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Contamination and Health Risk Assessment of Suspended Particulate Matter (SPM) in Uyo, Niger Delta, Nigeria

E. A. Moses[1*] and U. B. Orok[1]

[1]Department of Chemistry, Faculty of Science, University of Uyo, Uyo, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author EAM conceptualize the study, carried out data analysis and discussed sections of the manuscript. Author UBO wrote the study protocol, carried out laboratory analysis and literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This study was aimed to assess the level of particulate matter contamination and its associated health risks in Uyo, Niger Delta, Nigeria.
Study Design: The study involved sampling and analysis of suspended particulate matter and assessing the health risk associated with trace metal and anion content using mathematical models.
Place and Duration of Study: This study was conducted at the Uyo metropolis, Nigeria between October, 2012 and May, 2013.
Methodology: Particulate matter samples were collected from five selected locations in Uyo Metropolis and analysed for trace metals using Atomic Absorption Spectrophotometric technique and anions (SO_4^{2-}, NO_3^- and PO_4^{3-}) using UV-Visible Spectrometric technique. Metal Contamination indices were estimated using mathematical models for enrichment factor (EF) and contamination factor (CF). Target Hazard Quotient (THQ) was used to measure the health risk associated with the trace metals.
Results: The order of trace metal concentrations for the five locations were measured as

**Corresponding author: Email: enomoses27@yahoo.com;*

Fe>Cu>Zn>Ni>Cr>Al>Pb>Co>Ti. Pearson correlation analysis indicated strong positive correlations for Fe/Co (r=0.89), Pb/Ni (0.88), Co/Cr (r=0.72), Al/Co (0.70) and Cu/Ti (r=0.60). Mean enrichment factor was highest for Cu (8.2) and lowest for Co (0.1) with moderate and minimal contamination indices of 0.93 and 0.02 respectively for all locations studied. Mean sulphate concentrations ranged between 911.5±1.49 and 1343.5±1.56 mg/kg, phosphates 15.9±2.64 and 98.8±1.52 mg/kg, while nitrate concentration was between 46.7±7.35 and 1371±19.6 mg/kg. Calculated THQ values were highest for Fe (2.30-2.43) and Cu (0.24-0.44).
Conclusion: Findings in the study indicated no significant contamination of particulate matter and no measurable health risk associated with the particulate matter at the time of study. However, there is need for continuous monitoring of these indices due to increased urbanisation and anthropogenic activities in the area.

Keywords: Particulate matter; health risk assessment; target hazard quotient; enrichment factor.

1. INTRODUCTION

Airborne particulate represents a complex chemical composition and originates from the interaction of solid, liquid and gaseous materials produced from different sources and activities [1]. It is a complex mixture of particulates and contaminants derived from an extensive range of urban and industrial sources and processes [2]. Particulate matter have been implicated to have the potential of carrying a high loading of contaminant species such as trace metals, anions and organic pollutants [3]. Particulate matter is therefore a useful indicator of the level and distribution of trace metal contamination in the environment.

Road dust pollution which gives rise to airborne trace metal is derived through industrial, vehicular and urban activities. Increasingly, airborne particles emitted from geologic media pose threat to human health and environment [4]. The average adult breathes about 10,000 litres to 20,000 litres of air daily. Children breathe 50 percent more air per kilogram body weight than adults [5]. Major environmental effects include damage to respiratory organs, visibility reduction, chemical deterioration of materials, acid rain and vegetation problems while health respiratory diseases like acidosis, pneumonia, bronchitis, asthma, respiratory tuberculosis are associated with particulate matter inhalation.

The city of Uyo located in the Niger Delta region of Nigeria, is currently undergoing rapid urbanization and population growth owing to several developmental projects. Accompanying the rapid growth are increased vehicular activities, waste generation and improper disposal habits. These activities generate particulates matter into the atmosphere with possible threat to health.

