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Accumulation of heavy metals and polycyclic aromatic hydrocarbons in soils around the industrial area of Aba, Nigeria

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Abstract
The simultaneous accumulations of heavy metals and polycyclic hydrocarbons (PAHs) have gained considerable attention since soils contaminated with PAHs were frequently reported to contain high amounts of heavy metal. The present study was carried out to assess heavy metals and polycyclic aromatic hydrocarbons in soils around the industrial area of Aba. Samples were collected from Ogbor hill and Umuobo village. Umuobo village, served as the control. Heavy metals analyzed were lead, cadmium, iron, argon, manganese, mercury, zinc and copper using atomic absorption spectrophotometer method. Polycyclic aromatic hydrocarbon analyzed were naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, benzo (b) fluoranthene, benzo (k) fluoranthene, benzo (e) pryene, dibeno (a,h) anthracene, Indeno (1,2,3-cd) pyrene, benzo (b) triphenylene and benxo (ghi) perylene using Gas Chromatography-Flame Ionization Detection (GC-FID) method. The statistical methods used were standard error of mean, two way analysis of variance and multiple unpaired T-test of variance. Iron recorded the highest concentration in all the sampling points with the mid slope having the highest concentration of 295.83±1.15 mg/kg, while cadmium has the lowest concentration in all the points, with the valley bottom having the lowest with 0.01±0.02 mg/kg. The control recorded a very low concentration of the heavy metals in both sampling sites. The highest was at the crest with the concentration of 0.7±0.00 mg/kg (15-30 cm) in Iron. Mercury and argon were not detected in crest, mid slope and valley bottom of Ogbor hill. For the polycyclic aromatic hydrocarbon, indeno (1, 2, 3-cd) pyrene recorded the highest concentration at both the crest and mid slope, with 2.53±0.43 ppm and 1.02±0.03 ppm respectively, while Benzo (e) pryene recorded the highest concentration at the valley bottom with 0.68±0.28 ppm. The control also recorded the lowest concentrations of the entire polycyclic aromatic hydrocarbon. The highest concentration was recorded at the crest with 1.86±1.64 ppm (15-30 cm) of Indeno (1, 2, 3-cd) pyrene. It is recommended that the industry owners/operators should ensure that effluent treatment plants are installed in their facilities, and should be operated at optimum conditions and manned by qualified personnel.

Keywords
Heavy metal, polycyclic aromatic hydrocarbons, soil

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Introduction

During the process of industrialization and urbanization, contamination by industrial waste has long been recognized as priority environmental concern. The simultaneous accumulation of heavy metals and polycyclic hydrocarbons (PAHs) has gained considerable attention since soils contaminated with PAHs were frequently reported to contain high amounts of heavy metal. Several studies carried out have demonstrated that the combination of these two types of contaminants could potentiate great environmental risk to vegetation, soil microbial, and human health (Maier *et al.*, 2002; Achten and Hofmann, 2009; Wang *et al.*, 2009; Sun *et al.*, 2013). Direct pollution of the urban environment can be as a result of the washing of these harmful substances such as heavy metals and PAHs by rainfall into the soil (Long *et al.*, 2011). Heavy metal and polycyclic aromatic hydrocarbon are non-biodegradable, hence are not readily detoxified and removed by metabolic activities once they are found in the environment. This may subsequently lead to their buildup to toxic levels or bioaccumulation in the ecosystem.

Heavy metals are characterized by density higher than 4.5 $g.cm^{-3}$, they are good thermal and electrical conductivity in liquid and solid states, and they are not transparent and have gloss (Ociepa-Kubicka and Ociepa, 2012). They also show toxic properties caused by their ability to accumulate in tissue and organs. These elements can get through the skin, can be inhaled and consumed with plant and animal products. Some of the heavy metals (As, Zn, Cd, Cu, Hg) can cause immediate acute poisoning, others (As, Zn, Cd, Cr, Cu, Hg, Pb, Sn, Co, Ni, Mn, Se, Fe and Ag) cause chronic conditions (Kostrz and Satora, 2017). Non-biodegradability is the reason for their long-term persistence in the environment (Majewski and Łykowski, 2008). Due to their high durability and toxicity, heavy metals play an important role in the pollution of the environment. The sources of heavy metals in soil and plants are mainly natural, including geologic sources such as rock formation, soils, and transported sediments by winds, while the artificial sources include industrial sources that supply the heavy metals to the air and soil causing contamination of the environment. It is expected that the heavy metal concentration varied considerably with the polluted, industrial and contaminated areas, depending on the wind speed and directions (Ahrens, 2005). The high concentration of heavy metals in soils is reflected by higher concentrations of metals in plants.

