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Potential Toxic Elements and Human Health Risk Assessment in Air at Some Communities in Rivers State Nigeria

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Abstract
The concentrations of Potential Toxic Elements (Zn, Cd, Ni, Cr, As, V, Cu, Pb, Ba, and Hg) in air at Omoku, Obrikom and Elele-Alimini communities in Rivers State were determined using Shimadzu AA-6650 Atomic Absorption Spectrophotometer following ASTM D1971/4691 method after collection on glass fibre filters. Potential health risk assessment of children and adults exposed to the metals were estimated using United States Environmental Protection Agency (USEPA) standards; assessment of non-carcinogenic risks was done by estimating the hazard quotient (HQ) while Carcinogenic risk was evaluated by target cancer risk (TCR). Non-carcinogenic risks assessment of the elements (Heavy metals and metalloid) evaluated in the three main pathways of ingestion, inhalation and dermal contact respectively showed that Total Hazard Quotient (THQ) and Total Hazard Index (THI) values were all < 1 and therefore there are no non-carcinogenic risks of the elements in both adults and children at the study area. Cancer risk assessment for carcinogenic elements (As, Cr, Cd and Pb) was all below acceptable minimum range of 1.0 x 10^{-6} to 1.0 x 10^{-4} which may adversely affect health conditions under prolonged exposure. The control station (station 8) generally showed significantly higher levels of the elements than the study stations. The study therefore recommended that impact assessment should be conducted regularly on residents of these communities to determine the level of impacts of the pollutants.

Keyword: *Toxic Elements, Air, Health Risks, Omoku, Obrikom*

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I. Introduction

Air pollution constitutes the largest health risk among all environmental risks and 92% of the world's population breathes substandard air (WHO, 2006). Six million five hundred thousand annual deaths around the world have been attributed to poor air quality and this has made air pollution the world's fourth-largest threat to human health, behind high blood pressure, dietary risks and smoking (WHO, 2006). Despite this statistics from WHO there is limited information on air quality and the human health risk associated with air pollutants in the study area.

Pollution results from interferences with the natural state of the environment that leads to imbalance in the naturally interacting forces (physical forces and chemical reaction). If the intrusions occur at the atmospheric component of the environment it becomes air pollution and results in deteriorating air quality.

Irrespective of air pollution sources and classification, their impact on man and the environment is a major issue of concern. These impacts are pronounced in their dispersion, travel distance, particle size, transformations and final effect. According to the WHO, air pollution constitutes the largest health risk among all environmental risks and 92% of the world's population breathes substandard air as they live in places where air pollution exceeds safe limits. WHO attributed annual deaths around the world resulting from poor air quality inside and outside as about 6.5 million, making air pollution the world's fourth-largest threat to human health, behind high blood pressure, dietary risks and smoking. It has also been showed that air pollutant with small particle size (decreased diameter), are able to infiltrate finer lung structures and cause severe health effects such as asthma (WHO, 2006), chronic obstructive pulmonary disease (COPD) or increased cardiovascular risks (Gauderman *et al.* 2007). Other air pollution effects include the development of upper airways diseases such as sinusitis, mild otitis, olfactory impairment, rhinitis and sinonasal cancer (Shusterman, 2011).

Since air pollution and deteriorating air quality are mostly attributed to human activities, most countries have strengthened laws to control air pollution and safe limits for air quality in the past decade to reduce its impact on man and the environment.

Studies have documented that air pollution in the Nigeria Delta arises from the burning of fossil fuels for transportation and industrial power generation, use of fuel wood and kerosene for domestic cooking and lighting, and gas flaring and that these are results of urbanization and industrialization (Gobo *et. al*. 2012, Ideriah *et. al*., 2020, Hicks, 1998, Fagbeja *et al*. 2008, Asubiojo, 2016).

.Kalagbor *et al.* (2019) investigated the presence and levels of heavy metals in soot along with a cancer risk assessment of heavy metals exposure in Port Harcourt, Nigeria and found significant correlation among the metals. The results of their study also showed that the carcinogenic health risks of the heavy metals were within the acceptable limits for cancer risks. However, the cancer health risks for Cd and Pb for children were found to be 3 times higher than those for adults.

