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Use of integrated pollution indices in assessing heavy metals pollution in soils of three auto mechanic villages in Abuja

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This research work targeted at the use of integrated pollution indices models of Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$) in assessing heavy metals pollution in soils of three auto mechanic villages of Abuja. Soil samples were randomly collected with a stainless hand auger to a depth range of 0 to 15 cm and were analyzed with atomic absorption spectrophotometer of model Unicam 969 Solar to determine the heavy metal contents in them. Mean concentration (mg/kg) of heavy metals from the results were observed to follow a decreasing order; Apo: Cu (7668) > Zn (5360) > Cr (1174) > Fe (467) > Pb (333) > Ni (196) > Cd (10.5); Kugbo: Zn(1587) > Cu (1042) > Cr (783) > Ni (234) > Fe (217) > Pb (170) > Cd (9.47) and Zuba: Zn(1190) > Cr (767) > Cu (512) > Fe (279) > Pb (250) > Ni (127) > Cd (10.4). Strong positive correlations exist between heavy metals which indicate same source of contamination, mutual dependence and identical behaviors. Results of integrated pollution indices showed that investigated soils have been polluted to various degrees ranging from low to high level pollution. This indicates deterioration of sites quality.

Key words: Auto mechanics villages, atomic absorption spectrophotometer, heavy metals, integrated pollution indices, soil, statistical analysis.

INTRODUCTION

One of the major fallout of industrialization and urban development is the release and accumulation of heavy metal containing wastes and other environmental pollutants in the environment (Du et al., 2013). Pollution of natural environment by heavy metals over the years has been a global problem due to their indestructive nature, potential toxicity, wide spread sources, non-biodegradable nature, and bioaccumulation properties (Kacholi and Sahu 2018; Ihejirika et al., 2016; Zhu et al., 2012). Pollution sources of heavy metals in environment

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are mainly from anthropogenic sources which include; traffic emission (Wei et al., 2010), industrial emission (Jiang et al., 2017; Ekeocha et al., 2017; da Silva et al., 2016; Du et al., 2015; Jiang et al., 2014), and agricultural processes (Arao et al., 2010). Heavy metals can exert their toxicity via dermal, skin contacts (exposure/ absorption), inhalation and ingestion which all have adverse effect on health of humans and organisms (De Miguel et al., 2007). Bioaccumulation of heavy metals in human tissue can lead to some health problems like: cellular and tissue damage, infertility, neurotoxic effects in children, circulatory and nerve tissues damage, breakage of metabolism route, heart and liver disease, kidney damage, chronic renal, cancer, lung infection, cardiovascular diseases, respiratory system disorders, skin and tooth decay among others (Jarup et al., 2013; Damek-Proprawa et al., 2003). Hence there is need to assess the contamination level and environmental effects of selected heavy metals in major auto mechanic villages of Abuja, bearing in mind the inflow of vehicles to these auto mechanic sites on daily basis for various vehicle maintenance.

With the development of ecological and exploration geochemistry survey, a great deal of data related to heavy metal concentration in soils and water sediments have been measured which can be used to assess the quality of ecological geochemistry environment. Many calculation methods have been presented to assess the environmental quality, such as pollution index (Gong et al., 2008) and Principle correlation (Cheng et al., 2007). Pollution index is a powerful tool for processing, analyzing and conveying raw environmental information to decision makers, managers, technicians and the public (Caeiro et al., 2005). This research was carried out in Abuja, North Central part of Nigeria in order to evaluate the contamination level(s) of various heavy metals in soils in selected auto mechanic villages in the area. Nevertheless, the research was not conducted as a regulatory sampling or as a result of an outbreak of any disease. The sole objective was to assess the levels of heavy metals in soils and to evaluate the degree of contamination of soils by heavy metals using various integrated pollution indices models.

