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Heavy metals in dry depositions as indices of atmospheric pollution in Enugu Urban, Enugu State, Nigeria

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A B S T R A C T

The study determined the concentrations of heavy metals in dry deposition in Enugu Urban, Nigeria. Dry deposition samples are collected using plastic containers mounted on elevation of 3 meters at 9 various locations with 3 sampling stations per location and left for 30 days. The dust samples were collected for 3 consecutive times from November 2018 to March, 2019 and a total of 27 composite samples were collected for analysis. The samples were treated in accordance with the standard method of analysis and analyzed for Cu, Cr, Ni, Mn, Zn, Pb and Cd using Perkin Elmer Optima 8000 Inductively Coupled Plasma – Optical Emitting Spectrometer (ICP – OES). The result shows the highest mean values of the metals concentrations (mg/kg) as follows; Cu – 146.29 ± 10.23 , Cr – 13.01 ± 0.30 , Ni – 30.35 ± 0.37 , Mn – 179.07 ± 0.83 , Zn – 507.24 ± 2.97 , Pb – 0.43 ± 0.09 , Cd – 2.43 ± 0.21 . The mean values of the concentrations of the metals decrease in the following order; Zn > Mn > Cu > Ni > Cr > Cd > Pb. The values of potential ecological risk indexes ranges in each sampling period across the locations are as follows: (November/December) 457.31 - 915.12, (January/February) 412.81 – 911.09, (February/March) 260.29 – 933.48. The indication is that Enugu urban atmosphere is continuously being contaminated with toxic metals and it poses a great ecological risk. Regular atmospheric monitoring is very important and effective pollution control measures must be in place and enforced.

Introduction

Heavy metals are ubiquitous substance in various human environments which occurs naturally, mostly from weathering of parent materials. They also emanate from a wide range of human activities like mining, metal processing and smelting, emissions from industries, use of fertilizers, pesticides and sewage irrigation (Pan et al. 2018; Lu et al. 2010; Chen et al. 2015).The quantities of most heavy metals that settle on the surface of the earth from human activities are many times greater than deposits from natural sources. Combustion activities are the most important origin of heavy metals, especially, power generation, smelting, incineration and the internal combustion engine (Duce and Tindale 1991; Galloway et al. 1982; Hutton and Symon, 1986; Nriagu, 1989; Nriagu and Pacyna, 1988). Heavy metals are of great concern because they are toxic and some have carcinogenic properties (Cao et al. 2009).

The microelements; Nickel (Ni), Zinc (Zn), Boron (B), Iron (Fe), Copper (Cu), Molybdenum (Mo), Manganese (Mn), Chlorine (Cl), have been acknowledge as essential and sodium (Na), Silicon (Si), Cobalt (Co) and Strontium (Sr) as beneficial or quasi – essential for plants. In addition to these plant essential micro elements, human beings and animals require Chromium (Cr), Iodine (I) and

Selenium (Se). Micro-elements constitute less than 0.1% of dry plant tissue and are used in relatively small amount, some of which are potential toxins if ingested in elevated concentration (Nieder et al. 2018).

Heavy metals are highly mobile in air and water and can be transported in various forms through the exchange of substances among ecosystems (Pan et al. 2018). It can be dangerous to both animals and plants, depress the decomposition rates of plant litter and inhibit soil microbial ecosystem services (Duval et al. 2011; Patra et al. 2004; Strojan, 1978; Giller et al. 2009). They may enter the human body through inhalation of dust, direct ingestion of soil and water, dermal contact of contaminated matrix and consumption of vegetables grown on contaminated fields (Nieder et al. 2018). The heavy metals which include copper may affect the reproductive systems, nervous system (Ashish et al. 2013), chromium on high human exposure affects the liver, damages the immune system (ATSDR 1998; WHO 1988) and nickel is shown to cause cancers of the lungs, nasal cavity (IARC 1990).

The entrance and accumulation of toxic metals into the atmosphere is basically from human activities (Giordano et al. 2005). The removal or the transportation of gases and particles from the atmosphere which is a very essential process is known as atmospheric deposition (WMO 2019). With the increasing concentrations of pollutants in the atmosphere as a result of human activities, atmospheric deposition has become a major environmental problem in most parts of the world because of issues of bioaccumulation of toxic substances and metals, impact on biodiversity, human health, and global climate change (WMO 2019).

Atmospheric deposition is a very intricate natural recycling of numerous substances within the ecosystem which involves meteorological, hydrological, physical, chemical and biological processes. The process of deposition occurs in the form of dry deposition and wet deposition (Pacyna 2008). Dry deposition is the process of settling, impaction and adsorption of atmospheric gases and particulate matter during the dry weather or season then falling freely on the earth surface (Pacyna 2008; WMO 2019).

There are various studies recently on the composition and concentration of heavy metals in dry deposition in urban and rural areas being categorized as industrial, commercial, residential locations (Bilos et al.2001; Ekere and Ukoha 2013; Ogugbuaja and Barsisa, 2001; Das et al. 2005; Jeffries et al. 1981; Leung et al. 2009; Seung et al. 2006; Zheng et al. 2005).