Polycyclic aromatic hydrocarbons are organic pollutants and composed of two or more fused aromatic rings of carbon and hydrogen atoms, which are primarily colorless, white, or pale yellow solid compounds (Abdel-Shafy and Mansour, 2016; Suman *et al.*, 2016).. The molecular arrangements of aromatic rings in space can be linear, angular, or in clusters (Abdel-Shafy and Mansour, 2016). Polycyclic aromatic hydrocarbons (PAHs) are condensed polycyclic hydrocarbons containing from two to several aromatic rings without substituents. PAHs with two or three rings (naphthalene, acenaphthene, anthracene, fluorene, phenanthrene), are present in the air mainly in the gas phase, whereas those with four rings (fluoranthene, pyrene, chrysene) are present in both the gas phase and the aerosol, and those having five or more rings (benzo[a]pyrene, benzo[g,h,j] pyrene) are mainly condensed on suspended particulate matters. These compounds never occur individually; the presence of one of the compounds from this group indicates the presence of the others (Abdel-Shafy and Mansour, 2016). Monitoring of PAH content in the air is very important because of the toxic, carcinogenic and mutagenic effects on living organisms (Rusin and Marchwinska-Wyrwal, 2014).. PAHs emitted to the atmosphere are produced in the process of pyrolysis and incomplete combustion of solid fuels, waste, plant residues, etc. with oxygen deficiency (Wieczorek and Wieczoreki, 2011).. Such processes take place in the installation of solid fuel heating furnaces, central heating furnaces, tiled kitchens and fireplaces. The polycyclic aromatic hydrocarbons (PAHs) in the environment largely are a product of the incomplete combustion of petroleum, oil, and coal (Li *et al.*, 2010).. Sources in the urban environment include industrial emissions and wastes, power plants, vehicles, mineral/crude oil extraction, and petroleum refining processes. It is conceivable that faster deposition of exhaust aerosol droplets occurs close to the highway, while further spreading mediated by their adsorbed form on the dust particles that are distributed with wind affects other media (example, air, water, soil, and plants). The spatial heterogeneity of concentrations of PAHs in soil and plants is also affected by heterogeneity of soil property. Once PAHs are released into the atmosphere, they attach to particles, and via dry and wet deposition, they tend to accumulate in soils (Jiao *et al.*, 2013). This research work was aimed at assessing the heavy metal and polycyclic aromatic hydrocarbon accumulation in soils around industrial area of Aba.

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Materials and Methods

Study area

Aba lies along the west bank of the Aba River, and is at the intersection of roads leading to Port Harcourt, Owerri, Umuahia, Ikot Ekpene, and Ikot Abasi. The city became a collecting point for agricultural products following the British made railway running through it to Port Harcourt. Aba is a major urban settlement and commercial center in a region that is surrounded by small villages and towns. The indigenous people of Aba are the Ngwa. Aba is well known for its craftsmen. The coordinate of the study area lies within latitudes 5° 06' 60.00" N and Longitude 7° 21' 59.99" E. The study area falls within the humid tropical rainforest climate. The average rainfall for the area is about 2285 mm and falls from March to November with a relative humidity of 80% and mean temperature of 27 °C. Most parts of the area are flooded during the rainy season due to poor drainage system and construction. The dry season in the area is from November to March and is characterized by dry, cold and windy weather, with little or no rainfall. The temperature is highest in December and lowest in February due to the harmattan (Ijeh and Onu, 2013).

