioaccumulation and biomagnifications causing heavier exposure for organisms than is present in the environment alone. Toxic metals accumulate in organisms as a result of direct uptake from surrounding across the body walls, from respiration and from food[7].

Rainwater can also carry RDS horizontally as well as vertically along with the various chemical constituents like heavy metals, thus polluting surface and groundwater. The studies by Poleto, *et al*[8] indicated that on average, 46% of the fluvial suspended sediments originated from paved areas, 23% come from unpaved roads, and 31% come from the stream channel itself. In a similar research to present the relation between pollutants in the street sediments and suspended sediment sample in river, Poleto and Merten[9] showed that concentrations of metals in rivers vary temporarily during storms due to input of street run-off containing elevated concentration of metals.

The impacts of highway run-off on receiving water are described in terms of the water quality or biological changes induced by the toxicity level or both. Heavy metals and other pollutants affect water quality and are potentially toxic to stream biota. In three surveys of heavy metals in whole fish in 109 streams across the United States, high levels of zinc and copper were found in Manoa streams[10]. Maltby, *et al*[11] and Pitt, *et al*[12], have established a link between

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road run-off and the deleterious influence of inorganic metal toxicants on benthic community structure and function in receiving water bodies. Humans may ingest these pollutants directly, by drinking contaminated water, or indirectly through contaminated fish.

Suleja is a city in Niger state, Nigeria. It is located at longitude 7°11E and latitude 9°11N, just north of Abuja, the Federal Capital Territory of Nigeria. In recent years, it has witnessed a population explosion and high traffic density owing to its proximity to Abuja. The aim of this study is to evaluate the degrees of contamination of these metals in Suleja, by geo-accumulation index method and to assess the potential ecological risk posed by metals, with the aid of potential ecological risk index method.

2. Materials and Methods

2.1. Sample Collection

The sampling points were selected along the major and minor roads within Suleja town, namely Usman Farouque Minna road (M), Suleiman Barau road (S), Alhasan Bako drive (A), Jibrin Bala Road (J), Abdulahi Zuba road (Z), IBB market road (I), and Hassan Dalhatu Road (H). The sediment sampling was carried out from pavement edges using a plastic dustpan and brushes. About 4 sub-samples were taken, pooled and homogenized to obtain a sample (about 200g) for each site. In order to get the accordant samples, all the RDS samples were collected under similar weather conditions, on a sunny day. The collected samples were kept in polyethylene Ziploc bag.

2.2. Sample Pretreatment and Analysis

The collected RDS were air dried and mixed thoroughly with the aid of agate mortars and pestles. The sediment samples were then sieved through a 2mm and 0.5mm plastic sieve to obtain fine particles. 1g each of the dried sieved samples was picked by the aid of a high precision analytical balance. Subsequently, the samples were put in polytetraflouroethylene vessels and digested at 100℃ for 2hrs using 20ml of a mixture of conc. HCl and conc. $HClO_4$ in the ratio of 2:1. The digested samples were cooled and filtered. The filtrates were made up to $100cm^3$ with distilled water. The total metal levels in the digested samples were determined using Atomic Absorption Spectrophotometer. The blanks and duplicates were similarly determined[12].

Table 1. Mean Concentrations (mg/kg dry weight) of Heavy Metals in Sediment Samples

Street	Pb	Cu	Cr	Zn	Ni	Cd
M	31.42 ±13.99	42.17±59.85	19.79±5.12	154.29±88.86	19.29±5.35	17.86±8.59
S	49.79±44.52	29.92±24.29	21.82±8.79	75.69±25.24	20.00±13.54	29.38±29.33
A	20.41±13.28	40.27±60.03	14.42±4.72	60.83±22.68	25.00±10.00	13.33±5.77
H	22.08±12.09	21.50±13.32	16.90±5.11	89.90±37.66	27.00±9.08	18.00±4.47
J	26.85±11.50	43.77±47.44	18.26±2.55	105.00±38.57	28.00±4.47	17.00±8.37
I	47.89±21.19	12.90±1.02	19.79±11.89	168.33±13.68	26.67±2.89	26.67±7.64
Z	50.59±27.71	4.75±1.78	12.34±3.58	102.50±8.66	18.33±7.64	15.00±5.00

Table 2. Pollution Grades of Geo-Accumulation Index of Metals

I_{geo} class	I_{geo} value	RDS quality
0	$I_{geo} \leq 0$	uncontaminated
1	$0 < I_{geo} < 1$	uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	moderately contaminated
3	$2 < I_{geo} < 3$	moderately to heavily contaminated
4	$3 < I_{geo} < 4$	heavily contaminated
5	$4 < I_{geo} < 5$	heavily to extremely contaminated
6	$5 < I_{geo}$	extremely contaminated