MATERIALS AND METHODS

Study sites, sample collection and analysis

The study was conducted in three major auto mechanic villages in Abuja namely; Apo, Kugbo and Zuba (Figure 1). The area is located in the North-Central part of Nigeria with geographical coordinates of latitude 9°40' N and 9°29' E. The city also shares a land border with six other states namely: Benue, Kaduna, Kogi, Nassarawa, Niger and Plateau States. Soil samples were randomly selected with a stainless hand dug auger to a depth range of 0 - 15 cm with five of the soil samples drawn from each of the mechanic villages (Apo, Kugbo and Zuba). A control sample was also collected from a distance of 100 km were neither industrial nor commercial activities takes place. Sampled soils were homogenized, air dried; crushed and sieved in a mechanical sieve of mesh size 338 μm with make Endecott's Limited London, England, serial number 489494. Heavy metals concentrations in each sample were determined using atomic absorption spectrophotometer (Unicam 969 Solar) immediately after digestion of soil samples (George et al., 2013; Kouadia et al., 1987). The sampling and analyses were all done in the month of November, 2014.

Statistical analysis

Descriptive statistics were conducted to determine the average, range, mean and standard deviations of investigated heavy metals in soil samples. Person's correlations matrix was also performed to evaluate sources of heavy metals in soils of studied sites, the dynamic of the contamination and potential relationship among measured variables. Statistical analysis was done using IBM SPSS 16.0 software.

Integrated pollution indices assessment

Integrated indices are indicators used to calculate more than one metal contamination which are based on single indices and each kind of integrated index might be composed by the above single indices separately (Gong et al., 2008). Four integrated pollution indices: Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$) were used.

Pollution index

Pollution index is defined as the ratio of the metal concentration in the city to the background concentration of that metal (Wei et al., 2009).

$$PI = \frac{C_i}{C_{ri}} \quad (1)$$

Where C_i is the mean concentration of each of the investigated metal in soil or sediment drawn from at least five sampling sites and C_{ri} is the background value of the metal. In order to unify the assessment results, reference values as provided by DPR (2002) were used as background values (Cr = 100, Fe = 5000, Ni = 35, Cu = 36, Zn =140, Cd = 0.8 and Pb = 85). The following terminology was used for the pollution index model: PI < 1, non pollution; 1 ≤ PI < 2, low level pollution; 2 ≤ PI < 3, moderate level of pollution; 3 ≤ PI < 5, strong level of pollution; PI ≥ 5, very strong level of pollution (Yang et al., 2011).

An average of pollution

An average of pollution index (PI_{Avg}) model is an aspect integrated indices used to calculate more than one metal contamination and it's mathematical written as:

$$PI_{Avg} = \frac{1}{m}\sum_{i=1}^{m} P_i \quad (2)$$

Where P_i is the single pollution index of heavy metal i and m is the count of the heavy metal specie. Values of $PI_{Avg} < 1$ indicates high