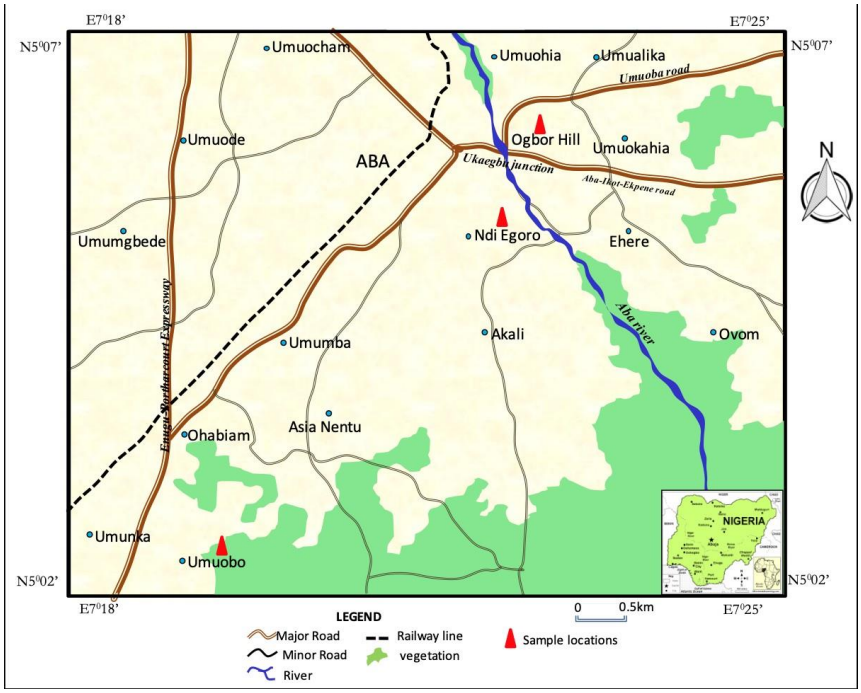

Figure 1. *Location map of the study area.*
(Source: Nigeria Geological Survey Agency, 2004)

2.2 Soil sampling and preparation

The samples were collected from Industrial area in Aba which include; Ogbor hill (Ikot Ekpene road) and Umuobo village serves as the control. Samples were collected randomly 5 m distance from three different points and combined to form a composite sample, with this process repeated at two different depths (0-15 cm and 15-30 cm) for heavy metal determination and two depths (0-15 cm and 15-30 cm) for PAH determination. Samples were collected in triplicates. Samples for PAH determination were collected with a stainless steel hand trowel, while plastic was used for collection of samples for heavy metal determination. The stainless hand trowel and plastic were cleaned thoroughly to prevent cross contamination. Samples for PAHs were packed in pre-cleaned aluminum foil, which was previously solvent rinsed and dried at 80°C. Polyethylene bags were used for packing soils for heavy metal determination. Samples for metals were air-dried in the laboratory after manual removal of stones, twigs and other large materials then ground in a porcelain mortar and passed through a 2-mm sieve. PAH samples were preserved on ice and kept in the refrigerator prior to extraction and analyses. This method was a modification from Adeyi and Oyeleke (2017).

Laboratory analysis

Heavy metal determination. Five grams (5 g) of the sieved samples were weighed into digestion tubes and 10 ml aqua regia (concentrated nitric acid, hydrogen chloride and hydrogen fluoride (HNO_3, HCl,HF) ratio 5:3:2 v/v) added (Ibe *et al.*, 2018). The tubes were

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covered, heated in a water bath to 100^{0}C for 2 hours with intermittent shaking, cooled to room temperature, and then filtered using filter papers (pore size 110 mm). The filtrate was diluted with distilled water to 25 mL and analyzed for total lead (Pb), cadmium (Cd), iron (Fe), argon (Ar), manganese (Mn), mercury (Hg), zinc (Zn) and copper (Cu) using atomic absorption spectrophotometer.

Analysis of Polycyclic Aromatic Hydrocarbons in the samples. The extraction and analysis of soil samples for PAH characterization followed the method in Noramani and Suhaimi (2013). In this method, 500 mg of the soil samples were dissolved using a mixture of 25 ml n-hexane and acetone (7:3, v/v). A microwave extraction arrangement was used with its pressure carefully controlled for 45 minutes. After cooling, the extract was filtered with a Whatman glass fiber filter in a glass bottle, followed by a concentration of the extract to 1.5 ml using a rotatory evaporator. PAH was determined by the GC quadrupole Mass Spectrometer (GC-FID) (Agilent 5975 MSD). The samples were separated into its components by chromatographic separation using a capillary column of an internal diameter of 30 m×0.25 mm and film thickness of 0.25 µm, HP- 5MS and a helium carrier gas of high purity (99.5%), having a flow rate of 1 mL/min from a steel cylindrical pipe. The chromatographic separation conditions include an injector temperature of 250˚C and an initial 70˚C temperature of the chromatographic column which was held for 1 minute. The temperature increase by 30˚C/min to 200˚C, by 35˚C/min to 250˚C, and by 10˚C/min to 300˚C and this was maintained for 25 minutes. The PAH content of the soil samples was quantified from the resulting chromatogram as earlier reported (Rauckyte et al., 2010).