This study aimed to assess the level of particulate matter contamination and its associated health risks in Uyo, Nigeria.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was conducted in five locations characterised by high traffic and construction activities in Uyo, the capital of Akwa Ibom State, Nigeria. Uyo lies at latitude 5º3'60N and longitude 7º56'60E. The area is climatically characterized by two seasons; the long wet season (March/April – November) and the short dry season (November – March) [6]. The area has recently experienced rapid development in terms of road and housing construction and economic development which has led to increased population and huge vehicular activities. Locations of the five sampling points (University of Uyo/Ikpa road, Uruan Street, road construction site at Shelter Afrique estate, Itu road, and UruaUdofia.) used in this study are shown in Fig. 1.

2.2 Sampling Collection

Dusts in the form of suspended particulate matter were collected from eight locations spread across each of the sites and then pooled together to give a representative sample of each location. A total of 40 sample points were sampled. Dust samples at the sampling sites were collected by direct gravitational deposition on to a Whatman No.41 filter paper. The filter papers for dust collection were pre-weighed and placed in plastic containers along the road and construction sites, raised to a height of about 3.0 m [7]. The collected dust samples were then carefully brushed off into a plastic container

using a hand brush and the containers covered prior to analysis [8]. Sampling was conducted over a period of six months from October, 2012 to March, 2013.

2.3 Sample Preparation

The collected samples were dried in an oven prior to digestion at 100 - 110ºC. Digestion of the dust samples was done by the method described by [8]. About 1 g of each of the oven dried dust samples was weighed and acid-digested at a ratio 2:1. All reagents used for the preparation were analytical grade. 2M HNO_3, and 30% w/w H_2O_2 were heated at 90ºC. The digest was filtered and the filtrate made up to the mark in a 100 ml volumetric flask using distilled water. Blanks were similarly prepared but without samples.

2.4 Procedure

2.4.1 Determination of anions concentration

The digested samples were analysed for SO_4^{2-}, NO_3^- and PO_4^{3-} using standard methods [9] and the concentrations were read at 420 nm, 470nm and 652 nm for SO_4^{2-}, NO_3^- and PO_4^{3-} respectively using spectrophotometer (DR 621, HACH). The blanks were also read and the anions concentration determined using the relation;

$$C_{sample} = (A_{sample} \times C_{std} \times Df)/(A_{std} \times Wt_{sample}) \quad (1)$$

where C_{sample} and C^{std} are the concentrations of the sample and standard solutions; A_{sample} and A_{std} are the absrobances of the sample and standard solutions; Df is the dilution factor and Wt_{sample} is the weight of the sample.

2.4.2 Determination of trace metals concentration

Standard solutions for the elements were prepared for calibration of the instrument. Solutions of Fe, Cu, Ni, Cr, Co, Zn, Pb, Al, Ti and Cd at concentrations ranging from 1-2mg/ml by serial dilutions of single-element stock solutions were made. The digested samples were then analysed for the trace metals using Unicam 939/959 Atomic Absorption Spectrophotometer as described by [9]. The concentrations of the anions and trace metals obtained in this study were compared to reference standard values stipulated by United States Environmental Protection Agency (USEPA) [10].

2.5 Contamination Assessment

2.5.1 Enrichment factor

This is the minimum factor by which the percentage of metals in the particulate is greater than average occurrence in earth crust. Enrichment factor (EF) has been employed for the assessment of contamination in various environmental media by several researchers [11,12]. Its version adapted to assess the contamination of this environmental media is as follows:

$$EF_x = [X_s/Es_{ref}]/[X_c/Ec_{ref}] \quad (2)$$

Where;

EF_x is the enrichment factor of the trace metal, Xs is the concentration of element in sample, Es_{ref} is concentration of reference element, Xc is the concentration of element in crust, Ec_{ref} is the concentration of reference element in crust. Contamination categories recognized on the basis of the enrichment factor: EF < 2 states deficiency to minimal enrichment; EF = 2-5 moderate enrichment; EF = 5-20 severe enrichment; EF = 20-40 very high enrichment; and EF > 40 extremely high enrichment [12].

