British Journal of Applied Science & Technology
19(2): 1-10, 2017; Article no.BJAST.30779
ISSN: 2231-0843, NLM ID: 101664541

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Application of Multiple Ecological Risk Indices for the Assessment of Heavy Metal Pollution in Soils in Major Mechanic Villages in Abuja, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author CIE designed the study, wrote the protocol and modeled the work. Authors CIE and JON carried out the field work, laboratory analysis and wrote the first draft of the manuscript. Author CEO provided analytical advice. Authors JON and CEO managed the literature searches. All Authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2017/30779
Editor(s):
(1) Jakub Kostecki, Department of Civil and Environmental Engineering, University of Zielona Góra, Poland.
Reviewers:
(1) Caroline Lomalungelo Dlamini, University of South Africa (UNISA), South Africa.
(2) Ndwiga Taratisio, Moi University, Eldoret, Kenya.
(3) Flávio Henrique Silveira Rabêlo, University of São Paulo, Brazil.
(4) Adams Sadick, CSIR-Soil Research Institute, Ghana.
Complete Peer review History: http://www.sciencedomain.org/review-history/18023

Original Research Article

Received 30th November 2016
Accepted 15th February 2017
Published 2nd March 2017

ABSTRACT

Heavy metal contamination has become a serious environmental problem due to their negative effects on humans, organisms, soil quality, underground water and ecosystem. This research was targeted at the use of multiple ecological risk indices approach in assessing the ecological risk associated with heavy metal contamination in soils in some mechanic villages in Abuja, central Nigeria. To achieve this set objective, four pollution indices models namely: contamination factor (C_f), ecological risk factor (E_r), degree of contamination (C_D) and potential ecological risk index (PERI) were explored. Fifteen soil samples were randomly collected with a hand dug auger to a depth range of 0-15 cm with five sample points from each of the three investigated mechanic villages. A control sample was also collected from a distance of 100 km where neither commercial

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nor industrial activities take place. The sampled soils were further subjected to standard chemical analysis. The automated Atomic Absorption Spectrophotometer (AAS) was used for this purpose. The results of the chemical analysis revealed that concentrations of heavy metals in Apo, Kugbo and Zuba mechanic villages followed a trend of Cu > Zn > Cr > Fe > Pb > Ni > Cd; Zn > Cu > Cr > Ni > Fe > Pb > Cd and Zn > Cr > Cu > Fe > Pb > Ni > Cd respectively. The multiple ecological risk indices models explored in the study showed various ecological risk level associated with heavy metal contamination of soils from the investigated sites with classes ranging from low to very high ecological risks. This could be traceable to anthropogenic activities like indiscriminate discharge of heavy metal containing waste in soil and poor waste management practice in the mechanic villages. This calls for urgent measure in curtailing indiscriminate waste discharge and the introduction of environmental friendly waste management in the mechanic villages so as to avert epidemics and environmental degradation due to heavy metal pollution.

Keywords: Soil pollution; heavy metals; Automated Atomic Absorption Spectrophotometer; multiple ecological risk indices; anthropogenic activities; auto-mechanics; mechanic village.

1. INTRODUCTION

With the advent of industrialization, pollution associated with heavy metals has become a serious environmental problem due to its toxicity, wide sources, non biodegradables and accumulative properties as it affect human, organisms, soil, water and the ecosystem at large [1-2]. Heavy metals can also be enriched through food chain, body adsorption, inhalation, direct intake (ingestion) through water and soil [3]. In recent years, with the development of global economy, heavy metal contaminations caused by anthropogenic processes have gradually increased resulting in the deterioration of the environment [4-6].

Anthropogenic processes, unlike geogenic processes, have been a major source of heavy metal contamination in the environment. Some of the anthropogenic processes that have contributed towards the pollution of the environment among others include: Mining of minerals, electro wining, extraction and refining processes, industrial waste, combustion process, municipal waste, application of metal based pesticides and fertilizers, electronics (manufacture, use and disposal) and auto-mechanic repairs etc [7-9]. These processes tend to release in large quantity various types and levels of heavy metals into the environment. Soil being of the repositories for most of the anthropogenic waste do serve as a media and sink for these pollutants and also acts as a buffer by controlling the transport of these chemical elements (heavy metals) into the environment [1].