USEPA, (2002) considered human health risk assessment as the characterization of the potential adverse health effects of humans as a result of exposures to environmental hazards. According to Lushenko (2010) potential health risk is a numerical value calculated using information from an identified and measured hazard and the possible route of exposure. Thus, a human health risk assessment involves hazard identification, dose-response assessment, exposure assessment, and risk characterization. Health risk assessment classifies elements as, carcinogenic or non-carcinogenic. Based on the classification, the procedure to be followed when potential risks are calculated is determined. For non-carcinogenic chemicals a threshold is assumed. The threshold is considered as a dose below which no adverse health effects will be observed and an essential part of the dose-response portion of a risk assessment includes the use of a reference dose (RfD). For carcinogens, they are assumed to have no effective threshold. This assumption implies that there is a risk of cancer developing with exposures at low doses and, therefore, there is no safe threshold for exposure to carcinogenic chemicals. Carcinogens are expressed by their Cancer Potency Factor (Lushenko, 2010).

The aim of this study is to quantify Potential Toxic Elements in air at Omoku, Obrikom and Elele-Alimini (control) communities in Rivers State and assess the human health risks associated with the elements.

II. Materials And Methods

The Study Area

Omoku and Obrikom Towns are located approximately on latitude 4° 51' 29.16" N longitude 6° 55' 15.24" E, and on latitude 4° 51' 29.16" N longitude 6° 55' 15.24" E, while Elele Alimini is located on latitude 4° 51' 29.16" N longitude 6° 55' 15.24" E. They are all situated in Rivers State, southern Nigeria in the core of the Niger Delta region which covers an area of about 21,110 square kilometers (NDDC, 2004).

The study area is basically a huge floodplain formed primarily by centuries of silt washed down by the Niger and Benue Rivers. It is crisscrossed by a web of creeks that link together the main rivers of Benin, Bonny, Brass, Forcados, Nun, and other rivulets and streams (all estuaries of the Great River Niger). It has a rich and diverse variety of ecological types with several mangrove and freshwater swamp forest that accommodates very high biodiversity, with many unique species of plants and animals.

The meteorological conditions of the study area display climatic characteristics that could be classified as semi-hot equatorial zone. The equatorial maritime air mass characterizes the climate with high humidity and heavy rainfalls (annual mean ranges between 72% -81% and 3,000mm-4,000mm). Specifically, these climatic characteristics range from the hot equatorial forest type in the southern lowlands to the humid tropical in the northern highlands. The wet season is relatively long, lasting between seven and eight months of the year, from the months of March to October (considered as rainy season). There is usually a short break around August, otherwise termed the "August break". The dry season begins in late November and extends to February or early March, a period of approximately three months although; the atmosphere sustains adequate moisture throughout the year. (Gobo & Abam, 1991).

The climatic characteristics are governed by the general circulatory patterns of two air masses: the dry dusty North-East Trade wind (Tropical continental air masses) from the Sahara Desert which come in the dry season (October - March), bringing in the harmattan from December – January and the moisture laden south-west wind (tropical maritime air masses) which bring rain during the wet season (April - October).

The meteorological analysis of the prevailing wind patterns in the study area revealed that the wind direction persists from the southwest for most of the year (Ojo, 1977).

Temperatures are generally high in the region and fairly constant throughout the year. Average monthly maximum and minimum temperatures vary from 28^{o}C to 33^{o}C and 21^{o}C to 23^{o}C, respectively, increasing northward and westward with the warmest months being February, March and early April. The coolest months are June through to September during the peak of the wet season.

Geographically and topographically the study area is such that air borne pollutants travel fast and the farthest, as high lands are practically absent. Furthermore, occurrences of land breeze, as well as Harmattan, facilitate emission transfer into the study area (NDDC, 2004).

Sampling Stations

Samples were collected at 8 stations identified as (1) Federal Colledge of Education Omoku Campus 1 Residential, (2) FCT Campus 1 main Gate, (3) Omoku Main Market, (4) FCT Campus 2 School of Business Studies, (5) NAOC OB/OB Gas Plant junction Obrikom, (6) Obrikom Civic Center, (7) Buhari Road Obrikom and (8) Elele-Alimini Market (Control).