2.5.2 Contamination factor

This factor is used to assess the extent of contamination of trace metals in the particulate sample. It is a single element index determined by the relation;

$$C^i_f = C^i_s/C^i_n \quad (3)$$

Where;

C^i_f is the contamination factor of the element; C^i_s is the concentration of element in the sample, and C^i_n is the background concentration. The sum of the contamination factors of all the elements in a sample gives the degree of contamination;

$$C_{deg} = \Sigma C^i_f \quad (4)$$

The CF is classified into four groups [13,14] where the contamination factor CF < 1 means low contamination; 1 ≤ CF < 3 means moderate contamination; 3 ≤ CF ≤ 6 indicates considerable contamination and CF > 6 indicates very high contamination.

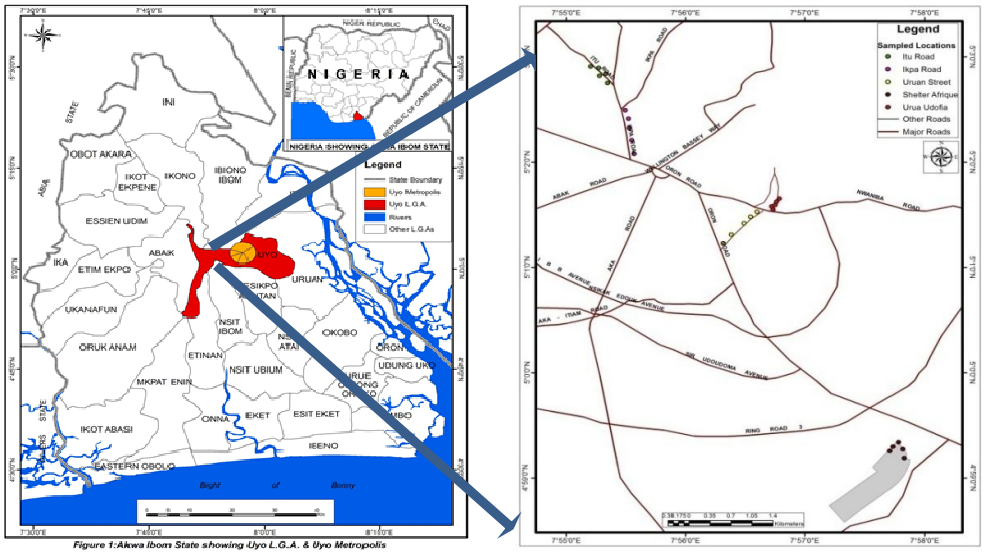

Fig. 1. Map of Uyo Metropolis, Akwa Ibom State, Nigeria, showing the sampling locations

2.6 Health Risk Assessment

2.6.1 Target hazard quotient (THQ)

This is the ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the THQ is calculated to be≤1, then no adverse health effects are expected as a result of exposure. If the THQ > 1, then adverse health effects are possible. The Target hazard Quotient was utilized to assess the health risk associated with the particulates. Target Hazard Quotient (THQ*)* was estimated using the equation;

$$THQ = 10^{-3} [E_F E_D D_{IR} C] / [R_{FD} W_{AB} T_A] \text{ [15]} \quad (5)$$

Where;

E_F is exposure frequency (days.yr^{-1}) = 365 days/yr [16]
E_D is Total exposure duration (years) = 70 years [16]
D_{IR} is the dust ingestion rate (mgday^{-1}) = 50 mg/day [16]
C is the metal concentration in dust (mg/kg)
R_{FD} is the Reference Dose (mgkg-1day^{-1}) = (Cu..4E-2, Zn..3E-1,Cd..1E-3 [17] Pb..4E-3, Ni..2E-2, Cr..1.5, Co...6E-2,..Al..5E-2, Fe..7E-3 [17]
W_{AB} is the Average Body Weight (kg) = 60 kg [16]
T_A is the average exposure time (days) = (exposure frequency x no of exposure yrs.....25550days) [16].