Statistical analysis

The statistical methods used were standard error of mean, two way analysis of variance and Multiple Unpired T-test of variance

Results

The results for the concentrations of heavy metals in soil sample from Ogbor hill were shown in Table 1, Figure 2A and Figure 2B respectively. Iron (Fe) had the highest concentration in all the sampling points with mid slope having the highest concentration of 295.83±1.15 mg/kg (0-15 cm), while cadmium had the lowest concentration in all the points, with the valley bottom having the lowest with 0.01±0.02 mg/kg (15-30 cm). Argon (Ar) and mercury (Hg) both had concentration 0.00, in all the sites. The control had very low concentrations of some of the metals. All the metals with the exception of argon (Ar), mercury (Hg) and the control exceeded NESREA standard. For 0-15 cm, the mean Pb value (29.57±0.21) from mid slope recorded was significantly ($p=0.001369$) higher than other Pb values from other sites of collection and control, respectively. The mean Zn value (165.17±0.35) from mid slope recorded was significantly ($p=0.000015$) higher than other Zn values from other sites of collection and control.

There was no significant difference ($P=0.346746$) as compared to test and control in Cd-(mg/kg) test. The mean Samples collected from mid slope (58.43±2.05) recorded a significant ($p=0.000093$) highest Cu- (mg/kg) as compared to other sites of collection and control, respectively. The mean Samples collected from mid slope (295.83±1.15) recorded a significant ($p=0.000007$) highest Fe- (mg/kg) as compared to other sites of collection and control. The mean Samples collected from mid slope (30.1±0.61) recorded a significant ($p=0.000475$) highest Mn- (mg/kg) as compared to other sites of collection and control. The mean Samples collected from crest (5.4±0.20) recorded a significant ($p=0.000475$) highest PAH- (mg/kg) as compared to other sites of collection and control, respectively. Two way analysis of variance showed that the test samples recorded a significant greater number of heavy metals as against the control samples. [($F=8.36, 8.36, 1.36$); ($p=<0.0001, <0.0001, <0.0001$)]. For 15-30 cm, the result of heavy metals determined from soil samples from Ogbor hill showed no significant difference ($p>0.05$) among the samples collected from different points. Although there was a numerical different between the test samples and control samples, but Two way analysis of variance showed that; there were no significant different between control and test samples in the area sampled. [($F=0.7870, 2.32$); ($p=0.6033, 0.1019$)].

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Table 1. *Concentrations of heavy metals in soil sample from Ogbor hill*

Heavy Metals (mg/kg)	Depth (cm)	Ogbor hill TEST			Control			P value	NESREA Standard
		Crest (Mean±SEM)	Mid slope (Mean±SEM)	Valley BOT-TOM (Mean±SEM)	Crest (Mean±SEM)	Mid slope (Mean±SEM)	Valley BOT-TOM (Mean±SEM)		
Pb	0-15	21.93±1.33	29.57±0.21	19.7±0.62	0.06±0.01	0.05±0.00	0.00±0.00	0.001369	0.1
	15-30	19.93±0.32	29.6±0.21	0.07±0.08	0.00±0.00	0.03±0.03	0.00±0.00	0.368952	
Zn	0-15	150±1.59	165.17±0.35	144.8±1.54	0.03±0.00	0.02±0.00	0.01±0.00	0.000015	0.2
	15-30	132.43±8.75	0.13±0.16	1.68±2.91	0.00±0.00	0.00±0.00	0.00±0.00	0.351781	
Cd	0-15	0.5±0.02	21.1±35.42	0.4±0.03	0.00±0.00	0.00±0.00	0.00±0.00	0.346746	0.01
	15-30	0.33±0.06	2.92±5.05	0.01±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.317015	
Cu	0-15	53.23±1.21	58.43±2.05	46.9±1.48	0.00±0.00	0.00±0.00	0.01±0.00	0.000093	0.01
	15-30	47.40±2.17	0.02±0.03	0.42±0.72	0.00±0.00	0.00±0.00	0.00±0.00	0.358516	
Fe	0-15	286.43±0.06	295.83±1.15	264.2±3.25	1.00±0.00	0.01±0.00	0.01±0.00	0.000007	-
	15-30	236.83±2.22	0.72±1.25	0.29±0.51	0.70±0.00	0.00±0.00	0.00±0.00	0.371096	
Ar	0-15	0.00±0.00	0.00±0.00	0.00±0.00	0,00±0.00	0.00±0.00	0.00±0.00		0.01
	15-30	0.09±0.00	1.21±0.88	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00		
Mn	0-15	25.2±0.53	30.1±0.61	21.7±0.70	0.05±0.00	0.01±0.00	0.00±0.00	0.000475	-
	15-30	18.40±2.08	0.00±0.00	0.34±0.59	0.30±0.00	0.00±0.00	0.00±0.00	0.338418	
Hg	0-15	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00		0.01