Enugu is the capital of Enugu State and a very important city in the south-east of Nigeria, being the former capital of the East Central state which is now dividend into 5 states. It is an industrial, administrative and as well a highly populated with potential atmospheric pollution from various human activities especially fossil fuel combustion, vehicle exhaust.

The previous studies of Sobhanardakani (2019); Wan et al. 2018; Duan etal, 2017 showed that heavy metals in the atmosphere are potentially ecological risk that is of great concern.

The risk associated may be human health, loss in biodiversity, emergence of new diseases, climate change, flooding and increase in atmosphere temperature.

The present study aimed to determine, the heavy metals, Cu, Cr, Ni, Mn, Zn, Pb and Cd in the dry deposition and their potential ecological risk.

Materials and Methods

The study area is Enugu Urban, South-East, Nigeria which is located between Latitude 6^{o} 00^{0} N and $7^{0}00^{o}$ N and longitude 7^{0} 00^{0}E and 7^{0} 45^{0}E. It is in the tropical rainforest zone of south-eastern Nigeria with two distinct seasons, wet seasons from April to October, dry season from November to March (Ajah et al. 2015).

The study area is divided into five areas and they are as follows:- as shown in figure 1.

1. Commercial Areas: (a) Ogbete Layout (b) Uwani
2. Industrial Areas: (a) Emene (b) Iva Valley
3. Low Density Residential Areas: (a) Akwuke (b) Maryland
4. High Density Residential: (a) Abakpa (b) Achalla Layout
5. Rural Area: (a) Ugwuogo Nike

The 5^{th} area which is a rural settlement was identified about 4Km from the metropolis to serve as a control. In each of the 4 areas, two sampling locations/site were selected.

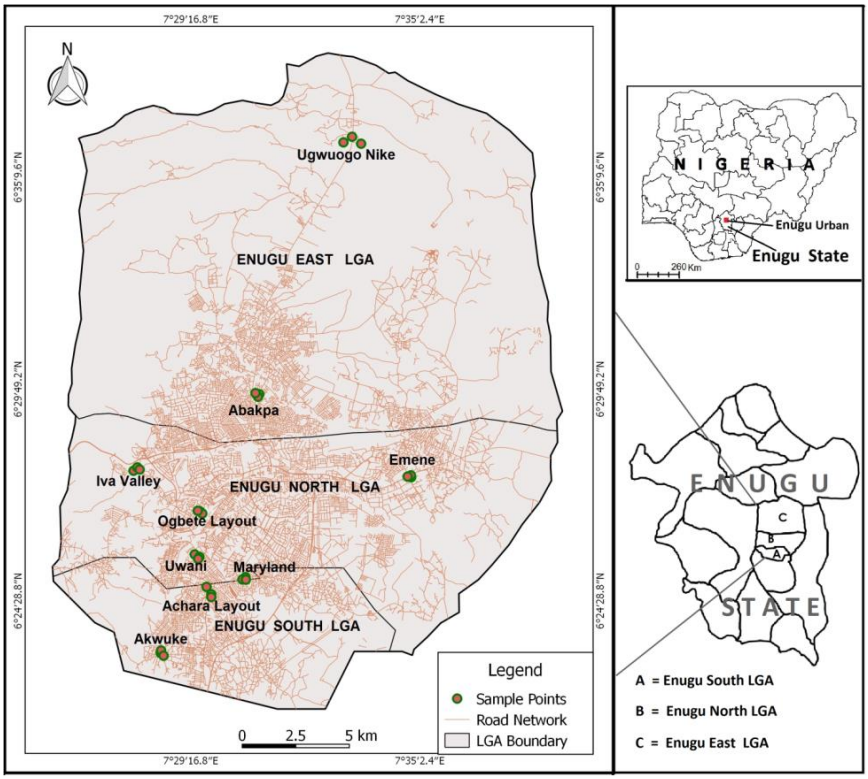

Fig.1 .Enugu Urban Showing Sampling locations of the study

Dry deposition samples were collected according to ASTM (American Society for Testing and Materials) 1739D, using cylindrical plastic containers. The sampling containers were placed on elevation of 3 meters above the ground covered with sieve pore size of 63µm and away from any visible pollution sources (Moaref et al. 2014).

The samples were collected after 30 days (ASTM 2004) in each of the period during the dry season starting from November, 2018 to March, 2019.

The dust collected within the period were transferred into sample bottles and taken to laboratory for analysis. A 1.0g of the dust sample was taken and mixed thoroughly. Concentrated nitric acid (10ml) was added and refluxed for 10 minutes. Then additional 5ml of concentrated nitric acid was added and reflux for 30 minutes. The mixture was evaporated to 5ml and cooled. 2ml of distilled water and 3ml of 30% hydrogen peroxide were added continually until bubbling stops. It was evaporated to 5ml.