2.7 Statistical Analysis

Pearson's correlation coefficient was used to determine the relationship between the trace metals in terms of sources.

3. RESULTS AND DISCUSSION

3.1 Trace Metal Concentration Analysis

The results of trace metal concentrations in the particulate samples from the study area are presented in Table 1. The major trace metal component of the dust as can be seen from the table are; Fe, Cu and Zn with range of values (18.48±10.21-20.45±9.44) mg/kg, (11.65±4.31-21.00±6.21) mg/kg and (15.05±4.35–18.20±7.83) mg/kg respectively. The concentrations of Ni, Cr and Al with range of values were (1.35±0.52–4.05±1.82) mg/kg, (0.80±0.21–1.35±0.83) mg/kg and (0.50±0.13–1.05±2.41) mg/kg respectively.

Much lower concentrations of Co, Pb and Cd with ranges (0.05±0.02 – 0.25±0.02) mg/kg, (0.55±0.35 – 0.77±0.91) mg/kg and (0.25±0.12 – 1.00±0.65) mg/kg respectively, were detected. From the analysis, Fe, Cu and Zn had comparative higher concentrations with respect to the other trace elements. The concentrations of Fe in the samples may be attributed to metal

construction works, iron bending and welding works [3], which are common practice at the study locations in Uyo metropolis. Virtually, in every auto repair shops, there are various sections that deal with either filing of metals or welding works which could contribute to the concentration of these elements in the dust sample. It is also believed that exhaust emissions from gasoline and diesel fuelled vehicles contain variable quantities of these elements [15] which may likely pollute the air.

Generally, Zinc in air is relatively low and fairly constant [18]. Air exposure to zinc in the study area is probably due to some welding activities, paints, construction sites and automobile wears and repairs. It has been reported that tire-thread materials releases zinc content into the environment when lost to road surfaces from automobile tires during transportation [19]. This explains why Uniuyo sample area has the highest zinc content since it is the busiest in terms of vehicular activities. However, the mean concentration of zinc in the study area (15.04 $mgkg^{-1}$) was lower when compared with 20.59 $mgkg^{-1}$ as reported by [7] in Okigwe.

The comparative high content of copper in the Uniuyo study area can be attributed to the waste dump site around Uniuyo and environs, coupled with the combustion of fossils in the area. Fine particles of this metal have high surface area and can remain suspended for prolonged period of time, making it more hazardous [20]. High levels of copper exposure and uptake can be considerable under conditions of tight copper binding to dust particulates. Hence, long term exposure leads to nose, eye and mouth irritations and also causes headache, dizziness, nausea and diarrhoea [21]. Copper was least in Shelter Afrique location and it is the least busy in terms of vehicular activities but highest in Uniuyo and Itu road with higher vehicular activities. Results for copper concentrations are close to those of other researchers [22].

Result of inter elemental correlation analysis using Pearson's correlation is represented in Table 2. Positive correlation results were indicated for some elemental pairs such as; Fe/Co (r=0.89), Ni/Pb (r=0.88), Fe/Al (r=0.78), Co/Cr (r= 0.72), and Co/Al (r=0.70). Co/Ni (r=0.52), Al/Cr (r=0.46), Fe/Cr (r=0.45), Al/Ni (r=0.43), Pb/Co (r=0.43), Ni/Zn (r=0.39) and Cr/Ni (0.38) have moderate relationship. Strong anti-correlation was observed for Cu/Cr (r=-0.98), and Cd/Zn (r=-0.92). Correlation analysis indicated stronger positive correlation for Fe/Co, Ni/Pb, Fe/Al, Co/Cr and Co/Al. The possible common anthropogenic sources of the metals include: construction activities, vehicular emissions, automobile part wears, refuse disposal, tobacco smoking, metal works etc. The negative correlation observed in this study shows that independent sources are contributing to these elements presence in the dust particulate [23].