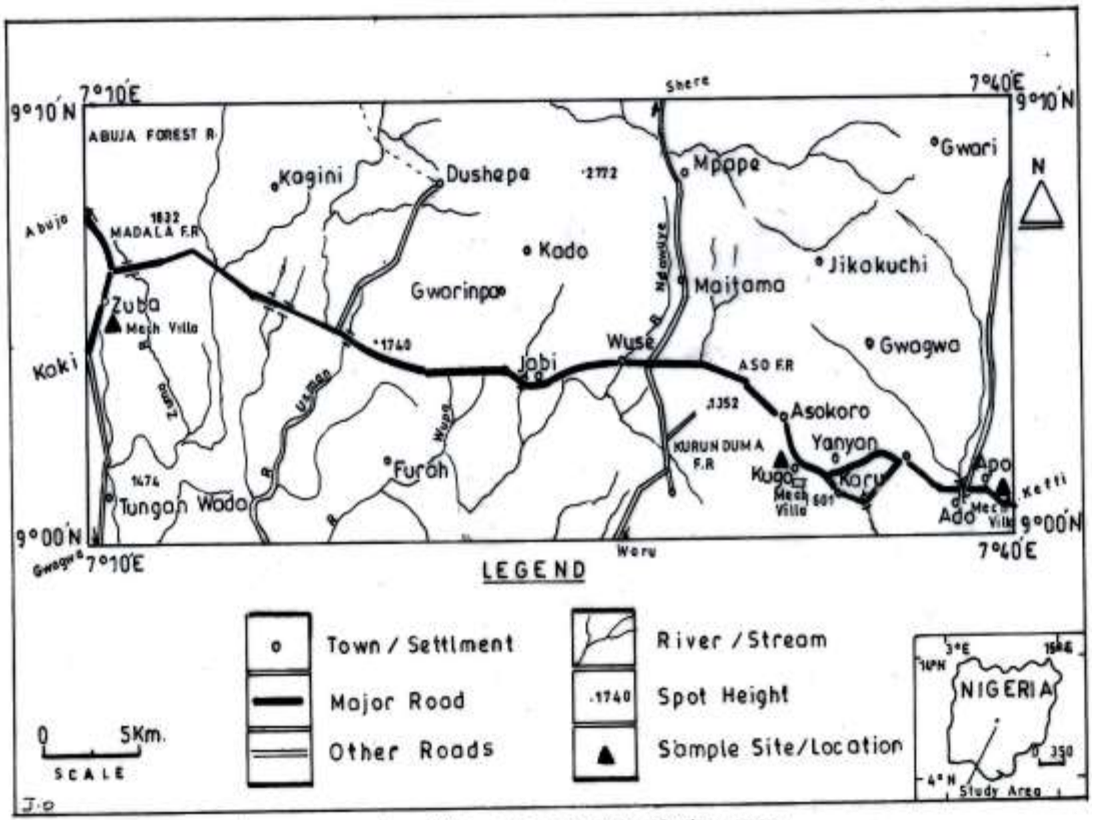

Figure 1. Geographical location of investigated Auto Mechanic Sites in Abuja.

quality soil and $PI_{Avg} > 1$ indicates low quality soil. This type of pollution index was used to assess the quality of abandoned-mined-tailings environment (Bhattacharya et al., 2006).

Pollution load index

Pollution load index is an example of root of the product of pollution index indices which is based on contamination factor of each metal in soil. This aspect of integrated pollution indices have been used to quantify pollution load of heavy metals in both soils and sediments. The model also provides an easy and comprehensive means of assessing the quality of an investigated site (Waheshi et al., 2017; Goher et al., 2014).

$$\text{PLI can be defined as; PLI} = (PI_1 \times PI_2 \times PI_3 \times \text{------} \; PI_n)^{\frac{1}{n}} \quad (3)$$

Where PI is pollution load index of individual metal described earlier and n is the number of investigated metals. The following terminology was used for the pollution load index: PLI < 1, perfection; PLI = 1, only baseline levels of pollutants present; and PLI > 1, deterioration of site quality (Tomlinson et al., 1980).

Nemerow pollution index

The formula of Nemerow pollution index contains the biggest monomial pollution index in the evaluation of parameter which illustrates the effect of the pollutant the highest pollution index on the environmental quality. In recent times, some researchers have applied Nemerow pollution index model in assessing the quality of soil in an environment (Jiang et al., 2014; Cheng et al., 2007).

$$NIPI_{Nemerow} = \frac{\sqrt{\left(\frac{1}{m}\sum_{i=1}^{m} P_i\right)^2 + \left(P_{imax}\right)^2}}{2} \quad (4)$$

