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Research Article

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Assessment of Heavy Metals pollution in Soils within Hot Mix Asphalt Plants Vicinity in Port Harcourt, Rivers State, Nigeria

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Abstract Soil samples were collected from three asphalt hot mix stations and examined for heavy metals using standard procedures. The results obtained showed that the concentrations of the heavy metals occurred in the order; iron (Fe)>zinc (Zn)>chromium (Cr)>lead (Pb)>copper (Cu)>nickel (Ni)>arsenic (As)>cobalt (Co)> cadmium (Cd). All the metals examined in the soil were lower than the reference value stipulated by DPR except As and Cd and Co in stations 2 (JADAC HMX) and 3 (H & H (HMA) respectively. Contamination factor studies on the concentrations of the heavy metals in the soil showed various degrees of contamination by the heavy metals except As and Cd and Cu in station 3and cobalt in stations 2 and 3 that have stretched to pollution status in the soil. Pollution index analysis showed that the soils from the various asphalt plant stations were slightly polluted with the heavy metals. Contamination factor evaluation of metals varied from considerable contamination degree to high contamination degree in the stations. Modified contamination degree analysis revealed that all the stations were at a level of moderate degree of contamination by the heavy metals. Geo-accumulation findings revealed a variation between non-contaminations to extreme contamination of the soil with individual heavy metals. Ecological risk assessment of the soils suggested varying degrees of risks posed by each metal to the environment. Enrichment factor analysis revealed serious anthropogenic influence on the metal content of the soil. The results obtained from the stations in this study coupled with the different analytical assessments showed that human activities are the major contributors of the heavy metals in the examined soils.

Keywords Heavy metals, Asphalt plants, pollution assessment indices**,** Environment**,** anthropogenic sources

Introduction

The effect of human activities has substantively amplified the presence of heavy metals content in the environment. These metals, though may be produced or released at very small scale, yet they produce effects that affects the ecological environment at the long run. The effects of heavy metals on ecological atmosphere is noticed more especially when the natural structure and characteristics or functions of both biological and non-biological environment has been destroyed or negatively affected [1]. In the immediate past decades, the pollution of the environment with heavy metals and the management of pollution based issues by the relevant agencies all over the

world has attracted a lot of politicking, thus leading to more devastating effects of degrading the important uses of the different constituents of the environment [2].

Metals are naturally found in the earth's crust, but their concentrations can be increased in the soil and other atmospheric cycles from weathering of rocks. The natural or background levels or values of metals can be altered as a result of anthropogenic activities [3]. Some heavy metals are needed for proper plant growth in very small amount, but at high concentrations are lethal and deadly due to quite a number of health issues associated with their intake and presence in human body [4].

The contamination of soil and different landforms have serious environmental consequences on ecological habitation and habitats [5]. Despite the fact that heavy metals are natural constituents of the soil (the natural sink for pollutants), they are considered as contaminants when they have exceeded the required concentrations, have widespread occurrence, cause both acute and chronic toxicity [6].

One of the major factors responsible for heavy metals introduction into the soil is through the application of metal based pesticides on arable farms, discharge of industrial wastewater, metal production processes, traffic congestion and home discharged wastes [7].

In urban and city settlements, the issue of road construction is very vital. It is accompanied with the use of high powered machineries, which produce the surfacing materials so that vehicles can move conveniently and others used to convey materials in and out of the industrial premises. Some of these materials contain heavy metals which either in the processes of production or storage can be transported to the soil within the immediate environment and can cause pollution depending on the amount discharged. Therefore, this study was undertaken to examine the concentrations of some heavy metals in soils within the immediate vicinity of selected asphalt hot mixed plants in Port Harcourt, Rivers State, Nigeria.

Materials and Methods

Soil samples were obtained from three asphalt hot mix plant stations within Port Harcourt using soil auger. The samples were randomly collected 3 metres apart from five points within each station. The samples were mixed together to form a representative sample. Three representative samples were obtained altogether in each station.

The samples were put into plastic bags previously washed and soaked in very dilute concentrated nitric acid solution and dried. The samples were transferred to the laboratory and allowed to dry by exposure to free air. After a constant weight of the soil samples had been recorded in three successive weighing, the samples were homogenized in a mortar with a pestle. The homogenized soil samples were sieved with a 2 mm mesh and subsequently stored in a fine plastic bottles. A well determined mass of 2 g of soil was taken from each of the samples and digested in mixed acid solution in a steam bath [8-9].