3.2 Anions Concentration Analysis

Levels of sulphate, nitrate and phosphate composition in the dust particulate were as presented in Table 3. The concentration ranges for sulphate was (911.47±1.49 - 3055.9±3.39) mg/kg, (46.701±7.35 - 1371.45±19.60) mg/kg for nitrate and (15.87±2.64 - 98.77±1.52) mg/kg for phosphate. Highest values of sulphate (3055.9±3.39) mg/kg was obtained for sample collected at Itu road, nitrate (1371.45±19.60) mg/kg from Uniuyo sample and phosphate (98.77±1.52) mg/kg for Shelter Afrique sample. The high concentration of SO_4^{2-} compared to NO_3^- and PO_4^{3-} in the particulates can be attributed to automobile activities resulting from the combustion of petroleum derived fuels and effluents from generating sets that contain sulphur. Sample from Uniuyo area recorded higher concentrations of NO_3^- and PO_4^{3-} compared to the other locations. Measured levels of NO_3^- and PO_4^{3-} may be due to agricultural activities involving the use of fertilizers as source of nutrient enrichment. The soils eventually become airborne and contribute to the particulate matter concentrations of the anions.

3.3 Enrichment Factor

The levels of enrichment of the trace metals in the dust particulate samples were as represented in Fig. 2. The enrichment factors of Zn, Cu, Ni, Cr, Co, Pb and Cd were in the ranges; 1.3-2.3, 5.2-9.4, 0.5-1.6, 0.1-0.2, 0.1-0.2, 0.2-0.3, and 0.2-0.7 respectively. Higher levels of enrichment for Cu were obtained for dust particulate samples from Itu road (9.4) and Uniuyo (9.3) when compared to other locations while Uruan Street had higher enrichment for Nickel (1.6). Highest enrichment for Zn was recorded for sample from Uniuyo. The mean EF calculated indicated that zinc (EF-2.0) has moderate level of enrichment while only copper (EF- 8.2) showed severe enrichment suggesting that the source is probably anthropogenic [23]. Ni, Cr, Co, Pb and Cd had EF values ranging from deficient to minimal enrichment indicating

that their concentrations can be ascribed to natural processes [23].

3.4 Contamination Factor

Results of computed contamination factors of the trace metals are as shown in Fig. 3. The contamination factors were in the ranges; 0.148-0.260, 0.588- 1.061, 0.057-0.174, 0.016-0.026, 0.004-0.021, 0.027-0.034, 0.034-0.049, 0.021-0.08, 0.063-0.131 and 3.93-4.351 for Zn, Cu, Ni, Cr, Co, Pb, Cd, Al and Fe respectively. This showed that the trace metals; Zn, Cu, Ni and Al are dominant in the dust sample. All the sample location showed considerable contamination for Fe and moderate contamination for Cu while other trace metals had low contamination levels at all the locations. The considerable contamination for Fe and Cu are probably from sources such as auto repair activities and metal works (welding and panel beating of cars), in the study area as earlier stated. Degree of contamination computed for each samples location gave the following results; Itu road-5.848, Uniuyo-5.521, Uruan Street-5.869, Urua Udofia-5.576, and Shelter Afrique-5.528. The calculated degree of contamination (C_{deg}) of the location with trace metals indicated that Uruan Street is the most contaminated location while Uniuyo is the least contaminated location. This may be due to the Uruan Street location being characterized with metal workshops, small and medium scale enterprises, vehicular activities and most especially the presence of a Chinese company, JIUHUA Nigeria Company Limited that specializes in fabrication of metal doors, frames and windows amongst other metal products. The immediate physical effect of this particulate pollution in the area has been the effect of rusting of roofs of buildings in the area. Overall, these results complement the estimated concentrations obtained by laboratory analysis.