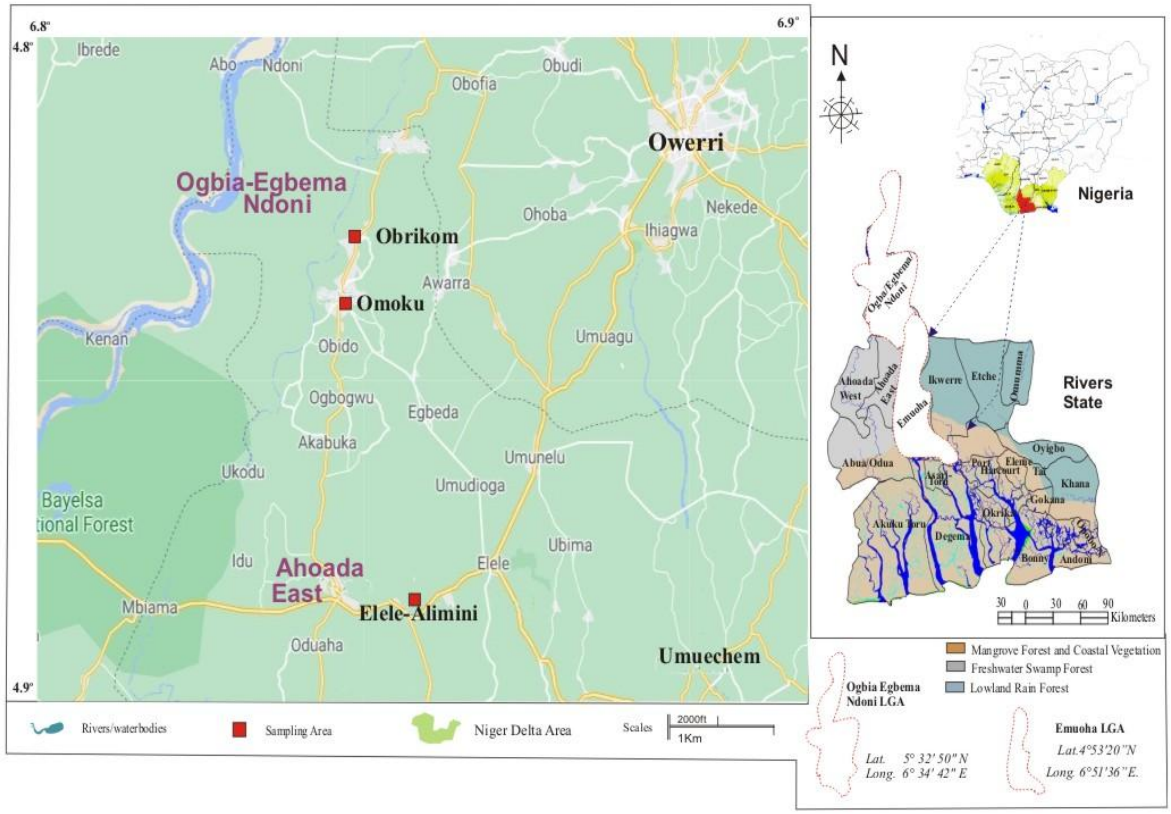

Fig. 1: Map of the Study Area showing the sampling locations

Analytical Methods

The method recommended by ASTM D1971/4691 was employed for the analysis of the elements (Cd, Ni, Cr, As, V, Cu, Pb, Hg and Fe). The levels of the elements in the ambient air were determined from the collected particulates. The glass fibre filters holding the fine particulates were digested as per standard procedure and thereafter analyzed with an Atomic Absorption Spectrophotometer (Shimadzu AA-6650).
Metal concentration was calculated as follows

$$C = (M_s - M_b) \times V_e \times \frac{F_a}{V} \times F_t \quad \text{.....(1)}$$

Where, C = concentration, µg metal/m^3.
M_s = metal concentration, µg/mL
M_b = blank concentration µg/mL
V_e = total volume of extraction in mL
F_a = total area of exposed filter in cm^2
V = Volume of air sampled in m^3
F_t = Area of filter taken for digestion in cm^2

Human Health Risk Exposure Assessment

The daily environmental exposures to metals in air were assessed for carcinogenic and non-carcinogenic elements. Three main pathways of exposure were assessed which are: ingestion of dust particle through the mouth, inhalation through the nose and mouth, and dermal contact through the skin (Ferreira-Baptista and De Miguel, 2005; Zheng *et al.* 2010b). This study estimates the potential health risk assessment of children and adults exposed to heavy metals and other gaseous pollutant using USEPA standards (The United States Environmental Protection Agency (USEPA), 2002).
The estimated daily dose exposure was calculated using equations (2), (3) and (4).