The digested mixture was decanted into a filter paper (Whatman size 2) already put in place and filtered into sample bottles. The bottles containing the filtrate were refrigerated and maintained at 4 ^{o}C. The filtrates or digests were then transported to the JAROS base Scientific Laboratory for quantitative metals analysis using the atomic absorption spectrophotometer.

The observed concentrations of the individual heavy metals in the soil were subjected to contamination factor (CF) [10], pollution load index (PLI) [11], contamination degree (CD) [12], modified contamination degree (mCD) [12], geo-accumulation index (I-geo) [13], ecological risk assessment (ERA) and enrichment factor (EF) [14] analysis. These pollution and ecological indices were applied on the concentrations to enable a proper perspective of interpretation of the effect and consequences and sources of the examined heavy metals.

Results and Discussion

The concentrations of the heavy metals in the soil samples obtained from the different asphalt hot mix stations is given in Table 1. The general observation on the concentrations of the heavy metals present in the soil from the different stations differed extensively. This implies that either the differences may be due to ecological location or other influences from anthropogenic and natural based activities [15]. These differences can further be explained on

the basis of the affinity that may have existed between heavy metals, soil inorganic components and biological matter [16].

Manganese (Mn)

The concentrations of Mn in the stations varied from 8.41 ± 2.72 to 15.92 ± 4.72 mg/Kg. This is lower than the DPR target value of 850 mg/Kg in soil and sediment. Different concentrations of Mn has been observed in other studies on soil where different anthropogenic activities took place [17-29]. In their observations, Mn was observed to be of higher value in the experimental stations when compared to the control. They attributed the increase in Mn concentrations in the studied areas to human influences as opposed to those of the control samples. The values of Mn in the present work are lower than the values observed in soils from beneath some plants in parts of Malaysia [19] and in soils heavily exposed to crude oil spills in different communities in the Niger Delta [17].

Arsenic (As) concentrations in the asphalt hot mix stations varied from 17.71 ± 5.68 to22.82 ± 6.64 mg/Kg. These values are higher than the DPR [20] target value for As. The values of As observed in the present work are higher than the values observed in soils from farms collected from Umuebulu community, Etche in Rivers State, Nigeria [21], the values observed in soils contaminated with petroleum hydrocarbons due to artisanal refining in some communities in Niger Delta, Nigeria [22] and also higher than those observed in soil from the Raoyanghe Wetland region of China [23].

Cadmium (Cd) concentrations in the asphalt hot mix stations varied from 3.54 ± 2.26to5.84 ± 3.78mg/Kg. These values are higher than the DPR [20] target value for Cd. the observed values of Cd in the soils examined were within the range observed in different contaminated soils from the Korle Lagoon area in Accra, Ghana except at one of the stations where concentration of Cd was very high to the level of 103.66 mg/Kg [24], generally lower than the observed concentrations of Cd in soil from a Pb-Zn mines where mining activities has stopped in Yelu, Bauchi State, Nigeria [25], but higher than the values reported in soil from the Raoyanghe Swamp, China [23].

Lead (Pb) concentrations in the asphalt hot mix stations varied from 13.42 ± 4.71- 62.49 ± 11.16mg/Kg. These values are higher than the DPR [20]target value for Pb. The determined concentrations of Pb in the asphalt stations were lower than the reported values observed in soils from Umuebulu in Etche, Rivers State [21], but within the range of values of Pb concentrations reported in Korle Lagoon, Accra, Ghana except in few stations where higher than this present work values were reported [24] and lower than the reported values of Sanusi *et al*. [25], in a non-functioning mine site in Yelu, Bauchi State.

Copper (Cu) concentrations in the asphalt hot mix stations varied from 26.71 ± 6.32 to 39.18 ± 6.12 mg/Kg. These values in stations 1(AUC HM) and 2 (JADAC HMX) were lower than the DPR value, while station 3 (H & H (HMA) is higher than the DPR [20] target value for Cu. The observed concentrations of Cu in the present study is in agreement with the observation of Perunović *et al*., [26], who reported values ranging from16.76 to 81.44 mg/Kg in soil from Kremna Basin, Serbia, contaminated by anthropogenic activities and also within the range of values observed in soils from abandoned iron mine in Morocco, where concentrations of Cu were reported to fall between 18.55 ± 3.16 and 48.98 ±30.09 mg/Kg [27]. However, the values are higher than those of Edori and Kpee [28], in soils around abattoirs in port Harcourt, Nigeria and slightly lower than the values of Marcus *et al*., [29], in soils contaminated with dumpsite leachates in Port Harcourt, Nigeria.