To the 5ml of digested sample, 10ml of concentrated hydrogen chloride was added and reflux for 15minutes. It was then filtered into 100ml volumetric flask and make up to the mark with distilled water. The samples were analyzed using Perkin Elmer Optima 8000 inductively coupled Plasma – Optical Emitting Spectrometer (ICP – OES).

Degree of Contamination Of heavy metals

The first step in determining the degree of contamination (C_d) is finding the contamination factor C_f which according to Hakanson(1980) is the ratio of heavy metals concentration in sediment and acceptable permissible limit of the same metal (Mortuza and Al-Misned 2017) as shown below

$C^i_f = \frac{C_i}{C_{in}}$ ..... (1)

Where C_i is the analysed concentration of the heavy metals in water and dust while C_{in} is the known limit of Cu, Cr, Ni, Mn, Zn, Pb, and Cd with values of 25, 25, 20, 30, 123, 10 and 6mg/kg respectively (Hakanson 1980; Mortuza and Al-Misned 2017).

The summation of all the contamination factors gives the degree of contamination as in the equation below,

$C_d \sum_{i=1}^{n} C_f^i$ ..... (2)

It is important to note that the contamination factor which can be categorized as low, moderate, considerable and very high when values are recorded as $C^i_f < 1$, $1 \leq C^i_f < 3$, $3 \leq C^i_f < 6$ and $C^i_f \geq 6$ respectively while degree of contamination which is equally categorized as low, moderate, considerable and very high when the values obtained are $C_d < 8$, $8 \leq C_d < 16$, $16 \leq C_d < 32$ and $C_d \geq$

32 respectively (Hakanson 1980; Mortuza and Al-Misned 2017).

Modified degree of contamination (mC_d)

The modified degree of contamination is obtained by the equation below;

$$mC_d = \frac{\sum_{i=1}^{n} C_f^i}{n} \quad (3)$$

where $\sum_{i=1}^{n} C_f^i$ is the summation of contamination factors and n is the number of analyzed contaminants and it is classified as nil to very low, low, moderate, high, very high, extremely high and ultra-high when the values obtained are $mC_d < 1.5$, $1.5 \leq mC_d < 2$, $2 \leq mC_d < 4$, $4 \leq mC_d < 8$, $8 \leq mC_d < 16$, $16 \leq mC_d < 32$ and $mC_d \geq 32$ respectively (Abrahim and Parker 2008; Mortuza and Al-misned 2017).

Pollution Load Index (PLI)

Pollution Load index was calculated using the equation below;

$$PLI = (C_{f1} \times C_{f2} \times \ldots\ldots \times C_{fn})^{\frac{1}{n}} \quad (4)$$

Which is a measure of degree of pollution of heavy metals, n is the number of metals analysed, C_{fi} is the contamination factor. PLI involves a systematic observation for the assessment of an environmental matrix and the values obtained are categorized as perfection when PLI is zero, permissible limit when PLI is one and continuous degeneration when the value is greater than one (Tomlinson et al. 1980; Gupta et al. 2013; Mortuza and Al-Misned 2017; Pobi et al. 2019).

Potential ecological risk assessment of the heavy metals.

Potential ecological risk of heavy metals was assessed by calculating the potential ecological risk factor (Er) of a given element using the equation;

$$Er = Tr \times C_f \quad (5)$$

Then using the values obtained to calculate the potential ecological risk index (RI) of all the elements under study using the equation;

$$RI = \sum_{i=1}^{n} Er \quad (6)$$

Where C_f is the contamination factor of the metal, Tr is the toxic response factor of the metal (Hakanson 1980). The metals Cr, Mn, Ni, Cu, Zn, Cd, Pb have a standard toxic response factor of 2, 1, 5, 5, 1, 30, 5 accordingly (Hakanson 1980; Xu et al. 2008).

The potential ecological risk is then categorized using the values of RI obtained as, low ecological risk, moderate ecological risk, considerable ecological risk and very high ecological risk when $RI < 150$, $150 \leq RI < 300$, $300 \leq RI < 600$ and $RI \geq 600$ respectively (Hakanson 1980; Xu et al. 2008; Pobi et al. 2019).

Statistical analysis was done using statistical package for social sciences (SPSS) version 20 at significance level $P<0.05$.

Results and Discussion

The result of the metal concentration in the dry deposition is shown in the table 1. below