3.5 Health Risk Assessment

The calculated target hazard quotients for the trace element in the particulate samples were as given in Table 4. Values ranged between 0.03-0.051, 0.243-0.438, 0.056-0.169, 0.001-0.004, 0.115-0.160, 0.208-0.833, 0.008-0.018, and 2.300-2.434 for Zn, Cu, Ni, Co, Pb, Cd, Al and Fe respectively. The Health risk assessment of the trace metals using the Target Hazard Quotient (THQ) showed that apart from Fe, other trace metals were below the exposure limit (THQ < 1). This indicated that the exposed population is safe at the level of contamination of the other trace metals, hence, no health implication of the dust particulate on the inhabitants of the area.

Generally, the results of trace metal concentrations in this study were low compared to those obtained from other cities as can be seen in Table 5. This may be attributed to the low industrialization in Uyo compared to these other cities. Similar studies in Maiduguri [24], showed that Fe, Cu, Zn, and Pb were the major trace metal components of atmospheric dust. However, the concentrations of these trace metals were higher compared to those of this study. This can be attributed to the weather conditions of Maiduguri in terms of high temperature and industrialization compared to Uyo.

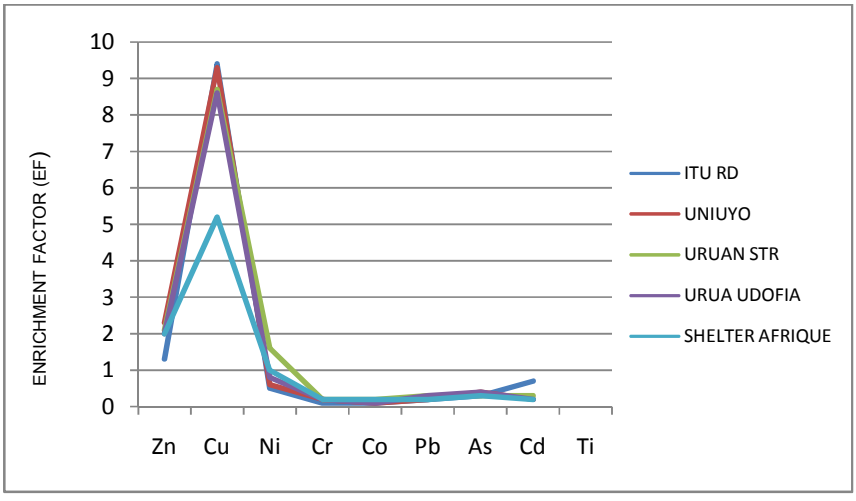

Fig. 2. Enrichment factors of the trace elements

Table 1. Trace metal concentration determined in dust collected from Uyo Metropolis

Location	Heavy metal concentrations (mg/kg)*									
	Zn	Cu	Ni	Cr	Co	Pb	Cd	Ti	Al	Fe
ITU RD.	10.35±8.32	21.00±6.21	1.35±0.52	0.80±0.21	0.15±0.01	0.55±0.35	1.00±0.65	ND	0.90±0.82	20.17±8.75
UNIUYO	18.20±7.83	20.80±7.02	.80±0.34	0.90±0.19	0.05±0.02	0.55±0.42	0.25±0.12	ND	0.65±0.41	18.48±10.21
URUAN STREET	16.15±8.78	19.30±4.70	4.05±1.82	1.00±0.85	0.20±0.01	0.77±0.91	0.34±0.24	ND	1.00±1.32	19.88±7.43
URUA UDOFIA	15.45±6.95	19.05±3.25	2.10±0.44	1.00±0.72	0.15±0.01	0.68±0.14	0.30±0.43	ND	0.50±0.13	19.32±8.67
SHELTER AFRIQUE	15.05±4.35	11.65±4.31	2.55±0.82	1.35±0.83	0.25±0.02	0.60±0.52	0.26±0.37	ND	1.05±2.41	20.45±9.44