Nickel (Ni) concentrations in the asphalt hot mix stations varied from 11.81 ± 3.63 to18.74 ± 2.11 mg/Kg. These values are lower than the DPR [20] target value for Ni. The asphalt soil content of Ni observed in this study are lower than those of Njoku *et al*. [22], in soils impacted by petroleum products discharges from unapproved refining sites in Bodo, Gokana, Nigeria and also those of Perunović *et al*., [26], in soil contaminated soils from Kremna Basin in Serbia. However, they are higher than the reported values of Mmolawa *et al*. [30], in soils from roadsides in Botswana.

Iron (Fe) concentrations in the asphalt hot mix stations varied from 101.91 ± 21.64 to 124.81 ± 16.72 mg/Kg. These values are lower than the DPR [20] target value for Fe. The Fe content of the soils from the asphalt stations were lower than the values of Fe observed in two different mechanic workshops in port Harcourt, Nigeria [8], also lower

than the values observed in leachate contaminated soils within Port Harcourt metropolis [29] and those [27] in soils previously used for the mining of Fe in Morocco.

Chromium (Cr) concentrations in the asphalt hot mix stations varied from 69.52 ± 12.89 to92.81 ± 18.48 mg/Kg. These values are slightly lower than the DPR [20] target value for Cr. The concentrations of Cr observed in the present research is higher than the values of Marcus *et al*. [29] dumpsite leachate contaminated soils, Hind *et al*. [19], in soils from some cultivated areas of Malaysia and those of Njoku *et al*. [22], in selected soils from the forest of Bodo Community where artisanal refining of crude oil to different fractions were in place.

Zinc (Zn) concentrations in the asphalt hot mix stations varied from 80.60 ± 10.34 - 98.71 ± 13.85mg/Kg. These values are lower than the DPR [20] target value for Zn. The content of Zn in the examined soils are higher than the values of Njoku *et al*. [22], in soils from contaminated soils in Gokana Rivers State and those of Hind *et al*. [19], in soils collected from different agricultural farms in Malaysia. However, these values from the asphalt sites were within the range of values reported in dumpsites soils contaminated with leachates [29] and those of [27] in soils from used Fe mine sites in Morocco.

Cobalt (Co) concentrations in the asphalt hot mix stations varied from 80.60 ± 10.34 to 98.71 ± 13.85 mg/Kg. The values observed in station 1 (AUC HM) is lower than the DPR [20] target value for Co, while the values of stations 2 (JADAC HMX) and 3 (H & H HMA) were higher than the DPR value. Cobalt (Co) concentrations in the present work is higher than those of Njoku *et al*., [22], in Niger Delta Region, where the levels of Co were in the range of 0.0027 and 0.0037 mg/Kg and those of Mmolawa *et al*. [30], in roadside soil from Botswana.

Table 1: Concentrations of heavy metals in soils from different hot mix asphalt plant stations

Heavy Metals (mg/Kg)	Stations			DPR (2002) Target Values (mg/Kg) [20]
	AUC HM	JADAC HMX	H & H (HMA)	
Mn	11.42 ± 3.16	8.41 ± 2.72	15.92 ± 4.72	850
As	17.71 ± 5.68	12.81 ± 5.69	22.82 ± 6.64	1.0
Cd	4.73 ± 1.84	3.54 ± 2.26	5.84 ± 3.78	0.8
Pb	62.49 ± 11.16	13.42 ± 4.71	41.91 ±6.68	85
Cu	26.71 ± 6.32	31.41 ± 8.36	39.18 ± 6.12	36
Ni	18.74 ± 2.11	15.81 ± 3.62	11.81 ± 3.63	35
Fe	137.81 ± 13.72	101.91 ± 21.64	124.81 ± 16.72	38000
Cr	92.81 ± 18.48	69.52 ± 12.89	88.10 ± 11.36	100
Zn	98.71 ± 13.85	91.69 ± 24.63	80.60 ± 10.34	140
Co	15.38 ± 4.62	31.41± 13.86	39.18± 12.88	20