In developing countries, excessive applications of metals and synthetic chemicals in the terrestrial environment coupled with deficient environmental management have led to large scale pollution of the environment [10]. Heavy metals are also natural component of earth crust which cannot be destroyed nor degraded completely. Essential heavy metals (Cu, Fe, Se, Zn, Mn) as well as non essential heavy metals (Cd, Pb, Cr, Ni, As, Hg, Sn) are considered highly toxic to human and aquatic life especially the later [11]. Recent scientific report had revealed some adverse health effects of exposure to certain heavy metals like cadmium and lead which include kidney damage, bone effects and fractures and neurotoxic effects in children [12]. A specific amount of chromium (III) is also needed in the body for normal body function while high concentration of it along with chromium (VI) are toxic and can cause liver and kidney damage [13]. In the earth crust, iron is the most abundant metal and is essential to all organisms except for few bacteria but excess of it in the body can also result to damage of liver and kidney [14].

Several studies have reported high increase in level of heavy metals in soils and sediments in Nigeria and other developing countries. This can also be attributed to activities of auto mechanics. In Nigeria, soil contamination associated with heavy metals has been reported [15-25]. “Mechanic Village” is a branded name given to a place where several auto mobile activities are performed. Mechanic villages are established in cities depending on the population density of both human and vehicle. The primary objective of this research was to assess the level of heavy metal contaminations in soil in three major mechanic villages in Abuja and the use of multiple ecological risk indices approach in assessing the ecological risk associated with such contamination. To achieve this set objective, four pollution indices models namely: contamination factor (C_f), ecological risk factor (E_r), degree of contamination (C_D) and potential ecological risk index (PERI) were explored.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Abuja, the capital city of Nigeria, was established in 1991 in the North Central Region of the Country. Geographically, it lies on latitude 9°40ʹ and 9°29ʹ E and falls in the Guinea Forest Savannah Mosaic Zone in the West Africa Sub-region. Three Mechanic Villages chosen for this study were Apo in Gudu district, Kugbo in Kugo district and Zuba in Madalla district.

2.2 Sample Collection and Treatment

Considering the representatives of heavy metal pollution in the investigated mechanic villages in Abuja, fifteen soil samples were randomly collected with a hand dug auger at a depth range of 0-15 cm. From the fifteen sampled points, five points were drawn from each of the three mechanic villages investigated. A control sample was also collected from a distance of 100 km where neither commercial nor industrial activities take place. The sampled soils were immediately enclosed in new separate dry polyethylene bags and were made air tight with a view to avoiding microbial degradation of the soil. The sampled soils where later taken to the laboratory for chemical analysis. Prior to commencement of the chemical analysis, all debris and materials in the soil were handpicked. The soils were further crushed and sieved to a mesh size of 338 µm with a laboratory sieve of make Endecott's Limited London, England serial number 489494.

2.3 Sample Preparation and Analysis

2.3.1 Soil digestion

Digestion of soil samples for the determination of heavy metal content was done according to method by George et al. [26] and Kouadia et al. [27]. 1.0 g of air-dried soil was placed in a digestion tube in a fume cupboard. While placed on a tube rack, 3 ml concentrated