Table 3. Indices and Grades of Potential Ecological Risk of Toxic Metals Contamination

E^i_r value	Grades of ecological risk of metals	RI value	Grades of the environment
E^i_r<40	low risk	RI<110	low risk
$40 \leq E^i_r < 80$	moderate risk	110≤RI<200	moderate risk
$80 \leq E^i_r < 160$	considerable risk	200≤RI<400	considerable risk
$160 \leq E^i_r < 320$	high risk	400≤RI	very high risk
$320 \leq E^i_r$	very high risk		

Table 4. The Heavy Metal Potential Ecological Risk Indexes in Suleja Streets

Street	E_i						RI	Pollution degree
	Pb	Cu	Cr	Zn	Ni	Cd		
M	7.40	21.52	2.40	3.25	9.65	53.58	97.8	Low risk
S	11.73	15.27	2.94	1.59	10.00	88.14	129.67	Moderate risk
A	4.81	20.55	1.94	1.28	12.50	39.99	81.07	Low risk
H	5.20	10.97	2.28	1.89	13.50	54.00	87.84	Low risk
J	6.33	22.33	2.46	2.21	14.00	51.00	98.33	Low risk
I	11.28	6.58	2.67	3.54	13.34	80.01	117.42	Moderate risk
Z	11.92	2.42	1.66	2.16	9.17	45.00	72.33	Low risk

2.3. Data Analysis

The results obtained were subjected to analysis to determine the Geo-accumulation Index and Potential Ecological Risk Index of the metals in the environment.

2.3.1. Geo-Accumulation Index (I_{geo})

The Geo-accumulation Index (I_{geo}), was introduced by Muller[13] for determining the extent of metal accumulation in sediments, and has been used by various workers for their studies. I_{geo} is mathematically expressed as:

$$I_{geo} = \log_2 C_n / 1.5 B_n \quad (1)$$

Where C_n is the concentration of element in the sediment, B_n is the geochemical background value. The factor 1.5 is incorporated in the relationship to account for possible variation in background data due to lithogenic effect. The geo-accumulation index (I_{geo}) scale consists of seven grades (0 –6) ranging from unpolluted to highly polluted (Table 2).

2.3.2. Potential Ecological Risk Index

The Potential Ecological Risk Index (RI) was originally introduced by Hakanson[14] to assess the degree of heavy metal pollution in soil, according to the toxicity of metals and the response of the environment. RI could evaluate ecological risk caused by toxic metals comprehensively. The calculating methods of RI are listed below:

$$F_i = C^i_n / C_o^i \quad (2)$$

$$E^i_r = T^i_r \times F_i \quad (3)$$

$$RI = \sum_{i=1}^{n} E \quad (4)$$

Where F_i is the single metal pollution index; C^i_n is the concentration of metal in the samples; C^i_o is the reference value for the metal; E^i_r is the monomial potential ecological risk factor; T^i_r is the metal toxic response factor according to Hakanson[14]. The values for each element are in the order Zn = 1 < Cr = 2 < Cu = Ni = Pb = 5 < As = 10 < Cd = 30. RI is the potential ecological risk caused by the overall contamination. There are four categories of RI and five categories of E^i_r as shown in Table 3.

3. Results and Discussion

The ranges of mean concentration (mg/Kg) of the heavy metals in RDS are Pb (20.41 – 50.59), Cu (4.75 – 43.77), Cr (12.34 – 21.82), Zn (60.83 – 168.33), Ni (18.33 – 28.00) and Cd (13.33 – 29.38), respectively (Table 1).

3.1. Contamination Degree Based On I_{geo}

The degree of pollution in sediments can be assessed by the determination of indices such as Geo-accumulation Index (I_{geo}). The calculated I_{geo} values for different RDS samples are summarized in Fig. 1. From the figures, the I_{geo} values for Pb shows that 56.67% of the samples fall in the uncontaminated class (≤0), 36.67% in the uncontaminated–moderately contaminated class (0-1), while the remaining 6.67% are moderately contaminated (1-2). I_{geo} values ≤0 (uncontaminated) for Cu, Cr, Zn, Ni, and Cd accounted for 63.33%, 93.33%, 20%, 26.67%, and 53.33% of the total values respectively. The I_{geo} values for uncontaminated– moderately contaminated are 13.33%, 6.67%, 63.33%, 56.67%, and 40% for Cu, Cr, Zn, Ni, and Cd respectively.