The value of the contamination factor, pollution index, contamination degree and modified contamination degree are given in Table 2. The contamination factor values in the examined stations showed the following variation; Mn (0.010 –0.019), As (12.810 – 22.820), Cd (4.425 - 7.300), Pb (0.158 – 0.735), Cu (0.742 – 1.088), Ni (0.337 – 0.524), Fe (0.003 – 0.004), Cr (0.695 – 0.928), Zn (0.576 – 0.705) and Co (0.769 – 1.959). Explaining the contamination factor values based on the different classes and their interpretations [10] showed that each of the asphalt mix stations fall into different classes of contamination/pollution by the individual heavy metals. The results showed that the soils were not contaminated with Mn in any of the stations. For As results, soils from JADAC HMX station were at the stage of very severe pollution, while AUC HM and H & H (HMA) stations were extremely polluted with As. The results for Cd in the sampled stations showed that the soils from the three sampled stations were severely polluted by Cd. The contamination factor values for Pb indicated that stations 2 (JADAC HMX) was at the stage of minor contamination by Pb, station3 (H & H (HMA) fall within the category of reasonable contamination by Pb and station 1 (AUC HM) values suggested that the soil was severely contaminated by Pb. The values for Cu showed that soil from station 1 (AUC HM) was severely contaminated by the Cu metal, station 2 (JADAC HMX) was very severely contaminated and station 3 (H & H (HMA) was slightly polluted by Cu.

The results of contamination factor for Ni in this study suggested that in all the stations, the soils were at different stages of contamination which ranged from reasonable contamination to severe contamination. Iron (Fe) values

showed non-contamination of the soil by Fe metal in all the examined asphalt stations. The values of Contamination factor for Cr in the stations were classified into severe contamination in station 2 (JADAC HMX) and very severe contamination in stations 1 (H & H (HMA) and 3 (H & H (HMA).The values observed for Zn in the soils when interpreted on the basis of intervals of contamination and or pollution showed that the soils from the stations were at the level of severe contamination by Zn. Cobalt (Co) contamination factor values suggested that soil from station 1 (AUC HM) was severely contaminated with Co, while soils from stations 2 (JADAC HMX) and 3 (H & H (HMA) were at the stage of being slightly polluted with Co.

The pollution index values of the heavy metals in the stations varied from 1.360 to 1.429. These results from the stations when compared with the charts on different categories of contamination and pollution showed that the soils were slightly polluted with the heavy metals. Contamination degree (CD) values ranged from 21.652 to 35.476 in the stations. These results suggested that stations 1 (AUC HM) and 2 (JADAC HMX) were at the stages of considerable contamination degrees by the heavy metals, while station 3 (H & H (HMA) was in the category of very high contamination degree. Modified contamination degree (MCD) varied from 2.165 to3.548 in the stations. All the stations values fall into the class of moderate degree of contamination by the assessed heavy metals.

Table 2: Contamination factor, pollution index, Contamination degree and modified contamination degree of soils from the different hot mix asphalt plant stations

Heavy Metals (mg/Kg)	**Contamination Factors**		
	AUC HM	**JADAC HMX**	**H & H (HMA)**
Mn	0.013	0.010	0.019
As	17.710	12.810	22.820
Cd	5.913	4.425	7.300
Pb	0.735	0.158	0.493
Cu	0.742	0.873	1.088
Ni	0.524	0.452	0.337
Fe	0.004	0.003	0.003
Cr	0.928	0.695	0.881
Zn	0.705	0.655	0.576
Co	0.769	1.571	1.959
PI	1.396	1.360	1.429
CD	28.043	21.652	35.476
mCD	2.804	2.165	3.548

The results of the geo-accumulation index of the heavy metals in the asphalt mix stations are given in Table 3. The values showed the following range in the stations; Mn (0.007 – 0.013), As (8.540 – 15.213), Cd (2.950 – 4.867), Pb (0.105 – 0.490), Cu (0.495 – 0.873), Ni (0.225 – 0.357), Fe (0.002 – 0.003), Cr (0.464 – 0.619), Zn (0.384 – 0.470) and Co (0.513 – 1.306). The results of geo-accumulation index of the heavy metals examined when compared with the classification of intervals of contamination (Muller, 1981) suggested the soils were practically uncontaminated with Mn and Fe, extremely contaminated by As in all the stations, moderately to heavily contaminated by Cd in station 2 (JADAC HMX), heavily contaminated in station 1 (AUC HM) and heavily to extremely contaminated in station 3 (H & H (HMA). The soils were uncontaminated to moderately contaminated by Pb, Cu, Ni, Cr and Zn in all the stations, but was at the level of uncontaminated to moderately contaminated in station 1 (AUC HM) and moderately contaminated in station 2 (JADAC HMX) and 3 (H & H (HMA). The inferences that could be drawn from the geo-accumulation results is that As, Cd and to a little extent Co are more of anthropogenic input into the soil than natural sources, while the other metals were within the natural causes.