*ND = not detected, *each value is mean for eight samples (mean ± SD)*

Table 2. Pearson correlation coefficients for the trace metals determined from the samples

Trace elements	Zn	Cu	Ni	Cr	Co	Pb	Cd	Ti	Al	Fe
Zn	1									
Cu	-0.77	1								
Ni	0.396	-0.244	1							
Cr	0.261	-0.977**	0.377	1						
Co	-0.303	-0.760	0.517	0.723	1					
Pb	0.273	-0.027	0.876	0.172	0.428	1				
Cd	-0.917*	0.411	-0.471	-0.585	-0.037	-0.373	1			
Ti	-0.242	0.602	-0.701	-0.704	-0.739	-0.772	0.555	1		
Al	-0.308	-0.495	0.455	0.416	0.700	0.106	0.206	-0.174	1	
Fe	-0.666	-0.570	0.234	0.451	0.898*	0.148	0.392	-0.394	0.775	1

**Correlation significant at 0.05 level (2 tail), **correlation significant at 0.01 level (2 tail)*

Table 3. Anions concentration determined in dust collected from Uyo metropolis

S/N	Location	Anions concentrations (mg/kg)		
		Sulphate (SO_4^{2-})	Nitrate (NO_3^-)	Phosphate (PO_4^{3-})
1	ITU	3055.1±3.93	955.4±12.74	59.1±1.52
2	UNIUYO/ IKPA RD	1343.5 ±1.56	1371.5±19.6	74.9±3.06
3	URUAN STREET	2555.2±1.49	505.3±19.46	15.9±2.64
4	URUA UDOFIA	911.5±1.49	46.70±7.35	37.1±2.65
5	SHELTER AFRIQUE	1142.1±5.15	713.4±12.74	98.8±1.52

Table 4. Calculated THQ for the trace elements

S/N	Location	Target hazard quotient								
		Zn	Cu	Ni	Cr	Co	Pb	Cd	Al	Fe
1	Itu Rd.	0.030	0.438	0.056	<0.001	0.001	0.115	0.833	0.015	2.401
2	Uniuyo	0.051	0.433	0.075	<0.001	<0.001	0.115	0.208	0.011	2.401
3	Uruan Street	0.044	0.402	0.169	<0.001	0.003	0.160	0.283	0.017	2.367
4	Urua Udofia	0.043	0.397	0.088	<0.001	0.002	0.142	0.250	0.008	2.300
5	Shelter Afrique	0.042	0.243	0.106	<0.001	0.004	0.125	0.217	0.018	2.434

Table 5. Mean concentrations of some heavy metals (mg/kg) in dust compared with other studies worldwide

Study locations	Cu	Cd	Co	Zn	Pb	Fe	References
Uyo	18.36	0.45	0.16	15.04	0.63	19.66	This study
Mubi	11.63-52.35	0.52-1.33	ND	102.22-105.80	47.50	5331-24100	Shinggu et al. (2007) [22]
Yola	28.97-196.00	0.42-1.57	ND	255.00-1006.00	20.37	6461-40500	Shinggu et al.(2010) [3]
Auckland	27.00	0.40	6.41	180.00	1650.00	20900	Jaradat & Momani (1999) [25]
Ecuador	ND	0.36	ND	509.00	293.00	ND	Jaradat & Momani (1999) [25]
Birmingham	ND	0.70	180.00	205.00	ND	ND	Jaradat & Momani (1999) [25]
Gwagwalada	97.00	3.4	-	79.00	210.00	120.00	Mashi et al. (2005) [26]
Okigwe	94.16	8.82	-	20.59	4.9	8678.43	Chiemeka (2010) [7]