Table 1. The mean values of the metals concentrations in the sampling locations

	Mean values of metals (mg/kg)						
Location	Cu	Cr	Ni	Mn	Zn	Pb	Cd
Emene	39.01 ± 0.34	12.07 ± 0.18	8.84 ± 0.5	94.80 ± 0.87	278.96 ± 0.95	0.32 ± 0.03	0.66 ± 0.19
Ogbete	53.27 ± 0.79	8.58 ± 0.52	10.81 ± 0.59	157.97 ± 2.13	125.06 ± 1.49	0.37 ± 0.09	0.59 ± 0.18
Layout							
Iva Valley	84.41 ± 0.18	0.73 ± 0.15	25.74 ± 0.41	117.93 ± 2.3	507.24 ± 2.97	0.39 ± 0.03	2.43 ± 0.21
Akwuke	42.95 ± 0.63	11.15 ± 0.45	16.75 ± 0.95	82.10 ± 1.53	312.24 ± 2.42	0.32 ± 0.08	0.79 ± 0.11
Achalla	146.29 ± 10.23	8.99 ± 0.27	30.35 ± 0.37	82.23 ± 0.45	119.68 ± 1.22	0.36 ± 0.02	0.88 ± 0.09
Layout							
Uwani	58.51 ± 0.59	11.47 ± 0.57	24.45 ± 0.62	124.44 ± 0.92	86.17 ± 2.14	0.35 ± 0.06	0.64 ± 0.14
Maryland	86.26 ± 0.73	13.01 ± 0.30	17.32 ± 0.62	131.07 ± 1.28	155.48 ± 1.27	0.40 ± 0.08	0.98 ± 0.05
Abakpa	70.46 ± 0.72	12.89 ± 0.36	9.26 ± 0.37	179.07 ± 0.83	228.61 ± 1.34	0.43 ± 0.09	0.95 ± 0.17
Ugwuogo	65.05 ± 0.91	7.14 ± 0.52	6.72 ± 0.44	144.34 ± 2.69	123.03 ± 1.88	0.32 ± 0.08	0.82 ± 0.10
Nike							

The mean values of copper concentration (mg/kg) in the locations ranges from 39.01 ± 0.34 to 146.29 ± 1.23. The highest value of 146.29 ± 1.23 was recorded in Achalla Layout, which is high density populated area. This high values may be as a result of indiscriminate dumping of E-waste in municipal dumpsites, widespread use of households power generators and vehicles emissions. The concentration of Cu is lower (25.9±10.1 ppm) in Maiduguri area and within the range of values of this study (122.0±48.0 ppm) in Yola area as recorded by Ogugbuaja and Barsisa

(2001). Copper is toxic and it is deposited in the kidney and liver, impairing their functions thereby affecting the reproductive system, nervous system, adrenal function and other body tissues (Ashish et al. 2013).

Chromium concentrations show a mean values in the range of 0.73 ± 0.15 to 13.01 ± 0.30 (mg/kg). The highest value of 13.01 ±0.30 (mg/kg) was recorded in Maryland which is a low density residential area but it is the location of timber and building materials market. There are a lot of welders, metal plating and coating in this area. All these activities increase the atmospheric concentration of Cr in the area. Stationary point sources which may come from numerous micro industries, commercial and residential fuel combustion release chromium into the atmosphere (Kimbrough et al. 1999; Pacyna and Pacyna 2001). Chromium is an important dietary element and it is very essential in the metabolism of glucose, fat and protein but high human exposure through inhalation affects the respiratory tract, gastrointestinal system, kidney, liver, neurological cells and immune system damage (ATSDR 1998; WHO 1988). The study of Wei et al. (2010) recorded high concentration of Chromium (54.28 mg/kg)

Nickel as recorded in this study has the mean values of concentration in the ranges of 6.72 ± 0.44 to 30.35 ± 0.37 (mg/kg). This value is higher than the earlier recorded value (0.1 – 0.8 mg/kg) by Ekere and Ukoha(2013). This elevated value may be as a result of increase in population as well as increase in anthropogenic activities in the area. The highest value of Ni was recorded in Acahalla Layout which is a high density populated area. Nickel is widely introduced into the atmosphere through anthropogenic activities, since it is used as alloys, nickel-plating, and batteries and through combustion of fossil fuels (Okpoebo et al. 2014). The combustion of fossil fuels globally in the year 1999 was estimated to release 570,000 tons of nickel (Rydh and Svärd, 2000).

Studies have shown abundant evidence in humans of the carcinogenicity of compounds of nickel and nickel metals (IARC 1990).

Manganese showed a mean value in concentration in the range of 82.10 ± 1.53 to 179.07 ± 0.82 (mg/kg) which is lower in the value recorded in Maiduguri (258.0±5.0 ppm) and Yola (284.0±0.5 ppm) (Ogugbuaja and Barsisa, 2001). Manganese is found almost everywhere in the environment and it is about 0.1% of the earth crust (Gradel, 1978). This amounts to its presence in the atmosphere and other environmental matrix. Anthropogenic activities like welding, fungicide application also contributes to increase of manganese in the air (Ferraz et al. 1988; Ruijten et al. 1994).The use of organo –manganese compound-methyl cyoclopentadienyl Manganese tricarbonyl (MMT) as anti knock ingredient in gasoline increase the manganese emissions in the air (Davis et al. 1988).There is about 8% increase in the levels of manganese tetroxide in urban air in most countries being the result of combustion of gasoline containing MMT (Loragner and Zayed 1995). Manganese is an essential nutrient in humans which is needed for bone mineralization, metabolic regulation and general well-being but elevated level of exposure through inhalation affects organs and systems in human body especially the lungs, nervous systems, reproductive system (WHO 1999).