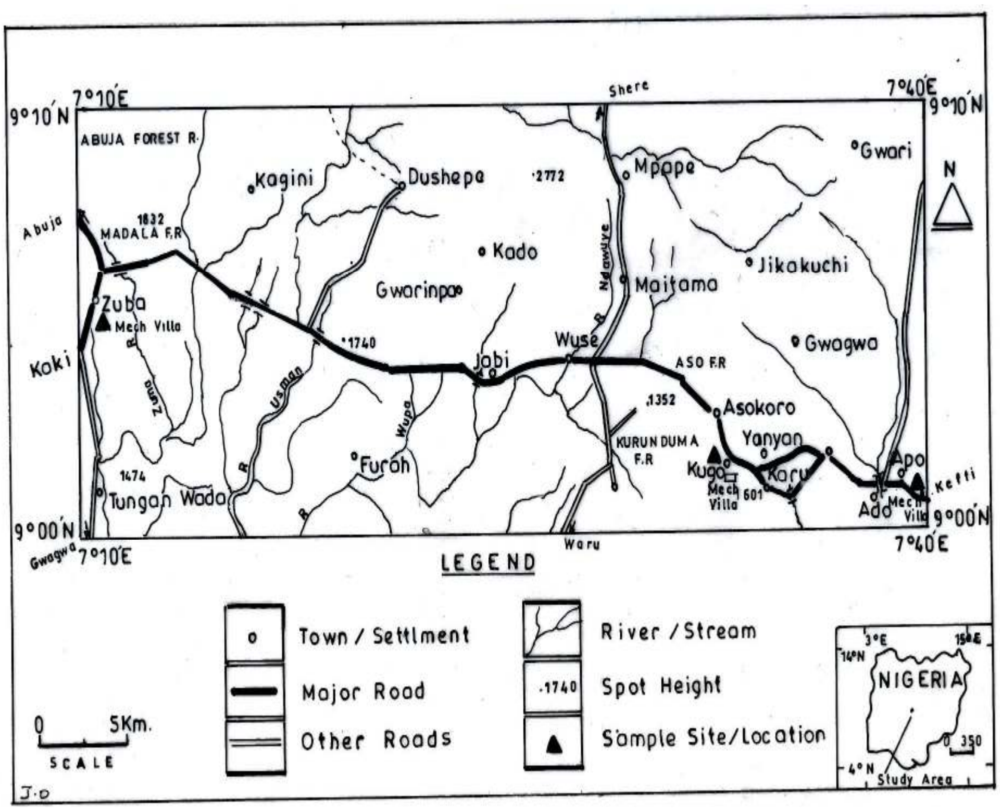

Fig. 1. Geographical map of investigated mechanic villages in Abuja

HNO_3 was added. The tube racks were further placed in a block digester and temperature increased to about 150℃ for 60 minutes. 4 ml of concentrated $HClO_4$ was also added with an increase in temperature to about 240℃ for extra 60 minutes. The tubes were brought out of the block digester, allowed to cool and filtered with Whatman No. 42 filter paper. The residue obtained from each sample after filtration was also washed with deionized water and filtered in their respective volumetric flasks. All the filtrates obtained were later made up to 100 ml prior to analysis.

2.3.2 Mineral content analysis

After complete digestion, minerals content in sampled soil were determined by AOAC [28] using an automated Atomic Absorption Spectrophotometer (AAS) of model Unicam 969 solar. Prior to the determination of level of heavy metals in soil, working standard solutions of the investigated heavy metals were also prepared from their respective stock solution of 100 ppm using serial dilution method. This was used in obtaining a calibration curve of concentration against absorbance.

2.4 Ecological Risk Index Assessment

Four pollution indices were used for the assessment of the ecological risk index associated with heavy metal contamination in soil from the selected mechanic villages in Abuja. They include two single indices namely: Contamination factor (C_f) and Ecological Risk Factor (E_r); and two integrated indices namely: Degree of contamination (C_D) and Potential Ecological Risk Index [PERI] [29]. It is imperative to conduct a comparative analysis of values of the heavy metals obtained from the study with those established (background or reference values) by some regulatory bodies like Department of Petroleum Resources DPR [31], United State Environmental Protection Agency USEPA (1999), Chinese Environmental Protection Agency CEPA (1990) etc. For this study, the background values and toxic response factor used were those provided by DPR and Håkanson [29-31].

2.4.1 Contamination factor

According to Håkanson [29], contamination factor (C_f) is a diagnostic tool used to express various levels of heavy metal contamination in sediment, water, sludge and soil. Contamination factor can also be used to differentiate between the metals originating from anthropogenic activities and those from geogenic processes [30]. Mathematically contamination factor can be expressed as:

$$C_f^i = \frac{C_i}{C_{ri}} \quad (1)$$

C_f^i : Contamination factor;

C_i : Metal content in soil or sediment;

C_{ri} : Background or reference values

Table 1. Classification of contamination factor [29]

Contamination factor	Classification
$C_f^i < 1$	low contamination
$1 \le C_f^i < 3$	moderate contamination
$3 \le C_f^i < 6$	considerable contamination
$C_f^i \ge 6$	very high contamination

2.4.2 Ecological risk factor

This is a component of pollution indices used for assessing the ecological risk associated with heavy metal contamination in soil and sediments [29]. Mathematically, Ecological risk factor can be calculated as:

$$E_r^i = T_r^i \times C_f^i \quad (2)$$

E_r^i : Ecological risk factor

T_r^i : Toxic response factor

C_f^i : Contamination factor

Table 2. Categorization of ecological risk index [29,32]