$$DD_{ing} = \frac{C \times I_{ng} R \times F \times EF \times ED \times CF}{BW \times AT} \quad \text{..... ....(2)}$$

$$DD_{inh} = \frac{C \times I_{nh} R \times F \times EF \times ED}{PEF \times BW \times AT} \quad \text{..... ....(3)}$$

$$DD_{der} = \frac{C \times CF \times SA \times SAF \times DAF \times F \times EF \times ED}{(BW \times AT)} \quad \text{..... ....(4)}$$

Where DD_{ing} DD_{inh}, DD_{der} in mg/kg/day are the adsorbed daily dose of exposure to heavy metals through ingestion, inhalation and dermal contact respectively. The unit is
C the concentration of heavy metals in air in mg/kg

IngR and InhR are ingestion and inhalation rate respectively. In this study, IngR is taken as 200mg/day for children and 100mg/day for adults (USEPA, 2002) while InhR is taken as 7.6m^3/day for children and 20m^3/day for adults.

F is a fraction of time spent at station in a day and value of carcinogenic and non-carcinogenic effects is 0.0694.
EF is the exposure frequency in day/year. The value used in this study is 250 day/year (MohseniBandpi, *et al.* 2018).
ED is the exposure duration in year. The value used in this study is 6 years for children and 24 years for adults (USEPA, 2002) while for carcinogenic and non-carcinogenic effects are 50 and 40 years respectively (MohseniBandpi, *et al.* 2018).
CF is the conversion factor and the value of carcinogenic and non-carcinogenic effects is 0.000001kg/mg (USEPA, 2002).
BW is the average body weight. The average body weight in this study is taken as 15kg for children and 70kg for adults (USEPA, 2002).
AT is the averaging time in days and values for carcinogenic and non-carcinogenic effects is 70*365 and ED*365 respectively (USEPA, 2002); (MohseniBandpi, *et al.* 2018).
PEF is the particle emission factor in m^3/kg and values for carcinogenic and non-carcinogenic effects for both populations is 1,360,000,000 m^3/kg (USEPA, 2002).
SA is the exposed skin surface area in cm^2 and is assumed to be 2800cm^2 for children and 5700cm^2 for adults (USEPA, 2002).
SAF is the dermal adherence factor in mg/cm^2/day and the assumed values for carcinogenic and non-carcinogenic effects used in this study is 0.2 mg/cm^2/day for children and 0.7 mg/cm^2/day
DAF is the dermal absorption factor and the value for carcinogenic and non-carcinogenic effects used in this study is 0.01 except for arsenic which value is 0.03 (De Miguel *et al*,. 2007).

Risk Assessment
Assessment of non-carcinogenic risks was achieved by estimating the hazard quotient (HQ). HQ was calculated as the quotient between the environmental exposure and the reference dose (RfD).
The formula is given in equation (5).

$$HQ = \frac{ADD}{RfD} \quad \text{..... ....(5)}$$

Where ADD in mg/kg/day are the adsorbed daily dose of exposure to heavy metals through ingestion, inhalation and dermal contact and RfD is the Reference Dose (an estimated maximum permissible risk posed to human through daily exposure. HQ values were obtained for each element and exposure pathway.

Hazard Index (HI) refers to the total risk through health exposure pathway. This was obtained by summing the HQ of each element using equation (6) (USEPA, 2011).

$$HI = HQ_{ing} + HQ_{inh} + HQ_{der} \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad \text{...(6)}$$

Total HI is calculated by summing the HI through all exposure pathway) (USEPA, 1989). Values of HI under unity are considered as safe i.e if HI<1, it implies that there is no remarkable risk of non-carcinogenic effects, but if HI>1 then there is a possibility that non-carcinogenic effect may occur and this possibility increases as HI increases (USEPA, 2002).