Zinc mean values of concentration ranges from 86.17±2.14 to 507.24 ±2.97 (mg/kg) which is within the ranges of values recorded in Maiduguri (318.0 ± 38.0 ppm) and Yola (139.0 ± 53.0 ppm) (Ogugbuaja and Barsisa 2001).The largest concentration of 507.24 ± 2.97 mg/kg was recorded in Iva – Valley, an industrial location with coal mine, pottery, metal smelting, foundry which is the possible contribution to this high level of zinc in the area. Metal smelting and mining activities are the main anthropogenic sources of zinc in the environment and the use of zinc in brass, bronze, die casting metals, alloys, rubbers and paints are potential release of zinc into the environment through various waste streams (ATSDR 1995). Zinc is essential to all life forms and it is used as a dietary supplement and considered important to humans for tissues and organs development (Hambridge 2000; Pennington et al. 1989; Wasteny et al. 1986). High exposures of zinc through inhalation have shown from studies that cholesterol metabolism in man can be disrupted (Katya-Katya et al. 1984). Excessive Zinc intake in whichever way has been reported to impair the immune response in humans (Chandra 1984). It also affects adversely the gastro intestinal, hematological and respiratory systems along with alternations in the cardiovascular and neurological systems of humans (Nriagu 2011).

The mean values of lead ranges between 0.32 ± 0.03 to 0.43 ± 0.09 (mg/kg), which is very low when compared with the values recorded in the studies by (Ogugbuaja and Barsisa 2001; Ekere and Ukoha 2013; Bilos et al. 2001), (97.5±5.8 ppm) and (81.8 ± 5.3 ppm); (4.8 ± 0.0 - 87.0 ± 0.1 mg/kg); (64 ± 62 ng/m^3), respectively. Lead in the atmosphere is from the combustion of waste notably and from indiscriminate discharge of spent lubricants. Lead also enters the air through the activities of electrical smelting; soldering work and it is toxic with adverse effects on humans and animals (Ekere and Ukoha 2013).The toxicity, persistence and ability to bioaccumulate in humans and environment informed the United States

Environmental Protection Agency (USEPA) to list Pb among pollutants of great concern (ATSDR 2007).

The mean values of the concentrations of cadmium ranged from 0.59 ± 0.18 to 2.43 ± 0.21 (mg/kg) and it is lower than the values recorded in Maiduguri (5.0±1.2 ppm) and Yola (5.6± 1.3 ppm) (Ogugbuaja and Barsisa 2001).The highest value was recorded in Iva valley, which is an industrial location with numerous mechanic workshops, foundry, coal mine, pottery, battery chargers and all these increase the cadmium levels in the air. Cadmium is highly toxic and at very low exposure, has acute and chronic effects on humans and environment. It is not degradable in nature and can persist in the environment and its compounds are soluble in water. Therefore, they are more mobile in soil and readily bioavailable and tend to bioaccumulate (WHO 1992a).

Human exposures to cadmium can be linked to lung and prostate cancer. The epidemiological data from reviews links cadmium to cancer of the lungs, prostate, liver, kidney and stomach (Waalkes 2000)

There are wide variations in the values of the heavy metal concentration in this study when compared with the results of other studies around the world by (Bilos et al. 2001; Das et al. 2005; Leung et al. 2009; Ekere and Ukoha 2013; Ogugbuaja and Barsisa 2001).This may be as a result of the environmental conditions of the area and most importantly the nature of human activities in the study area. The population of the area is also a factor and the type of settlement, then the mode of study, human error and assessment.

In the rural area (Ugwuogo Nike) which served as control for this study showed an elevated mean value in concentration of heavy metals. Ugwogo Nike is largely an agricultural settlement; the presence of the heavy metals may be as a result of the use of fertilizers, pesticides and herbicides. But the most important source may be the increase of vehicular movement on the link road to 9th mile – Markudi expressway that transverse the area, since year 2016 when the major road is closed for repairs and upgrade. Atmospheric transport can also add to presence of pollutants in the air as for example cadmium have the tendency to travel long distances and can be deposited on soils and surface water with no change in its form (ATSDR 2008).

The table 2 below shows the values of contamination factor (C_f), degree of contamination (C_d), modified degree of contamination (mC_d) and pollution load index (PLI) of the heavy metals obtained from the dust collected at various location and at different periods during the study.

Then the table 3 shows the values of potential ecological risk factor (Er), potential ecological risk index (RI) with their corresponding pollution degree.

The determinants of ecological risk in dry deposition from various locations as shown in the tables 2 and 3 has a mean range as follows: degree of contamination 18.02 – 35.99, modified degree of contamination 2.57 – 5.14, pollution load index 0.49 – 1.08 and the potential ecological risk has a mean value in the range of 418.68 – 919.90.

Comparing the result of ecological risk from some of the previous studies of Sobhanardakani (2018); Wan et al. (2018); Duan et al. (2017) the mean values are 0.13; 809; 366.42, respectively.