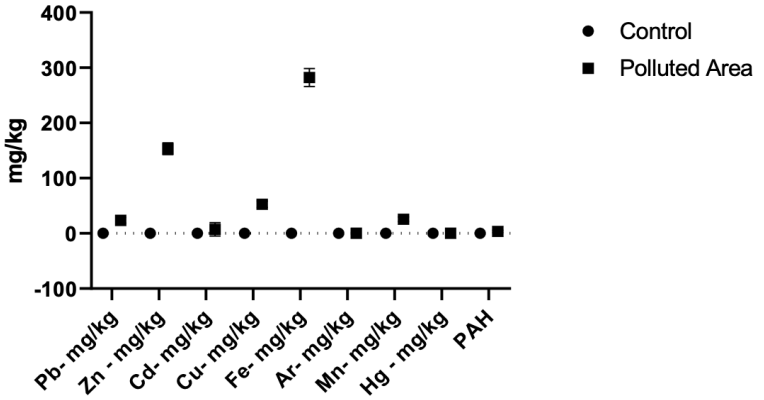

Figure 2A. *Concentration of heavy metals in polluted area (Ogbor hill) and control for 0-15 cm.*

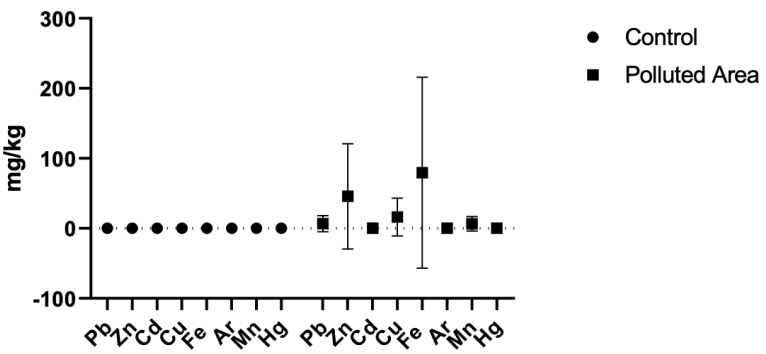

Figure 2B. *Concentration of heavy metals in polluted area (Ogbor hill) and control for 15-30 cm.*

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The results for the concentrations of polycyclic aromatic hydrocarbon in soil sample from Ogbor hill were shown in table 2, figure 3A and figure 3B. Indeno (1, 2, 3-cd) pyrene recorded the highest concentration at both the crest and mid slope, with 2.53±0.43 ppm and 1.02±0.03 ppm in 0-15 cm respectively, while Benzo (e) pryene recorded the highest concentration at the valley bottom with 0.68±0.28 ppm (0-15 cm). Acenaphthylene, Fluorene, Dibeno (a,h) anthracene and Benzo (b) triphenylene recorded the lowest concentration at the crest, with the concentration of 0.01. The control recorded 0.00 in the entire site, with the exception of Benzo (e) pryene, which recorded 0.01 in both crest and mid slope. Multiple Unpired T-test of variance for 0-15cm showed that, there was no significant difference in the PAHS parameters among samples collected from crest, mid slope and valley bottom. Although, there was no difference among the test samples, two ways analysis of variance showed that, the test samples recorded significant high concentration of PAHS as compared to the control samples. [(F 11.48, P=0.0104); (F=11.48, P=0.0098) (F= 14.93, P=0.0003)].