Carcinogenic risk was evaluated by target cancer risk (TR). The method for estimating TR was provided in USEPA Region III Risk-Based Concentration equation (7)(USEPA, 2002).

$$TR = \frac{(C \ x \ IR \ x \ 10 - 3 \ x \ CPS \ x \ EF \ x \ ED)}{BW \ x \ AT} \quad \text{..... ....(7)}$$

Where TR is the target cancer risk; C is the concentration of the element in air (μg/m^3); IR is the ingestion, inhalation or dermal contact rate; CPS is the carcinogenic potency slope, (mg/kg bw day-1), BW is the average body weight and AT is the averaging time, carcinogens (days year-1).

Another way to estimate Carcinogenic risks is by calculating the increase possibility of an individual to develop cancer as a result of exposure to the potential carcinogen over a lifetime. The estimated daily intake of toxin is converted by slope factor which is averaged by direct exposure over a lifetime to the increased chances of an individual to develop cancer using equation (8) (USEPA, 1989).

$$LCR = ADD \ x \ SF \quad \text{..... ....(8)}$$

Where, LCR = Lifetime Carcinogenic Risk and it is unit less
ADD = Absorbed daily dose in mg/kg/day of exposure to the elements through ingestion, inhalation and dermal contact.
SF = carcinogenicity slope factor (per mg/kg/day).
Risk is therefore a unit less chances of an individual developing cancer when exposed over a lifetime.
The Total Lifetime Carcinogenic Risk (TLCR) was calculated by summing all the LCRs calculated for ingestion, inhalation and dermal contact equation (9).

$$TLCR = LCR_{ing} + LCR_{inh} + LCR_{der} \quad \text{..... ....(9)}$$

For regulatory purposes, risks values exceeding 1×10^{-4} are regarded as intolerable, risks less than 1×10^{-6} are not regarded to cause significant health effects, and risks lying between 1×10^{-4} and 1×10^{-6} are regarded generally as satisfactory range, but circumstances and condition of exposure determine the range of the value of the circumstance (Hu *et al*., 2012).

III. Results And Discussion

Zinc concentrations ranged from 0.002μg/m^3 to 0.018μg/m^3 at stations 5 and 8 with a mean of 0.006 ±0.000μg/m^3 in the wet season and from 0.002μg/m^3 to 0.029μg/m^3 at station 3 with a mean of 0.010 ±0.001μg/m^3 in the dry season. The annual mean Zinc concentration was 0.008 ±0.000μg/m^3. Analysis of variance for concentration of Zn in the study area reveals that both monthly and station variations in Zn levels show significant difference at $p<0.05$. Grouping information by months using Tukey method reveal that the concentration of Zn is significantly higher ($p<0.05$) in the months of November-January than May-July. Grouping information by station using Tukey method revealed that Zn concentrations were significantly higher at station 3 and at the control station (station 8) than at all other stations; the levels of Zn at station 2 and 5 were significantly higher than the levels at stations 4, 6 and 7.

Copper concentrations ranged from 0.002μg/m^3 to 0.020μg/m^3 with a mean of 0.006 ±0.000μg/m^3 in the wet season and from 0.002μg/m^3 to 0.029μg/m^3 with a mean of 0.011±0.001μg/m^3 in the dry season. The annual mean Copper concentration was 0.008±0.001μg/m^3. The dry season concentrations of Cu were generally higher than wet season levels. Analysis of variance for concentration of Cu in the study area reveals that both monthly and station variations in Cu levels show significant difference at $p<0.05$. Grouping information by months using Tukey method reveal that the concentration of Cu is significantly higher ($p<0.05$) in the month of January than all other months in the year. The months of September, November and December recorded significantly higher ($p<0.05$) levels of Cu than the months of April-August. Station levels of Cu using Tukey method revealed that the concentrations of Cu were significantly higher at station 3, 2 and 5 than at stations 4, 6 and 7. Also the control levels of Cu were significantly higher ($p<0.05$) than the levels at station 4, 6, 7

Nickel concentrations ranged from 0.002μg/m^3 to 0.042μg/m^3 at station 3 with a mean of 0.006 ±0.001μg/m^3 in the wet season and from 0.002μg/m^3 to 0.044μg/m^3 at station 8 with a mean of 0.010 ±0.001μg/m^3 in the dry season. The annual mean Nickel concentration was 0.008 ±0.001μg/m^3 with the concentration of Nickel in the dry season generally higher than in the wet season. There was significant difference ($p<0.05$) at both monthly and station levels of Nickel. Nickel levels in the months of November-January were significantly higher ($p<0.05$) than from February-October, while station 3 levels of Ni were significantly higher that all other stations. Stations 2,5 and control showed significantly higher ($p<0.05$) concentrations of Nickel than at stations 1,4,6 and 7.