Table 2. Contamination factors (C_f), degree of contamination (C_d), modified degree of contamination (mC_d) and pollution load index (PLI) of heavy metals in dust samples collected at different periods

ocation	Period	C_f							C_d	mC_d	PLI
		Copper	Chromium	Nickel	Manganese	Zinc	Lead	Cadmium			
Emene	Nov/Dec	1.57	0.12	0.05	3.19	0.01	2.56	18.66	26.16	3.74	0.47
	Jan/Feb	1.58	0.12	0.10	2.43	0.01	2.67	19.55	26.46	3.78	0.56
	Feb/March	1.53	0.12	0.15	2.82	0.01	2.50	20.75	27.88	3.98	0.59
Ogbete Layout	Nov/Dec	2.23	0.16	0.05	1.45	0.09	1.95	14.32	20.23	2.89	0.67
	Jan/Feb	2.11	0.16	0.10	1.38	0.10	1.46	12.94	18.23	2.61	0.71
	Feb/March	2.07	0.16	0.15	1.48	0.09	1.62	13.80	19.35	2.77	0.76
Iva Valley	Nov/Dec	3.83	0.20	0.05	5.79	0.07	2.96	13.79	26.69	3.81	0.94
	Jan/Feb	2.91	0.20	0.10	3.93	0.07	3.06	13.85	24.12	3.45	0.95
	Feb/March	3.39	0.20	0.15	4.92	0.08	3.09	13.47	25.30	3.62	1.08
Akwuke	Nov/Dec	1.74	0.24	0.05	1.93	0.08	2.27	21.21	27.51	3.93	0.77
	Jan/Feb	1.65	0.24	0.10	1.92	0.10	2.50	20.39	26.89	3.84	0.88
	Feb/March	1.77	0.24	0.15	2.01	0.10	2.57	20.63	27.46	3.92	0.95
Achalla Layout	Nov/Dec	6.95	0.28	0.05	2.82	0.11	1.71	22.27	34.18	4.88	1.01
	Jan/Feb	4.71	0.28	0.10	2.87	0.11	1.90	22.09	32.05	4.58	1.09

	Feb/March	5.90	0.28	0.15	2.95	0.10	1.59	21.18	32.14	4.59	1.14
	Nov/Dec	2.31	0.32	0.05	2.34	0.10	0.95	29.69	35.76	5.11	0.81
Uwani	Jan/Feb	2.30	0.32	0.10	2.42	0.11	0.85	29.57	35.66	5.10	0.90
	Feb/March	2.41	0.32	0.15	2.30	0.11	0.99	30.28	36.55	5.22	0.98
	Nov/Dec	3.38	0.36	0.05	2.64	0.07	0.78	25.45	32.73	4.68	0.81
Maryland	Jan/Feb	3.44	0.36	0.10	2.12	0.05	0.64	23.12	29.83	4.26	0.79
	Feb/March	3.53	0.36	0.15	1.75	0.06	0.61	23.60	30.04	4.29	0.83
	Nov/Dec	2.81	0.04	0.10	1.32	0.10	0.96	15.36	20.67	2.95	0.58
Abakpa	Jan/Feb	2.90	0.04	0.15	1.28	0.10	0.97	16.13	21.55	3.08	0.62
	Feb/March	2.75	0.02	0.03	0.65	0.05	0.38	7.97	11.83	1.69	0.26
	Nov/Dec	3.17	0.08	0.10	1.76	0.07	1.10	26.72	32.99	4.71	0.71
Ugwuogo Nike	Jan/Feb	2.55	0.08	0.15	1.72	0.08	1.23	25.22	31.03	4.43	0.75
	Feb/March	2.10	0.04	0.03	0.94	0.03	0.46	13.52	17.10	2.44	0.29

Table 3. Potential ecological risk factors and potential ecological risk indexes (RI) of heavy metals in dust samples