The average I_{geo} for the observed metals were in the decreasing order of Ni (0.55) > Zn (0.45) > Cu (0.29) > Cd (0.15) > Pb (-0.17) > Cr (-0.46). This implies that Ni, Zn, Cu, and Cd unpolluted – moderately polluted the RDSs while Pb and Cr did not pollute the RDSs. No I_{geo} value was greater than 4 (i.e. heavily – extremely contaminated), and only two values Cu (3.55) at M5, and Cu (3.12) at J21 are in the heavily contaminated class.

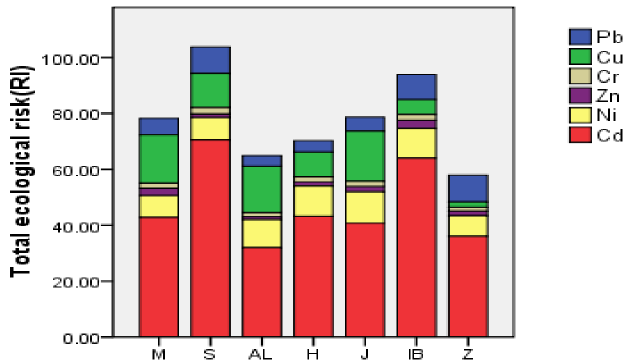

Figure 1. Contributions of different metals to ecological risk in different streets of Suleja. M, S, AL, H, J, IB and Z refers to Usman Faruque Minna road, Suleiman Barau road, Alhasan Bako Drive, Hassan Dalhatu Road, Jibrin Bala road, Abdulahi Zuba road and IBB market road respectively

3.2. Potential Ecological Risk Assessment

The ecological risk assessment results of toxic metals in RDSs were summarized in Table 4. It was found that the average monomial risk factors (E_r^i) of metals in the RDSs were ranked in the following order Zn<Cr<Pb<Ni<Cu<Cd. The average monomial ecological risk for Cd was above 40, indicating that Cd posed moderate risk to the local ecosystem. However, the values for Suleiman Barau Street(S) and IBB Market Road(I) are above 80, which indicate that Cd posed considerable risk at these regions. The average E_r^i values for other metals were below 40, indicating that these metals posed low risk to environment. For the metals in the different samples, there was only one monomial ecological risk above 160, which is 198 (Cd) in S11 indicating high risk. Other E_r^i values showing considerable risk (i.e. above 80) include 90 (Cd) in M3, 90 (Cd) in M6, 90 (Cd) in S9, 90 (Cd) in J24, and 105 (Cd) in I25. The E_r^i values for other metals in the samples were below 80, indicating low to moderate risk.

In order to quantify the overall potential ecological risk of observed metals in the RDSs, RI was calculated as the sum of all the six risk factors (Table 4). The RI values for the streets are in the following order Z (73.33) < A (81.07) < H (87.84) < M (97.80) < J (98.33) < I (117.42) < S (129.67). Suleiman Barau Road (S), and IBB Market Road (I) constitute moderate risk while other roads show low risk to the local ecosystem. RI could characterize sensitivity of local ecosystem to the toxic metals and represent ecological risk resulted from the overall contamination. The contribution of individual metals to overall potentially ecological risk was demonstrated in Figure. 1. The contribution to the total potentially ecological risk of the streets shows that Cd contributed 54.79%, 67.97%, 49.33%, 61.48%, 51.87%, 68.14%, and 62.21% respectively, Cu contributed 22%, 11.78%, 22.35%, 12.49%, 22.70%, 9.61% and 16.48% respectively, while Ni was 9.87%, 7.71%, 15.42%, 15.37%, 14.24%, 11.36%, and 12.67% respectively. Overall Cd contributed 60.15% of the total potentially ecological risk.

Results of Geo-accumulation evaluation indicated that Cd was mainly on the uncontaminated degree. However, ecological risk caused by Cd was considerable due to its high toxicity. On the other hand, Zn accumulated more than any other metal but its ecological risk was relatively low due to its low toxicity. Thus it can be seen that I_{geo} method focused mainly on the accumulation levels of individual metals without regard to the toxic response factor. Potential Ecological Risk Index could describe both ecological risk caused by single pollutant and overall risk or contamination from varied pollutants[14].

4. Conclusions

Contamination assessment based on Geo-accumulation Index (I_{geo}) showed that metals were in the uncontaminated to moderately contaminated degrees, and were in the decreasing order of: Ni > Zn > Cu > Cd > Pb > Cr while the streets are contaminated in the following order: I > S > J > M > H > Z > A. The ecological risk assessment results showed that Cd was the only metal posing a potentially high risk to environment. The overall risk indexes caused by the six toxic metals in Suleja streets indicate that two streets; Suleiman Barau road(S) and IBB Market road(I) are in the moderate risk class while other streets are in low risk.

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