Chromium concentrations ranged from 0.002μg/m^3 to 0.024μg/m^3 at station 3 with a mean of 0.004 ±0.000μg/m^3 in the wet season; 0.002μg/m^3 to 0.034μg/m^3 at station 2 with a mean of 0.010 ±0.001μg/m^3 in the dry season. The annual mean Chromium concentration was 0.007 ±0.000μg/m^3 with the concentration of Chromium in the dry season generally higher than in the wet season. There was significant difference ($p<0.05$) at both monthly and station levels of Chromium. Chromium levels in the months of November-January were significantly higher ($p<0.05$) than from February-September, while control levels of Cr were significantly higher than all other stations. Stations 3 also showed significantly higher ($p<0.05$) concentrations of Chromium all other stations except 8. Stations 6 and 4 showed significantly lower concentrations of Chromium than all other stations.

Cadmium concentrations ranged from 0.001μg/m^3 at station 5 to 0.048μg/m^3 at station 3 with a mean of 0.006 ±0.001μg/m^3 in the wet season and from 0.002μg/m^3 to 0.037μg/m^3 a station 3 with a mean of 0.011 ±0.001μg/m^3 in the dry season. The annual mean Cadmium concentration was 0.008 ±0.001μg/m^3. There was significant difference ($p<0.05$) at both monthly and station levels of Cadmium. Cadmium levels in the months of December-February were significantly higher ($p<0.05$) than from April-August, while the level in station 3 was significantly higher that all other stations. The control station (stations 8) also showed significantly higher ($p<0.05$) concentrations of Cadmium than all other stations except station 3. Stations 1, 4 and 6 showed significantly lower concentrations of Cadmium than all other stations.

Lead concentrations ranged from 0.009μg/m^3 at all stations to 0.026μg/m^3 at station 3 with a mean of 0.010 ±0.000μg/m^3 in the wet season and from 0.008μg/m^3 at stations 3 and 7 to 0.036μg/m^3 at station 8 with a mean of 0.013 ±0.001μg/m^3 in the dry season. The annual mean Lead concentration was 0.011 ±0.000μg/m^3. Analysis of Variance showed that Lead levels were significantly different both by station and monthly variations. In monthly variations, concentration of

Pb in November was significantly higher ($p<0.05$) than the concentration at all other months. The concentration of Pb in December was also significantly ($p<0.05$) higher than the concentrations observed in the months of April - August. Station variations in the concentrations of Pb showed significantly ($p<0.05$) higher concentrations of Pb at station 3 than at all other stations. Concentrations of Pb at stations 2 and control were also significantly higher ($p<0.05$) than the concentrations at stations 1, 4, 6 and 7.

Arsenic, Barium and Mercury did not vary from station to station and over the course of the year. The concentrations of the three metals were observed to be 0.02 μg/m^3, 0.003μg/m^3 and 0.001μg/m^3 respectively at both wet and dry season.

Zinc correlated moderately with other heavy metals in air such as Pb, Cd, Cr, Ni and and Cu with correlation coefficients (r) of 0.539, 0.619, 0.668, 0.552 and 0.640 (table 4.6.23). All the heavy metals recorded moderate correlation with other heavy metals with correlation coefficient (r) ranging from 0.552 (between Zn and Ni) to 0.696 (between chromium and cadmium. This observation agrees with several other studies which reported very high positive correlation between heavy metals in air (Kumar e*t al*., 2020; Kim *et al*., 2010).