Location	Period	Er							RI	Pollution degree
		Copper	Chromium	Nickel	Manganese	Zinc	Lead	Cadmium		
	Nov/Dec	7.85	0.24	5.05	3.19	0.01	12.79	559.80	588.92	considerable ecological risk
Emene	Jan/Feb	7.91	0.24	5.10	2.43	0.01	13.34	586.60	615.62	very high ecological risk
	Feb/March	7.65	0.24	5.15	2.82	0.01	12.48	622.55	650.91	very high ecological risk
	Nov/Dec	11.12	0.32	5.05	1.45	0.09	9.74	429.55	457.31	considerable ecological risk
Ogbete Layout	Jan/Feb	10.53	0.32	5.10	1.38	0.10	7.29	388.10	412.81	considerable ecological risk
	Feb/March	10.32	0.32	5.15	1.48	0.09	8.10	413.85	439.29	considerable ecological risk
	Nov/Dec	19.15	0.40	5.05	5.79	0.07	14.78	413.65	458.89	considerable ecological risk
Iva Valley	Jan/Feb	14.57	0.40	5.10	3.93	0.07	15.30	415.60	454.95	considerable ecological risk
	Feb/March	16.94	0.40	5.15	4.92	0.08	15.45	404.15	447.08	considerable ecological risk
	Nov/Dec	8.70	0.48	5.05	1.93	0.08	11.36	636.20	663.78	very high ecological risk
Akwuke	Jan/Feb	8.23	0.48	5.10	1.92	0.10	12.49	611.55	639.87	very high ecological risk
	Feb/March	8.86	0.48	5.15	2.01	0.10	12.84	618.90	648.33	very high ecological risk
	Nov/Dec	34.73	0.56	5.05	2.82	0.11	8.56	668.15	719.97	very high ecological risk
Achalla Layout	Jan/Feb	23.53	0.56	5.10	2.87	0.11	9.49	662.55	704.21	very high ecological risk
	Feb/March	29.52	0.56	5.15	2.95	0.10	7.95	635.30	681.52	very high ecological risk
	Nov/Dec	11.57	0.64	5.05	2.34	0.10	4.73	890.70	915.12	very high ecological risk
Uwani	Jan/Feb	11.50	0.64	5.10	2.42	0.11	4.23	887.10	911.09	very high ecological risk
	Feb/March	12.05	0.64	5.15	2.30	0.11	4.94	908.30	933.48	very high ecological risk
	Nov/Dec	16.89	0.72	5.05	2.64	0.07	3.90	763.50	792.76	very high ecological risk
Maryland	Jan/Feb	17.22	0.72	5.10	2.12	0.05	3.19	693.60	721.99	very high ecological risk
	Feb/March	17.66	0.72	5.15	1.75	0.06	3.01	708.05	736.38	very high ecological risk
	Nov/Dec	14.03	0.08	5.10	1.32	0.10	4.79	460.65	486.05	considerable ecological risk
Abakpa	Jan/Feb	14.50	0.08	5.15	1.28	0.10	4.81	483.80	509.70	considerable ecological risk

	Feb/March	13.76	0.04	5.03	0.65	0.05	1.88	238.90	260.29	moderate ecological risk
	Nov/Dec	15.83	0.16	5.10	1.76	0.07	5.48	801.70	830.09	very high ecological risk
Ugwuogo Nike	Jan/Feb	12.72	0.16	5.15	1.72	0.08	6.15	756.55	782.54	very high ecological risk
	Feb/March	10.48	0.08	5.03	0.94	0.03	2.30	405.63	424.47	considerable ecological risk

The figure 2 is the bar chart showing the mean values of PLI during the study period across the locations. PLI which is the level of pollution (Tomlinson et al. 1980; Mortuza and Al-Misned 2017). Achalla Layout is shown to have the highest PLI,followed by Iva Valley then Uwani.

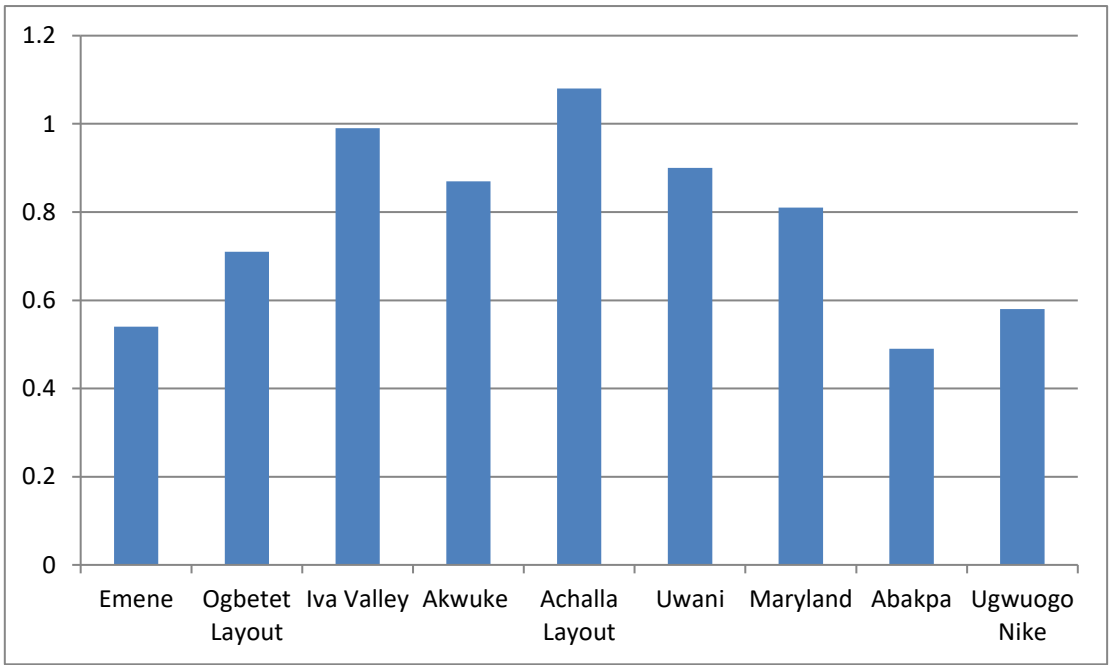

Fig. 2. The bar chart showing the mean values of PLI during the study period across the locations

The the figure 3 is also a bar chart showing the mean values of RI during the study period across the locations. R1 which categorizes the ecological risk shows Uwani as the location with the highest ecological risk, followed by Maryland then Achalla Layout.