Where, P_i is the single pollution index of heavy metal i; P_{imax} is the maximum value of the single pollution indices of the investigated heavy metal(s) and m is the count of the heavy metal species. The quality of soil were classified into five categories from Nemerow pollution index: $NIPI_{Nemerow} < 0.7$, unpolluted, $0.7 \le NIPI_{Nemerow} < 1.0$, little pollution; $1.0 \le NIPI_{Nemerow} < 2.0$, slight pollution; $2.0 \le NIPI_{Nemerow} < 3.0$, moderate pollution; $NIPI_{Nemerow} \ge 3.0$, serious pollution (Cheng et al., 2007). Sum of pollution index can be mathematically defined as:

$$PI_{sum} = \sum_{i=1}^{m} P_i \quad (5)$$

Where P_i is the single pollution index of heavy metal i and m is the count of the heavy metal species. The sum of pollution index was widely used in soil and sediment quality assessment by heavy metal such as the degree of contamination and potential ecological risk index (Maanan et al., 2014; Håkanson et. al., 1980).

Table 1. Heavy metal concentration in soils (mg/kg) in investigated sites compared with permissible limits of some international regulatory bodies

Samples	Cr	Fe	Ni	Cu	Zn	Cd	Pb
A_{p-1}	1117	561	238	1677	8200	12.5	96.4
A_{p-2}	1173	426	212	22000	5288	11.5	357
A_{p-3}	1916	423	402	12830	8421	10.6	967
A_{P-4}	814	411	48.6	219	847	8.90	194
A_{p-5}	848	512	80.5	1616	4045	8.90	51.7
Average	1174	467	196	7668	5360	10.5	333
Mean ±SD	1174±444	467±66.4	196±141	7668±9488	5360±3144	10.5±159	333±373
Range	814-1916	411-561	48.6-402	219-22000	847-8421	8.94-12.5	51.7-967
K_{u-1}	911	203	195	3144	2869	1.20	89.6
K_{u-2}	288	320	370	407	719	10.2	201
K_{u-3}	726	259	110	340	2016	15.2	316
K_{u-4}	915	145	178	1017	1441	1.50	15.7
K_{u-5}	1074	157	318	306	890	19.2	225
Average	783	217	234	1043	1587	9.47	170
Mean ±SD	783±303	217±73.3	234±107	1043±1210	1587±879	9.47±8.07	170±118
Range	288-1074	145-320	110-370	340-3144	719 - 2869	1.20-19.2	15.7- 316
Z_{u-1}	830	302	187	686	410	10.2	199
Z_{u-2}	764	331	148	351	976	12.5	58.3
Z_{u-3}	1120	195	127	956	1010	9.50	249
Z_{u-4}	630	306	126	352	1710	8.80	443
Z_{u-5}	491	260	48.0	217	1845	11.1	298
Average	767	279	127	512	1190	10.4	250
Mean ±SD	767±236	279±53.4	127±50.7	512±302	1190±589	10.4±1.41	250±140
Range	491-1120	195-331	48.0-187	217-956	410-1845	8.84-12.5	58.3-443
C_T	1108	2.45	108	37.3	73.4	na	102
B_T	100	5000	35.0	36.0	140	0.80	85.0
I_V	380	nl	210	190	720	17.0	530
UK [a]	130	n.a	130	n.a	n.a	10	450
Poland [c]	100	n.a	100	100	300	3.0	100
Japan [d]	n.a	n.a	100	125	250	n.a	400
Canada [e]	250	n.a	100	150	500	3.0	200
Germany [f]	200	n.a	100	50	2	300	500

Ap, Apo auto mechanic village; Ku, Kugbo auto mechanic village; Zu, Zuba auto mechanic village; C_T, control sample; na, not available; B_T, background values of DPR (2002); I_V, intervention value of DPR (2002). n.a, not available; n.l, no limit, [a]Kamunda et al. (2016);; [c]Mtunzi et al. (2015); [d]Fagbote et al. (2010); [e]Canadian Ministry of the Environment (2009); [f]Lacatusu (2000).