Carcinogenic and Non-carcinogenic Risks

Reference Doses of Heavy Metals were taken from Integrated Risk Information System (US EPA, 2002). The values of R_fD_{ing}, R_fD_{inh} and R_fD_{der} respectively are Zn (0.3, 0.35 and 0.3 mg kg^{-1} per day); Cu (0.04, 0.045 and 0.04 mg kg^{-1} per day); Ni (0.02, 0.025, 0.02 mg kg^{-1} per day); As (0.0003, 0.001 and 0.00005 mg kg^{-1} per day); Cr (1.5, 0.00003 and 0.003 mg kg-1 per day); Cd (0.001, 0.000057 and 0.001 mg kg-1 per day); Ba (0.2; 0.0005 and 0.014 mg kg-1 per day); Hg(0.0003, 0.000086 and 0.0003mg kg-1 per day); Pb (0.0035, 0.0035 and 0.00053mg kg-1 per day). The non-cancer risk for the heavy metals was evaluated by using the total hazard quotient (THQ) and total hazard index (THI) (USEPA 2002) for both adults and children. HQ is the ratio of determined dose of a pollutant to a reference dose level. If THI and THQ are lower than 1, there is no risk of exposure to ambient air levels of the heavy metals. From the result in table 4.7.2.1 and table 4.7.2.2 THQ and THI values were all <1 and so there are no non-carcinogenic risks of heavy metals in both adults and children at the study area.

The acceptable minimum cancer risk by the US EPA ranges from $1.0x10^{-6}$ to $1.0x10^{-4}$ (Kalagbor *et al*., 2019). The TLCR was obtained using the CSF, which was the risk produced by a lifetime average dose of 1 $mgkg^{-1}$ $BWday^{-1}$ and is contaminant specific. The TLCR values were within the acceptable limits for cancer

risks, however the results showed that the total TLCR values for As, Cr and Cd was 1.84 times higher in children than in adults while for Pb the TLCR value was 10 times higher in children than in adults. The non-carcinogenic risk and cancer risk values observed in this study were related to the findings of Kalagbor *et al.* (2019) in their study of heavy metals in soot samples and cancer risk assessment in Port Harcourt.

Table 1: Wet and Dry Seasons Levels of Heavy Metals Measured in the Study Area

Parameters ($\mu g/m^3$)	WET SEASON				DRY SEASON			
	Min	Max	Mean	SEM	Min	Max	Mean	SEM
Zn	0.002	0.018	0.006	0.000	0.002	0.029	0.010	0.001
Cu	0.002	0.020	0.006	0.000	0.002	0.029	0.011	0.001
Ni	0.002	0.042	0.006	0.001	0.002	0.044	0.010	0.001
As	0.002	0.002	0.002	0.000	0.002	0.002	0.002	0.000
Cr	0.002	0.024	0.004	0.000	0.002	0.034	0.010	0.001
Cd	0.001	0.048	0.006	0.001	0.002	0.042	0.011	0.001
Ba	0.030	0.030	0.030	0.000	0.030	0.030	0.030	0.000
Hg	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.000
Pb	0.009	0.024	0.010	0.000	0.008	0.036	0.013	0.001

Table 2: Annual Levels of Heavy Metals Measured in the Study Area

	ANNUAL VALUES			
Parameters ($\mu g/m^3$)	Min	Max	Mean	SEM
Zn	0.002	0.029	0.008	0.000
Cu	0.002	0.029	0.008	0.000
Ni	0.002	0.044	0.008	0.001
As	0.002	0.002	0.002	0.000
Cr	0.002	0.034	0.007	0.000
Cd	0.001	0.048	0.008	0.001
Ba	0.030	0.030	0.030	0.000
Hg	0.001	0.001	0.001	0.000
Pb	0.008	0.036	0.011	0.000