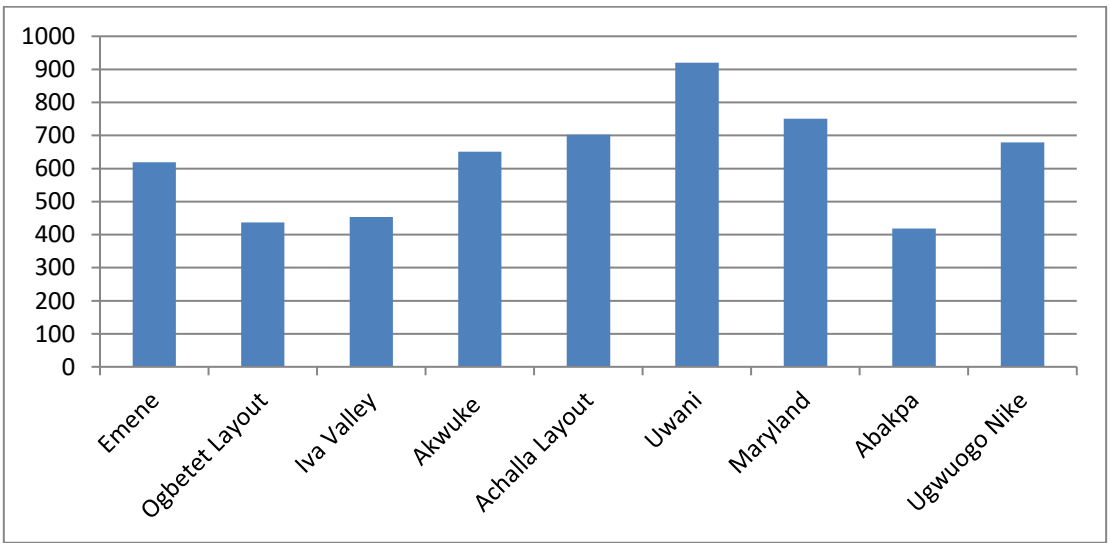

Fig.3 .The bar chart showing the mean values of RI during the study period across the locations

From the 27 samples collected from the 9 locations classifying the pollution degree as below:-

Low ecological risk	-	0 sample
Moderate ecological risk	-	1 sample
Considerable ecological risk	-	10 samples
Very high ecological risk	-	16 samples

The figure 4 is a pie chart presentation of the classification of pollution degree in terms of percentages.

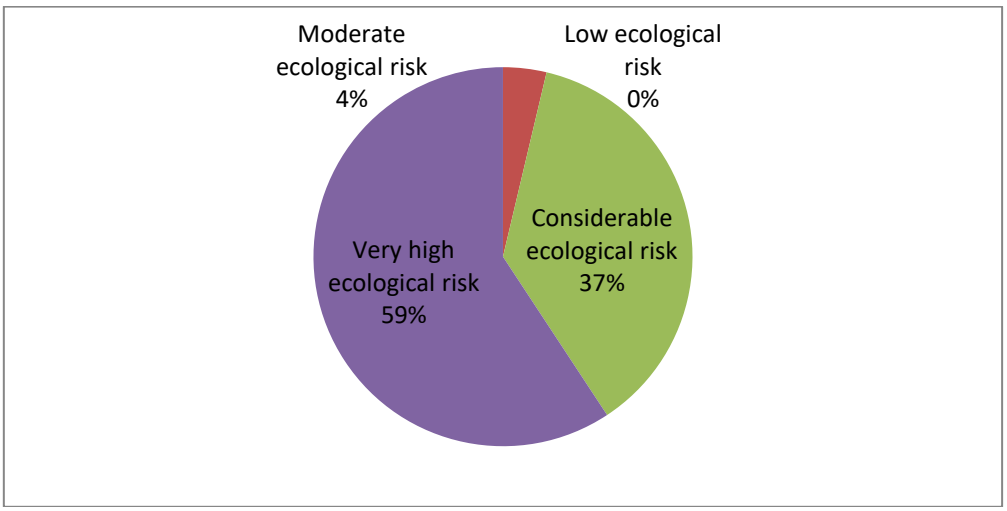

Fig.4. Pie chart showing the potential ecological risk in percentage of the areas during the study period

Therefore, the dry deposition in Enugu urban during the study period presents a high potential ecological risk.

Conclusion

The values of the concentrations of the metals identified in this study shows that the atmosphere is progressively polluted with heavy metals. Drawing inference from the reviews as mentioned in this study, this atmospheric enrichment of metals is predominantly from anthropogenic sources. The results of the potential ecological risk index obtained shows that the metals concentrations in the Enugu Urban during the study period presents a high potential ecological risk.

Therefore, periodic monitoring and pollution abatement measures must be strictly adhered to by the government and its agencies. All the major stakeholders must promote massive awareness programme on environmental management and pollution control.

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Conflict of interest

The author declares there is no conflict of interest.

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