Multiple Unpired T-test of variance for 15-30 cm showed that, there was no significant difference in the PAHS parameters among samples collected from Crest, Mid slope and Valley bottom. Although, there was no difference among the test samples, two ways analysis of variance showed that, the test samples recorded significant high concentration of PAHS as compared to the control samples. [(F=2.867, P=0.0057)].

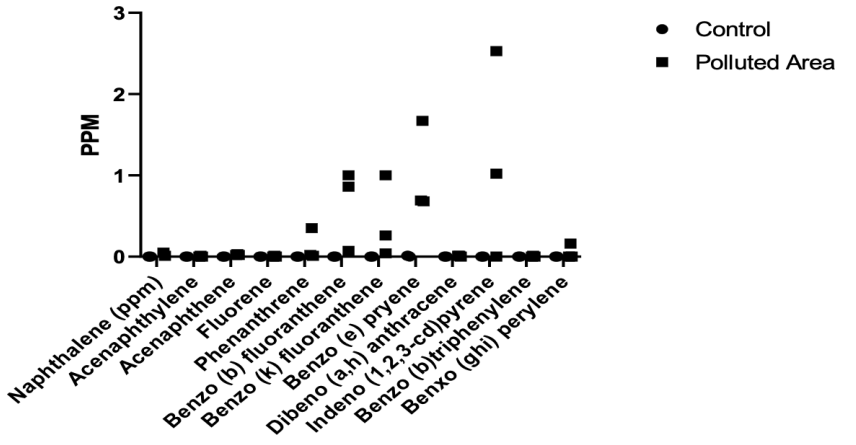

Figure 3A. *Concentration of PAH in polluted area (Ogbor hill) and the control for 0-15 cm.*

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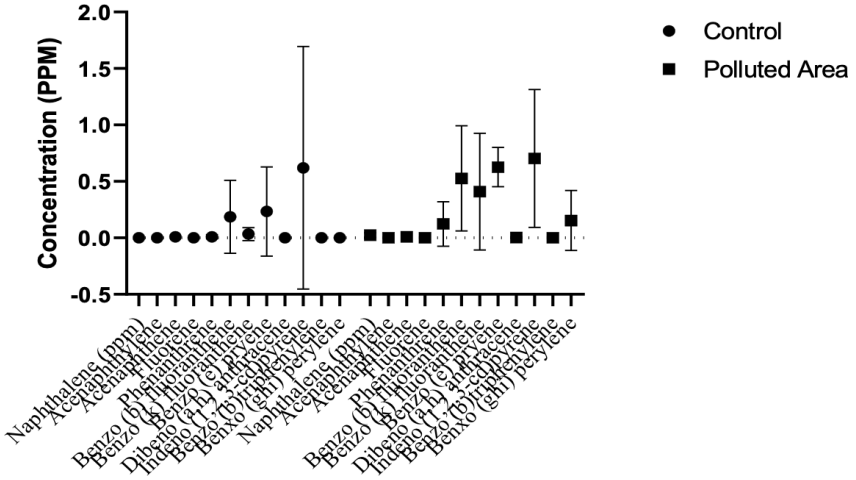

Figure 3B. *Concentration of PAH in polluted area (Ogbor hill) and the control for 15-30 cm.*

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Table 2. *Concentrations of polycyclic aromatic hydrocarbon in soil sample from Ogbor hill*