Table 3: Geo-accumulation index of heavy metal in soils from the different hot mix asphalt plant stations

Heavy Metals (mg/Kg)	Stations		
	AUC HM	JADAC HMX	H & H (HMA)
Mn	0.009	0.007	0.013
As	11.807	8.540	15.213
Cd	3.942	2.950	4.867
Pb	0.490	0.105	0.329
Cu	0.495	0.873	0.726
Ni	0.357	0.311	0.225
Fe	0.003	0.002	0.002
Cr	0.619	0.464	0.568
Zn	0.470	0.437	0.384
Co	0.513	1.047	1.306

The results of the ecological risk of the heavy metals in the asphalt mix stations are given in Table 4. The values showed the following variation range in the stations; Mn (0.01- 0.019), As (128.100 – 228.200), Cd (132.750 – 219.000), Pb (0.789 – 3.676), Cu (3.710 – 6.544), Ni (1.125 – 1.785), Cr (0.928 – 1.238), Zn (0.576 – 0.705) and Co (2.565 – 6.530). The ecological risk assessment of the examined heavy metals showed that Mn, Pb, Cu, Ni, Cr, Zn, and Co in the soil do not pose risk to the ecological environment, but As and Cd in the soil at station 2 (JADAC HMX) are at the level of considerable ecological risk to the environment and are athigh risk levelsin stations 1 AUC HM and 3 H & H (HMA).

Table 4: Ecological risk Assessment of heavy metals in soilsfrom the different hot mix asphalt plant stations

Heavy Metals (mg/Kg)	Stations			Toxic Response Factor
	AUC HM	JADAC HMX	H & H (HMA)	
Mn	0.014	0.010	0.019	1
As	177.101	128.100	228.200	10
Cd	177.375	132.750	219.000	30
Pb	3.676	0.789	2.465	5
Cu	3.710	6.544	5.442	5
Ni	1.785	1.555	1.125	5
Cr	1.238	0.928	1.136	2
Zn	0.705	0.655	0.576	1
Co	2.565	5.235	6.530	5

The results of the enrichment factor of the heavy metals in the asphalt mix stations are given in Table 5. The values showed the following variation ranges in the stations; Mn (3.698 - 5.702), As (4776.566 – 6947.838), Cd (1630.327 – 2222.582), Pb (58.871 – 202.719), Cu (205.585 – 331.357), Ni (102.734 – 168.434), Cr (255.916 – 268.232), Zn (175.284 – 243.409) and Co (212.046 – 596.443). The enrichment factor analysis of the results as interpreted on the basis of the terminologies suggested by Sutherland *et al*. [31], showed that Mn was moderately enriched in the soil of stations 1(AUC HM) and 2 (JADAC HMX), but all the other metals examined in the soils from the stations were at the stage of extremely high enrichment. The order of enrichment of the metals in the soil is as follows; As > Cd > Cr > Co > Cu >Zn >Ni >Pb > Mn. The enrichment factor (EF) figures obtained in the present work when interpreted on the basis of geochemical origins of the metals in Asphalt stations showed that the origin and sources of the heavy metals in the soil is due to anthropogenic spread in the examined environment [32], which in this case are the three stations occupied by the asphalt hot mix companies.