Category	Classification
$E_r^i < 40$	Low ecological risk
$40 \le E_r^i < 80$	Moderate ecological risk
$80 \le E_r^i < 160$	Considerable ecological risk
$160 \le E_r^i < 320$	High ecological risk
$E_r^i \ge 320$	Very high ecological risk

2.4.3 Degree of contamination [C_D]

Originally, degree of contamination was defined as sum of all the contamination factors of that particular heavy metal. It is used in calculating more than one heavy metal contamination in soil and sediment [29-35].

$$C_D = \sum_{i=1}^{m} C_f^i \tag{3}$$

C_D : Degree of contamination

C_f^i : Contamination factor from single pollution index

M : count of heavy metal species

Table 3. Four classes of degree of contamination [33]

Degree of contamination	Classification
$C_D < 1$	low degree of contamination
$1 \le C_D < 2$	moderate degree of contamination
$2 \le C_D < 4$	considerable degree of contamination
$C_D \ge 4$	very high degree of contamination

2.4.4 Potential ecological risk index [PERI]

Potential Ecological Risk Index was originally established by Håkanson [29] for contamination control of lakes and coastal systems in the Scandinavian environments. PERI is the summation of ecological risk factor [E_r^i] of all heavy metals in soil in all the studied mechanic villages. Mathematically potential ecological risk index is expressed as;

$$\text{PERI} = \sum_{i=1}^{m} E_r^i \tag{4}$$

Table 4. Classification of potential ecological risk index of heavy metal contamination in soil [34]

Potential ecological risk index	Classification
$PERI < 150$	low potential ecological risk
$150 \le PERI < 300$	moderate potential ecological risk
$300 \le PERI < 600$	considerable potential ecological risk
$PERI \ge 600$	very high potential ecological risk

3. RESULTS AND DISCUSSION

3.1 Level of Heavy Metals in Soil

The result in Table 5 shows the values of heavy metals in soil in the three mechanic villages compared with background or reference values of some regulatory bodies together with that of control site. Values of iron in all the sites together with that of control fell below the value provided by DPR [31] 5000 mg.kg^{-1}. The result also show that iron is the second most abundant element in all the studied sites which indicate low enrichment and uncontaminated. These results were also lower than those recorded in soil around auto mechanic villages in Benin City, Nigeria [23]. Zinc was also observed to be the third most abundant element and fluctuated between (719 – 8200) mg.kg^{-1}. Considering the various mean values, Zuba mechanic village had the least value of 1190 mg.kg^{-1} followed by Kugbo mechanic village with 1586 mg.kg^{-1} and Apo mechanic village with the highest value of 5360 mg.kg^{-1}. These values could be as a result of indiscriminate discharge of zinc containing particles and chemicals from scrapping of auto mobile body parts, attrition of vehicle tire, lubricating oil that contain zinc additives like dithiophosphates [36].

More so, copper was observed to be the most abundant heavy metal from the study with a range of (217 – 22000) mg.kg^{-1} in the three sites. Values of copper also exceeded those of regulatory bodies as shown in Table 5 and those reported by Gungshik et al and Osakwe et al. [37-38]. Indiscriminate discharge of worn out brake pads, car electrolytes, re-wiring of car coils and cables are some practices carried out in automobile workshops which helps in introducing copper into the soil. Nickel recorded mean values as follows: Zuba (127 mg.kg^{-1}), Apo (196 mg.kg^{-1}) and Kugbo (234 mg.kg^{-1}). These values were found to be higher than the maximum permissible limit of DPR [31] 35.0 mg.kg^{-1}, USEPA (1999) 16.0 mg.kg^{-1}, CEPA (1990) 27.0 mg.kg^{-1} and toxic response factor by Håkanson [29] 5.00 mg.kg^{-1}. High level of Nickel in soil could be from indiscriminate discharge of used lubricating oil, greases, oil sludge and diesel in the soil.