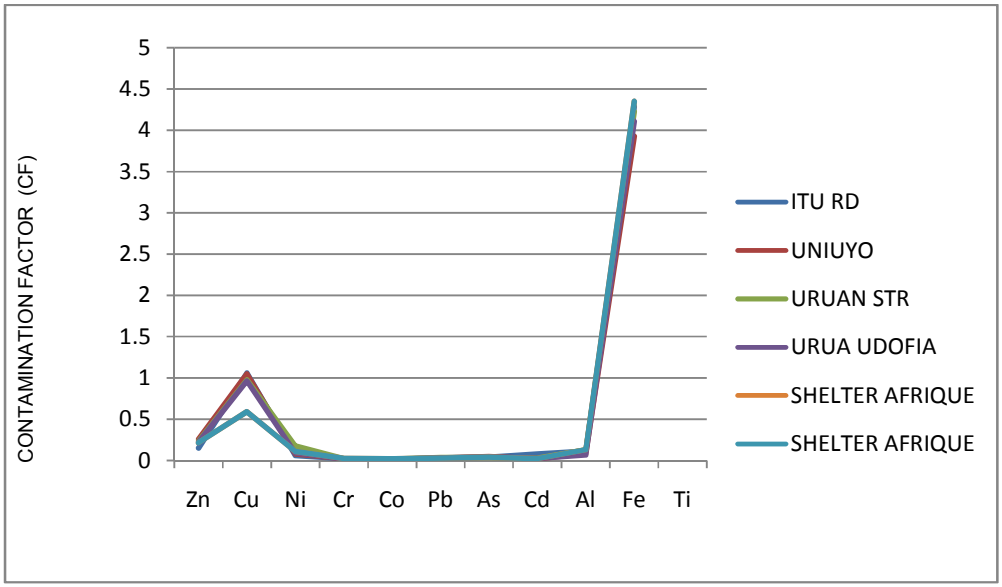

Fig. 3. Contamination factors of the trace elements

4. CONCLUSION

It has been established in Nigeria that both human beings and animals are unnecessarily over-exposed to numerous environmental hazards, often as a result of gross inefficiency and negligence. These poor environmental conditions have resulted in increasingly deteriorating health condition as well as drastic reduction in life expectancy, contrary to what obtains in the developed world. Suspended particulate matter (SPM) which represents a broad classification of chemical and physical substances is normally studied to estimate the level of atmospheric pollution. Dust particulate originates from the interaction of solid, liquid and gaseous materials produced from different sources [23]. The compositions of chemical matrix of dusts are indicators of environmental pollution.

Suspended particulate matter prevalent in Uyo the Akwa Ibom state capital may be due to varying inputs from stationary or mobile sources such as vehicular emissions, generating sets, waste incineration, road construction activities, metal works and welding activities, as well as re-suspension of the surrounding contaminated soils. Population and urbanization has also been a major factor that is responsible for environmental pollution in Uyo, the state capital.

Measurement of some elemental concentration in the suspended particulate matter provides means of evaluating the quality and state of air in the study area. The elements determined include: Zn, Cu, Ni, Cr, Co, Pb, Cd, Ti, Al and Fe. Sulphate (SO_4^{2-}), Nitrate (NO_3) and Phosphate (PO_4^{3-}) were also determined. The high level of Fe was expected since the element is mostly associated with natural background.

Pearson correlation suggests that these elements have common anthropogenic sources. Possible common anthropogenic sources include; construction activities, vehicular emissions, automobile part wears, refuse disposal, tobacco smoking, metal works etc.

The presence of SO_4^{2-} and NO_3^- in the sample is probably as a result of atmospheric processes of SO_2 and NO_2 and these ions contribute to acid deposition. PO_4^{3-} was present as a result of fertilizer application during agricultural activities. Two contamination indices; Enrichment Factor (EF) and Contamination Factor (CF) were used to assess the level of contamination of the study area. Target Hazard Quotient (THQ) was used to assess the level of health risk and the results showed that the exposed population is safe as at the time of this study. Nevertheless, there is need for continuous monitoring of these indices due to increased urbanisation and anthropogenic activities in the area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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