RESULTS AND DISCUSSION

Results of concentrations of heavy metal (mg/kg) in soil from investigated sites are presented in Table 1. The results revealed that in Apo auto mechanic village, values of investigated heavy metals fluctuated as follows; Cr (814 to 1916) mg/kg; Fe (411 to 561) mg/kg; Ni (48.6 to 402) mg/kg; Cu (219 – 22000) mg/kg; Zn (847 to 8421) mg/kg; Cd (8.90 to 12.50) mg/kg; and Pb (51.7 – 967) mg/kg. A trend of decrease in mean values of heavy metal concentration in Apo can be deduced as Cu > Zn > Cr > Fe > Pb > Ni > Cd. Values of heavy metals in Kugbo auto mechanic village also fluctuated as follows; Cr (288 to 1074) mg/kg, Fe (145 to 320) mg/kg, Ni (110 to 316) mg/kg, Cu (306 to 3144) mg/kg, Zn (719 to 2869) mg/kg, Cd (1.20 to 19.2) mg/kg and Pb (15.7 to 316) mg/kg.

Values of heavy metal in Zuba also fluctuated between (491 to 1120), (195 to 331), (48 to 187), (217 to 956), (410 to 1845), (8.80 to 12.5), and (58 to 443) mg/kg in Cr, Fe, Ni, Cu, Zn, Cd and Pb respectively. Comparatively

Table 2. Pearson's correlation coefficient matrix for heavy metals in investigated auto mechanic villages.

Apo	**Cr**	**Fe**	**Ni**	**Cu**	**Zn**	**Cd**	**Pb**
Cr	1						
Fe	-0.275	1					
Ni	0.962**	-0.073	1				
Cu	0.523	-0.490	0.530	1			
Zn	0.745	0.394	0.883*	0.330	1		
Cd	0.374	0.379	0.603	0.405	0.762	1	
Pb	0.943	-0.565	0.827	0.549	0.483	0.121	1
Kugbo							
Cr	1						
Fe	-0.928*	1					
Ni	-0.370	0.267	1				
Cu	0.277	-0.221	-0.274	1			
Zn	0.326	-0.144	-0.724	0.814	1		
Cd	0.003	0.179	0.283	-0.739	-0.508	1	
Pb	-0.268	0.530	0.050	-0.575	-0.201	0.865	1
Zuba							
Cr	1						
Fe	-0.532	1					
Ni	0.535	0.365	1				
Cu	0.949*	-0.626	0.498	1			
Zn	-0.654	-0.098	-0.867	-0.643	1		
Cd	-0.228	0.402	-0.074	-0.415	-0.149	1	
Pb	-0.321	-2.226	-0.389	-0.138	0.643	-0.840	1

Significant /r/*(p < 0.05); ** (p < 0.01)* (n = 5).

mean values of heavy metals in all the sites were observed to have exceeded those from control, DPR background value and those of some international regulatory bodies (Table 1). They also exceeded those reported by some researchers (Mugoša et al., 2016; Kamunda et al., 2016). This indicates that the studied sites have been contaminated by heavy metals generated from various auto mechanic repairs carried out the studied sites.

In other to determine the relationships that exist among the investigated heavy metals, Person's correlation analyses were conducted and the results are shown in Table 2. The results showed that in Apo site, strong positive correlation exist between Cr and the following metals; Ni, Pb, Zn (0.962**, 0.943*, 0.745) respectively. Ni also had good positive correlation with Zn, Pb, Cd and Cu (0.883*, 0.827, 0.603 and 0.530), Zn/Cd (0.762) and Cu/Pb (0.549). The results obtained also showed that the investigated heavy metals have mutual dependence, identical behaviour and same origin. Negative correlation also exist between Fe/Pb (-0.565*), Fe/Cu (-0.490) and Fe/Cr (-0.275) indicating different source(s). Strong positive and negative correlation exists between the following metals in Kugbo site; Cd/Pb (0.865), Cu/Zn (0.814), Fe/Pb (0.530), Cr/Fe (-0.928*), Cu/Cd (-0.739), Ni/Zn (-0.724), Cu/Pb (-0.575) and Zn/Cd (-0.508). In Zuba auto mechanic village, strong negative correlation also exist between Zn/Ni (-0.867), Cd/Pb (-0.823), Zn/Cr (-0.645), Zn/Cu (-0.643) and Fe/Cu (-0.626) with few strong positive correlation among Cr/Cu (0.947*) and Zn/Pb (0.643).