Furthermore lead recorded a decrease in the mean value in the sites as follows: Kugbo (169 mg.kg^{-1}) < Zuba (250 mg.kg^{-1}) < Apo (333 mg.kg^{-1}). Also from the result in Table 5 these values were observed to have exceeded the maximum permissible limits by some regulatory bodies which strongly indicated that the sites have been polluted to various degrees. Chromium recorded a decrease in the mean values as follows: Zuba (767 mg.kg^{-1}) < Kugbo (789 mg.kg^{-1}) < Apo (1173 mg.kg^{-1}). Lead in soil could be attributed to some anthropogenic activities of auto mechanics like car painting, welding and soldering, vehicle exhaust, leaded gasoline lead-chromium batteries etc. Cadmium also followed the pattern of lead with decrease in mean values as follows: Kugbo (9.50 mg.kg^{-1}) < Zuba (10.4 mg.kg^{-1}) < Apo (11.1 mg.kg^{-1}). These values also exceeded those reported by Japtap et al. [36], Håkanson [29] and Babatunde et al. [39,35].

3.2 Results of Ecological Risk Index Assessment

The results of contamination factor model shown in Table 6 revealed that 71.0% of the heavy metal (Zn, Cu, Ni, Cr and Cd) in Kugbo mechanic village were in the class of very high contamination, whereas iron and lead were in the class of low and moderate contamination respectively. In Zuba mechanic village, 54.1% of the heavy metals (Zn, Cu, Cr, Cd) in soil were in the level of very high contamination. Apo mechanic village also had 42.9% of its soil in the level of very high contamination and the metal responsible for this are; Cr, Cd and Zn. Ni and Pb were found to be in class of considerable contamination, whereas Cu and Fe had moderate and low contamination. Comparatively Zn, Cd and Cr had very high contamination factor in all the sites which could be attributed to anthropogenic processes. Fe had low contamination factor too in all the sites and this low contamination factor signifies that the pollution is from geogenic process as it dominates approximately 1.50% of the earth's crust as reported by Tippie, V.K [40]. Also the three sites had very high degree of contamination as a result of some anthropogenic activities carried out in the mechanic villages.

However results in Table 7 reveals that 66.7% of soil samples from Kugbo mechanic village though contaminated but are of low ecological risk to the environment. The remaining 33.3% of soil samples possess considerable ecological risk as a result of mild contamination. In Zuba mechanic village, 83.3% of soil samples indicated low ecological risk and copper which covers 16.7% showed moderate ecological risk. Copper because of its high content recorded high ecological risk in Apo mechanic village, cadmium showed moderate ecological risk and other

Table 5. Concentrations of heavy metals (mg.kg^{-1}) in soil in Apo, Kugbo and Zuba auto mechanic villages compared with maximum permissible limits of some regulatory bodies

Sample points	Fe	Zn	Cu	Ni	Pb	Cr	Cd
A_1	561	8200	1677	238	96.4	1117	12.5
A_2	426	5288	22000	212	357	1173	11.5
A_3	423	8421	12830	402	967	1916	10.6
A_4	411	847	219	48.6	194	814	8.90
A_5	512	4045	1616	80.5	51.7	848	8.90
K_1	203	2869	3144	195	89.6	911	1.20
K_2	320	719	407	370	201	288	10.2
K_3	259	2016	340	110	316	726	15.2
K_4	145	1441	1017	178	15.7	915	1.50
K_5	157	890	306	318	225	1074	19.2
Z_1	302	410	686	187	199	830	10.2
Z_2	331	976	351	148	58.3	764	12.5
Z_3	195	1010	956	127	249	1120	9.50
Z_4	306	1710	352	126	443	630	8.80
Z_5	260	1845	217	48.0	298	491	11.1
C_T	2.45	73.4	37.3	108	102	1108	ND
B_T	5000	140	36.0	35.0	85.0	100	0.800
I_V	NL	720	190	210	530	380	17.0
CEPA	NL	100	23.0	26.0	26.0	61.0	0.100
USEPA	NL	110	16.0	31.0	31.0	26.0	0.600
EUSTD	NL	300	140	300	300	180	3.00
UKSTD	NL	200	63.0	70.0	70.0	6.40	1.40
FAO/ISRIC	NL	175	50.0	150	150	250	5.00