Table 5: Enrichment factor Assessment of heavy metals in soils from the different hot mix asphalt plant stations

Heavy Metals (mg/Kg)	Stations		
	AUC HM	JADAC HMX	H & H (HMA)
Mn	3.705	3.689	5.702
As	4883.388	4776.566	6947.838
Cd	1630.327	1649.988	2222.582
Pb	202.719	58.871	150.118
Cu	204.585	325.336	331.357
Ni	147.640	168.434	102.734
Cr	255.916	259.225	268.232
Zn	194.418	243.409	175.284
Co	212.046	585.605	596.443

Conclusion

The spread pattern of heavy metals (Mn, As, Cd, Pb, Cu, Ni, Cr, Zn and Co) in soils collected from different asphalt plant stations in Port Harcourt Rivers State, Nigeria point out that these soils have been affected severely by the asphalt plants cited within the area. Arsenic (As) and Cadmium (Cd) were the metals in the soils greatly influenced by the asphalt activity. Pollution indices assessments indicated varying degrees of contamination to pollution by the heavy metals. Geo-accumulation index, ecological risk assessment and enrichment factor analysis implicated human induced heavy metal presence in the soils. Effort should be put in place to curtail further increase in the concentrations of heavy metals in the examined soils even though asphalt production and mixing activities cannot altogether be taken away**.**

References

[1]. Macklin, M. G. (1992). *Metal pollution of soils and sediments: a geographical perspective, M. D.* Newson (Ed.), Managing the Human Impact of the Natural Environment, Belhaven Press, London.

[2]. N'guessan, Y. M., Probst, J. L., Bur, T. and A. Probst, A. (2009). Trace elements in stream bed sediments from agricultural catchments (Gascogne region, S-W France): where do they come from? *Science of the Total Environment*, 407(8): 2939–2952.

[3]. Olu, U., Ugbomeh, A. P., Bob-Manuel, K. N. O. and Ekweozor, I. K. E. (2019). Levels of selected heavy metals in water and sediment of the Soku Oil Field Area of the Niger Delta, Nigeria. *Journal of Aquatic Pollution and Toxicology*, 3 (1):1-9.

[4]. Wegwu, M. O. and Wigwe, I. A. (2006). Trace-metal contamination of the African Giant Land snail (*Archachatina marginata*) from Southern Nigeria. *Chemistry and Biodiversity*, 3:88-93.

[5]. Purves, D. (1985). Trace Element Contamination of the Environment. Elsevier, Amsterdam.

[6]. Liu, Y., Su, C., Zhang, H., Li, X. and Pei, J. (2014). Interaction of soil heavy metal pollution with industrialisation and the landscape pattern in Taiyuan city, China. *PloS one*, 9(9): p.e105798.

[7]. Wokoma, O. A. F. and Edori, O. S. (2017). Heavy metals content of an oily wastewater effluent from an oil firm at the point of discharge. *International Journal of Chemistry, Pharmacy and Technology*, 2 (4):154-161.

[8]. Edori, O. S. and Edori, E. S. (2012). Effect of Automechanic Works on Lead and Iron in Two Mechanic Villages in Port Harcourt, Rivers State Nigeria. *Journal of Applied Science and Environmental Management*, 16 (4): 317-321.

[9]. Marcus, A. C. and Edori, O. S. (2016). Assessment of contamination status of Bomu and Oginigba Rivers, Rivers State, Nigeria, using some trace metals and Callinectes gladiator as indices. *Chemical Science International Journal*, 17(4): 1-10.

[10]. Lacatusu, R. (2000). Appraising levels of soil contamination and pollution with heavy metals. *European Soil Bureau Research Report*, 4: 393-402.

[11]. Tomilson, D. C., Wilson, J. G., Harris, C. R., and Jeffrey, D. W. (1980). Problems in assessment of heavy metals in estuaries and the formation of pollution index. *Environmental Evaluation*, 33(1): 566–575.

[12]. Håkanson L. (1980). An ecological risk index for aquatic pollution control: A Sedimentological Approach. *Water Research*, 14: 975-1001.

[13]. Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geological Journal*, 2, 108–118

[14]. Ato, A. F., Samuel, O., Oscar, Y. D., Alex, P., Moi, N., & Akoto, B. (2010). Mining and heavy metal pollution: Assessment of aquatic environments in Tarkwa (Ghana) using multivariate statistical analysis. *Journal of Environmental Statistics*, 1(4): 1–13.

[15]. Fong, F., Seng, C., Azan, A. and Tahir, M. (2008). Possible source and pattern distribution of heavy metals content in urban soil at Kuala Terengganu Town Centre. *The Malaysian Journal of Analytical Sciences*, 12: 458-467.

[16]. Jia, L., Yonghua, L. and Yang, L. (2010). Heavy metals in soil and crops of an intensively farmed area: Case study in Yucheng City, Shandong province, China. *International Journal of Environmental Research and Public Health*, 7: 395-412**.**

[17]. Iwegbue, C. M. A. (2011) Assessment of heavy metal speciation insoils impacted with crude oil in the Niger Delta, Nigeria. *Chemical Speciation and Bioavailability*, 23(1):7-15.