Results of the pollution index (PI) shown in Table 3 reveal that in Apo auto mechanic village, 71.24% of investigated heavy metals: Cu, Zn, Cd, Cr and Ni were in the class of very strong level of pollution. Pb and Fe were also in the class of strong level and non-pollution. In Kugbo auto mechanic village, 71.24% of the heavy metals were in the class of very strong level of pollution leaving 14.28% of it to moderate and non-pollution respectively. 57.14% of the heavy metals in Zuba auto mechanic village were also in the class of very strong level of pollution with 21.43% of the metals in the class of serious and non-pollution. High (PI_{Avg}) values (Table 3) recorded in the three sites depicts that soil in these sites

Table 3. Values and categories of Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$).

Sites		Cr	Fe	Ni	Cu	Zn	Cd	Pb	PI_{Avg}	PLI	$NIPI_{Nemerow}$
Apo	C_i	1173	467	196	7668	5360	11.1	333			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	11.7	0.093	5.60	213	38.3	13.9	3.92	40.9	8.26	153.4
	category	v_{sp}	n_p	v_{sp}	v_{sp}	v_{sp}	v_{sp}	s_p	lq	dsq	sp
Kugbo	C_i	783	216	234	1043	1587	9.40	169			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	7.83	0.043	6.70	29.0	11.3	11.8	1.99	9.81	1.83	21.65
	category	v_{sp}	n_p	v_{sp}	v_{sp}	v_{sp}	v_{sp}	m_p	lq	dsq	sp
Zuba	C_i	767	278	127	512	1190	10.4	250			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	7.67	0.056	3.63	14.2	8.5	13.0	2.94	7.14	3.59	11.24
	category	v_{sp}	n_p	s_p	v_{sp}	v_{sp}	v_{sp}	m_p	lq	dsq	sp

C_i, mean concentration of heavy metals from at least five points; C_{ri}, background value; PI; pollution index; n_p, non pollution; l_p, low level pollution, m_p, moderate level of pollution; s_p, strong level of pollution; v_{sp}, very strong level of pollution; PI_{Avg}, average of pollution index; lq, low quality of soil; hq, high quality of soil; PLI, pollution load index; p, perfection; bp, baseline pollutants; dsq, deterioration of site quality; $NIPI_{Nemerow}$, Nemerow pollution index; s_p, slightly polluted; mp, moderately polluted; sp, seriously polluted.

have low quality due to contamination by heavy metals. Results of pollution load index also revealed that Apo, Kugbo and Zuba sites had PLI values of 8.26, 3.99 and 3.59 which are all greater than 1 which indicate deterioration of site quality due to pollution. These values were also higher than those reported by Goher et al. (2014).

Conclusion

Different pollution indices models employed in the calculation of heavy metal pollution in soil samples from three auto mechanic villages of Abuja showed that mean content of these heavy metals (mg/kg) follow a decreasing order of: Apo site: Cu > Zn > Cr > Fe > Pb > Ni > Cd; Kugbo site: Zn > Cu > Cr > Ni > Fe > Pb > Cd and Zuba site: Zn > Cr > Cu > Fe > Pb > Ni > Cd. These values also exceeded those from control, background values of national and some international regulatory bodies. Results of correlation analysis indicated that some of the investigated heavy metals in all the sites are mutually dependence with identical behaviour and same origin.

Integrated pollution indices assessment conducted reveal that soils in the investigated sites have been polluted to various degrees by heavy metals. These heavy metals could also be traceable to anthropogenic sources probably from various auto repairs done in the area which poses serious ecological risk to human, organisms and environment at large.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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