A: Apo Auto mechanic village; K: Kugbo auto mechanic village; Z: Zuba auto mechanic village; C_T: Control; B_T (DPR): Background values, DPR (2002): Department of Petroleum Resources Nigeria; I_V: Intervention value of DPR; CEPA: (1990) Chinese Environmental Protection Agency; USEPA (1999): United States Environmental Protection Agency; EUSTD (1983): UKSTD: United Kingdom Standard; FAO/ISRIC (2004): Food and Agricultural Organization. NL: No Limit

Table 6. Values and classes of contamination factor and degree of contamination of soil samples from studied sites

Mechanic villages		Fe	Zn	Cu	Ni	Pb	Cr	Cd	C_{Dclass}
Kugbo	C_f	0.0400	11.3	29.0	6.70	2.00	7.90	11.8	68.8
	C_i	216	1587	1043	234	169	789	9.40	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.800	
	Class	l	vh	vh	vh	m	m	vh	vh
Zuba	C_f	0.0600	8.50	14.2	3.63	2.94	7.67	13.0	50.0
	C_i	278	1190	512	127	250	767	10.4	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.80	
	Class	l	vh	Vh	C	m	vh	vh	vh
Apo	C_f	0.0900	38.3	213	5.61	3.92	11.7	13.9	287
	C_i	467	5360	7668	196	333	1173	11.1	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.800	
	Class	l	vh	m	c	c	vh	vh	vh

C_i : Concentration of heavy metal in soil; C_{ri} : background value for each heavy metal adopted from DPR (2002); C_f^i : contamination factor; C_D:Degree of contamination; l: low contamination; m: moderate contamination; c: considerable contamination and vh: Very high contamination

Table 7. Ecological risk factor and potential ecological risk index values and pollution classes of soil from the studied sites

Mechanic village		Zn	Cu	Ni	Pb	Cr	Cd	PERI
Kugbo	E_r	11.3	145	33.4	10.0	15.8	35.5	251
	C_f	11.3	29.0	6.70	2.00	7.90	11.8	
	T_r	1.00	5.00	5.00	5.00	2.00	3.00	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.800
	Class	lp	cp	lp	lp	lp	cp	mp
Zuba	E_r	8.50	71.2	18.2	14.7	15.3	39.0	167
	C_f	8.50	14.2	3.60	2.90	7.70	13.0	
	T_r	1.00	5.00	5.00	5.00	2.00	3.00	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.80
	Class	lp	mp	lp	lp	lp	cp	mp
Apo	E_r	38.3	1065	28.1	19.6	23.5	41.6	1216
	C_f	38.3	213	5.60	3.90	11.7	13.9	
	T_r	1.00	5.00	5.00	5.00	2.00	3.00	
	C_{ri}	5000	140	36.0	35.0	85.0	100	0.80
	Class	lp	vhp	lp	lp	lp	mp	vhp

E_r: Ecological risk factor; C_f: Contamination factor; T_r: Toxic response factor for a given metal; PERI: Potential Ecological Risk Index; $PERI_{class}$: Classification of Potential Ecological Risk Index; l: Low potential ecological risk; m: Moderate potential ecological risk; C_p: Considerable potential ecological risk and v_{hp}: Very high potential ecological risk

heavy metals in soil in Apo site possess low ecological risk. Comparing the Potential Ecological Risk Index [PERI] on the three sites investigated, Kugbo and Zuba mechanic villages were in the class of moderate potential ecological risk while Apo with PERI value of 1216 falls in the class of very high potential ecological risk index. These results also indicated that soil in Apo mechanic village with the highest value of PERI possess more environmental trait to health of humans, organisms and ecosystem at large. Thus urgent steps have to be taken so as to avert the outbreak of an epidemic and series of health related problems caused by heavy metals in that area.

4. CONCLUSION

The various models applied in this research work revealed that soil in the selected mechanic villages in Abuja, Nigeria had various degrees of contamination as a result of anthropogenic activities associated with indiscriminate discharge of heavy metal containing waste and poor waste management practice. The multiple ecological risk indices applied showed that these heavy metals in soils in the investigated sites had varied classes of ecological risk both to human and the environment. This calls for urgent steps from relevant authorities with a view to checkmating the alarming rate of environmental pollution due to indiscriminate discharge of heavy metal containing waste in soil in the mechanic villages with a view to preventing the outbreak of epidemics, life threatening diseases to human and degradation of the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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    ISSN 2224-3216 (Paper) ISSN 2225-0948
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