Parameters (ppm)	Depth (cm)	PAHS@Ogbor hill TEST			Control			
		Crest (Mean±SEM)	Mid slope (Mean±SEM)	Valley BOT-TOM (Mean±SEM)	Crest (Mean±SEM)	Mid slope (Mean±SEM)	Valley BOT-TOM (Mean±SEM)	P value
Naphthalene	0-15	0.05±0.07	0.05±0.07	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.051374
	15-30	0.04±0.06	0.03±0.06	0.00±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.124170
Acenaphthylene	0-15	0.01±0.01	0.00±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.373901
	15-30	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	
Acenaphthene	0-15	0.03±0.03	0.02±0.02	0.02±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.002192
	15-30	0.01±0.02	0.01±0.01	0.01±0-00	0.03±0.00	0.00±0.00	0.00±0.00	>0.999999
Fluorene	0-15	0.01±0.01	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.373901
	15-30	0.00±0.00	0.00±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	
Phenanthrene	0-15	0.02±0.03	0.35±0.56	0.01±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.320167
	15-30	0.01±0.02	0.35±0.56	0.01±0.01	0.03±0.00	0.00±0.00	0.00±0.00	0.375566
Benzo (b) fluoranthene	0-15	0.86±0.17	1.00±0.00	0.07±0.12	0.00±0.00	0.00±0.00	0.00±0.00	0.090390
	15-30	0.51±0.11	1.00±0.00	0.07±0.12	0.56±0.00	0.00±0.00	0.00±0.00	0.357290
Phenanthrene	0-15	0.02±0.03	0.35±0.56	0.01±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.320167
	15-30	0.01±0.02	0.35±0.56	0.01±0.01	0.03±0.00	0.00±0.00	0.00±0.00	0.375566
Benzo (b) fluoranthene	0-15	0.86±0.17	1.00±0.00	0.07±0.12	0.00±0.00	0.00±0.00	0.00±0.00	0.090390
	15-30	0.51±0.11	1.00±0.00	0.07±0.12	0.56±0.00	0.00±0.00	0.00±0.00	0.357290
Benzo (k) fluoranthene	0-15	0.04±0.05	1.00±0.00	0.26±0.08	0.00±0.00	0.00±0.00	0.00±0.00	0.209881
	15-30	0.04±0.05	1.00±0.00	0.19±0.08	0.10±0.00	0.00±0.00	0.00±0.00	0.277644
Benzo (e) pryene	0-15	1.67±0.57	0.69±0.58	0.68±0.28	0.01±0.00	0.01±0.00	0.00±0.00	0.037449
	15-30	0.76±0.21	0.69±0.58	0.43±0.23	0.69±0.01	0.01±0.00	0.00±0.00	0.189964
Dibeno (a,h) anthracene	0-15	0.01±0.01	0.01±0.00	0.01±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.116117
	15-30	0.00±0.00	0.00±0.01	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.373901
Indeno (1,2,3-cd) pyrene	0-15	2.53±0.43	1.02±0.03	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.182643
	15-30	1.09±1.96	1.02±0.03	0.00±0.00	1.86±1.64	0.00±0.00	0.00±0.00	0.912600
Benzo (b)triphenylene	0-15	0.01±0.01	0±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.373901
	15-30	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	
Benxo (ghi) perylene	0-15	0.16±0.26	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.373901
	15-30	0.46±0.16	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.373901

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Discussion

The metals that were analyzed in this study included; lead (Pb), cadmium (Cd), iron (Fe), argon (Ar), manganese (Mn), mercury (Hg), zinc (Zn) and copper (Cu). The results obtained showed that Iron (Fe) recorded the highest concentration in Ogbor hill, while the lowest concentrations were recorded in cadmium. This is in line with Ekere *et al.* (2017), where their results showed that the sediment samples were heavily polluted with Fe and moderately polluted with Cd. Cadmium had the lowest concentration of 0.4±0.03 mg/kg in Ogbor hill; this is in line with Ziola and Slaby (2020), in their study, cadmium recorded the lowest concentration of 0.62 ±0.41 mg/kg. In most cases, Cu, Zn and Pb concentrations were highest in topsoil, which was evidence of recent/anthropogenic contamination (Gowd *et al.*, 2010), this is also in agreement with this present study where Cu, Zn and Pb recorded concentrations that exceeded National Environmental Standards and Regulations Enforcement Agency National (NESREA, 2011) and United States Environmental Protection Agency (US EPA, 2001) standards. Pb, Zn and Cu recorded concentration of 29.57±0.21 mg/kg, 165.17±0.35 mg/kg and 58.43±2.05 mg/kg respectively. Heavy metal levels obtained showed that (Pb), cadmium (Cd), iron (Fe), argon (Ar), manganese (Mn), mercury (Hg), zinc (Zn) and copper (Cu) had concentrations higher than the maximum permissible limit stipulated by both National Environmental Standards and Regulations Enforcement Agency National (NESREA, 2011) and United States Environmental Protection Agency (US EPA, 2001). Cd concentration levels were less than 1 mg/kg to 8.5 mg/kg for the study area in the study carried out by Muze (2020).The observed values were higher than the control values of less than 1mg/kg and also higher than the allowed value of 1 mg/kg by USEPA (Muze *et al.*, 2020). This is in agreement with this study where observed values are also higher than the control. The high-level of Pb observed in the soil from the study area could be from the indiscriminate disposal of waste from lead-acid batteries, lead-based solder; metallic alloy, lead-based paints, used oil, waste incineration, scrap and junk part of automobile (Nkansah *et al.,* 2011). Pb has no known biological benefit to humans as it can damage various systems of the body including the nervous system, reproductive system, and the kidney, and can further cause high blood pressure and anaemia (WHO, 2011). The Cd concentrations in the study area may be a result of the disposal of waste containing Cd such as waste batteries and paints (Muze et al., 2020). The metals in both Ogbor hill and Ndi Egoroshowed the following trend:

Ogbor hill (Ikot Ekpene road): Fe > Zn > Cu > Mn > Pb > Cd > Ar and Hg;

The source of the PAH may be products of incomplete combustion of fossil fuel while other important sources may include automobile and truck emissions. The observed differences in the concentration of the pollutants in Ogbor hill may be attributed to the mode of wastes disposal and type of soil (Ololade, 2014). Relatively high concentrations of benzo[a]pyrene, considered a carcinogen, have been reported. High concentrations of polycyclic aromatic hydrocarbon in the environment is of public health concern, since several of the measured PAHs are considered probable human carcinogens (benz(a)anthracene, benzo(a) pyrene, benzo(k)fluoranthene, chrysene, dibenz(a,h) anthracene and indeno(1,2,3-c,d)pyrene) or possibly (benzo(a)fluoranthene, benzo(k) fluoranthene and indeno(1,2,3-c,d)pyrene) (TPPAHs, 1995).The USEPA identified 16 priority PAHs, which can be classified as being of low or high molecular weight. Low molecular weight (LMW) PAHs (i.e., acenaphthylene, naphthalene, acenaphthene, fluorene, phenanthrene and anthracene), also referred to as petrogenic (formed during the emission of non-combustion-derived matter, including inadvertent oil spills), have molecular weights ranging from 128.2 to 178.2 g/mol. High molecular weight (HMW), pyrolytic PAHs, are fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b) fluoranthene, benzo(a) fluoranthene, benzo(k)pyrene, dibenzo(a, h)anthracene, benzo(g, h, i) perylene and indeno(1,2,3-cd) pyrene and have molecular weights ranging from 202.3 to 278.4 g/mol (Oketola and Akpotu, 2015; Duke, 2008). The mean PAH levels observed in the study are in the order;

Ogbor hill (Ikot Ekpene road)

Crest; Indp>Bep> Bbf> Bgp>Nap> Bkf>Ant>Phe> Apt, Flu, Dbh and Bbt;

Mid slope; Indp> Bbf and Bkf > Bep> Phe > Nap > Ant>Apt, Flu, Dbh, Bbt and Bgp;

Valley bottom; Bep> Bkf> Bbf> Ant> Nap, Phe and Dbh> Ant, Flu, Indp,Bbt and Bgt.

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Conclusions

The degree of contamination posed by heavy metals and polycyclic aromatic hydrocarbon in soils in the industrial area in Aba, Nigeria were evaluated in the present study. The results provide evidence that open burning, stockpiling, and other improper waste management practices may have resulted in toxic heavy metal and polycyclic aromatic hydrocarbon accumulation in soils of industrial area in Aba. Various heavy metals contamination indices showed moderate to very high levels of contamination in soils around the industrial areas soils, indicating potential threats to human and ecological health. We found PAHs at levels exceeding National Environmental Standards and Regulations Enforcement Agency National (2011) and United States Environmental Protection Agency (2009) standards, suggesting anthropogenic contamination from both petrogenic and pyrogenic sources. Our work shows that improper industrial waste handling at these sites may contribute additional heavy metals and PAH contamination.

There is need for effective monitoring of industrial wastewater discharges by the regulatory bodies to ensure good quality effluent and compliance with set standards. NESREA, the regulating body in Nigeria and other stakeholders should map out holistic measures to tackle this continuous menace to our receiving water bodies and environment.

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