[18]. Ideriah, T. J. K., Harry, F. O., Stanley, H. O. and Igbara, J. K.(2010). Heavy metal contamination of soils and vegetation around solid waste dumps in Port Harcourt, Nigeria. *Journal of Applied Science and Environmental Management*, 14(1): 101 – 109.

[19]. Hind S. J., Mushrifah, I., Aminah, A. and Kadhum, A. A. H (2014). Determination of Heavy Metals in Soil and Different Parts of *Diplazium esculentum* (Medicinal Fern). *AIP Conference Proceedings*, 1614, 713 – 718, https://doi.org/10.1063/1.4895289.

[20]. DPR. (2002). Environmental Guidelines and Standards for the Petroleum Industry in Nigeria. Department of Petroleum Resources, Lagos, Nigeria. https://dpr.gov.ng/index/egaspin/.

[21]. Orubite, K. O., Ogunka-Nnoka, C. U. and Okpokwu, K. K. (2015).Heavy metal concentrations in soil, fluted pumpkin leaf and surface water in Umuebulu community in Rivers State, Nigeria.European Journal of Basic and Applied Sciences, 2(1): 46-52.

[22]. Njoku, J. D., Ebe, T. E. & Enem, A. O. (2016). Analysis of heavy metal contamination by artisanal refining plants in the Niger Delta Region, Southern Nigeria. *British Journal of Environmental Sciences*, 4(3), 39-48.

[23]. Wang, X., Sun, Y., Li, S. and Wang, H. (2019). Spatial distribution and ecological risk assessment of heavy metals in soil from the Raoyanghe Wetland, China. PLoSOne, 14(8): e0220409.https://doi.org/10.1371/journal.pone.0220409.

[24]. Fosu-Mensah, B. Y., Addae, E., Yirenya-Tawiah, D. and Nyame, F. (2017). Heavy metals concentration and distribution in soils and vegetation at Korle Lagoon area in Accra, Ghana. *Cogent Environmental Science*, 3: 1405887

[25]. Sanusi, K. A., Hassan, M. S., Abbas, M. A. and Kura, A. M. (2017). Assessment of heavy metals contamination of soil and water around abandoned Pb-Zn mines in Yelu, Alkaleri Local Government Area of Bauchi State, Nigeria. *International Research Journal of Public and Environmental Health*, 4 (5): 72-77.

[26]. Perunović, T., Stojanović, K., Kašanin-Grubin, M., Šajnović, A., Simić, V., Jovančićević, B. and Brčeski, I. (2015). Geochemical investigation as a tool in the determination of the potential hazard for soil contamination (Kremna Basin, Serbia). *Journal of Serbian Chemical Society*, 80 (8) 1087–1099.

[27]. Nouri, M. and Haddioui, A. E. M. (2016). Assessment of metals contamination and ecological risk in Ait Ammar abandoned iron mine soil, Morocco. *Ekológia* (*Bratislava*), 35(1): 32–49.

[28]. Edori, O. S. and Kpee, F. (2017). Assessment Models for Heavy Metal Pollution in Soils within Selected Abattoirs in Port Harcourt, Rivers State, Nigeria. *Singapore Journal of Applied Research*, 7(1): 9-15.

[29]. Marcus, A. C., Nwineewii, J. D. and Edori, O. S. (2017). Heavy metals assessment of leachate contaminated soils from selected dumpsites in Port Harcourt, Rivers State, South-South, Nigeria. *International Journal of Chemical Studies*, 5(6): 1507-1511.

[30]. Mmolawa, K. B., Likuku, A. S. and Gaboutloeloe, G. K. (2011). Assessment of heavy metal pollution in soils along major roadside areas in Botswana. *African Journal of Environmental Science and Technology*, 5(3): 186-196.

[31]. Sutherland, R. A., Tolosa, C. A., Tack, F. and Verloo, M. G. (2000) Characterization of selected element concentration and enrichment ratios in background and anthropogenically impacted roadside areas. *Archives of Environmental Contamination and Toxicology*, 38: 428–438.

[32]. Pekey, H., (2006). The distribution and sources of heavy in Izmit Bay surface sediments affected by a polluted stream. *Marine Pollution Bulletin*, 52 (10), 1197 – 1208.