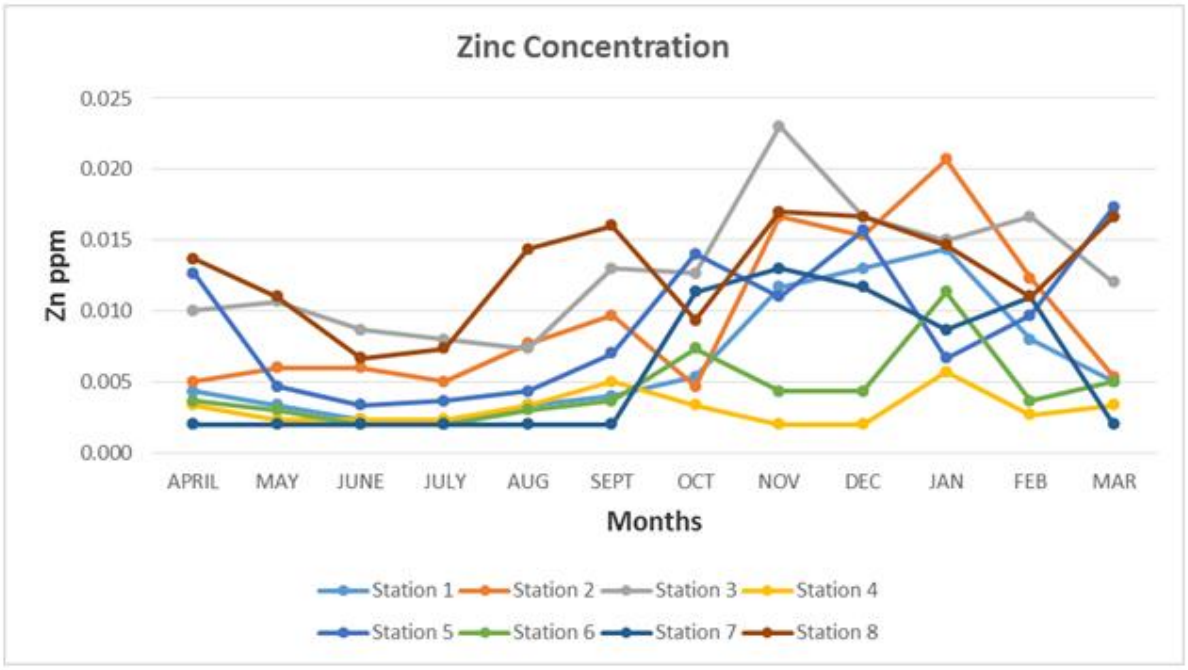

Fig 2. Monthly Variations in Zn Concentrations at the Study Area

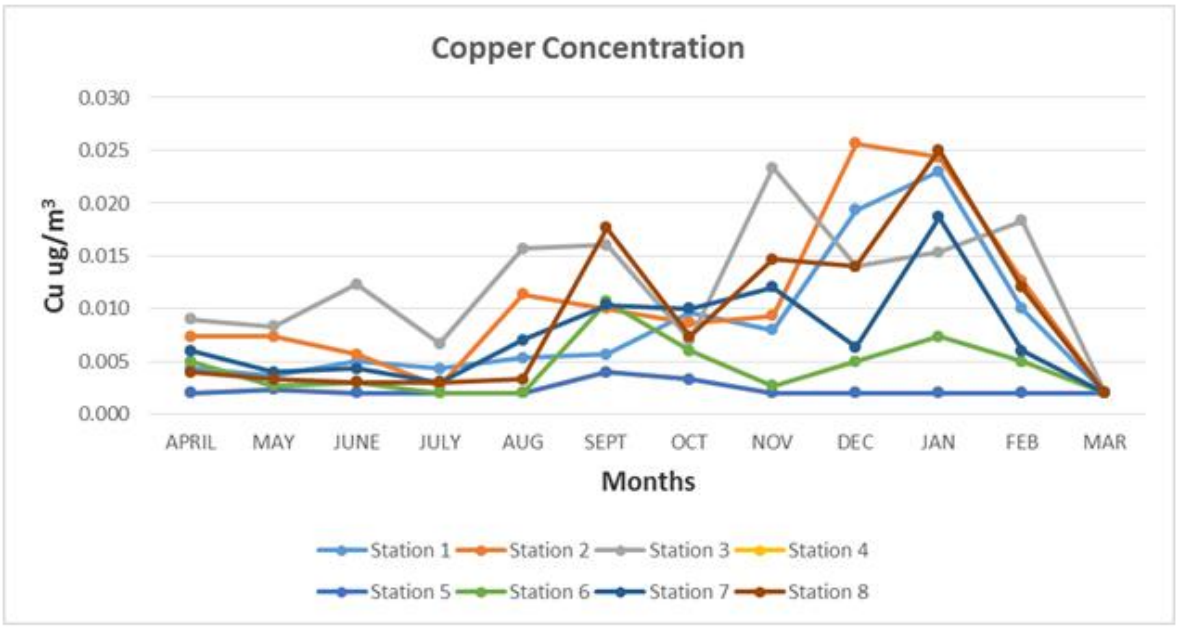

Fig 3. Monthly Variations in Cu Concentrations at the Study Area

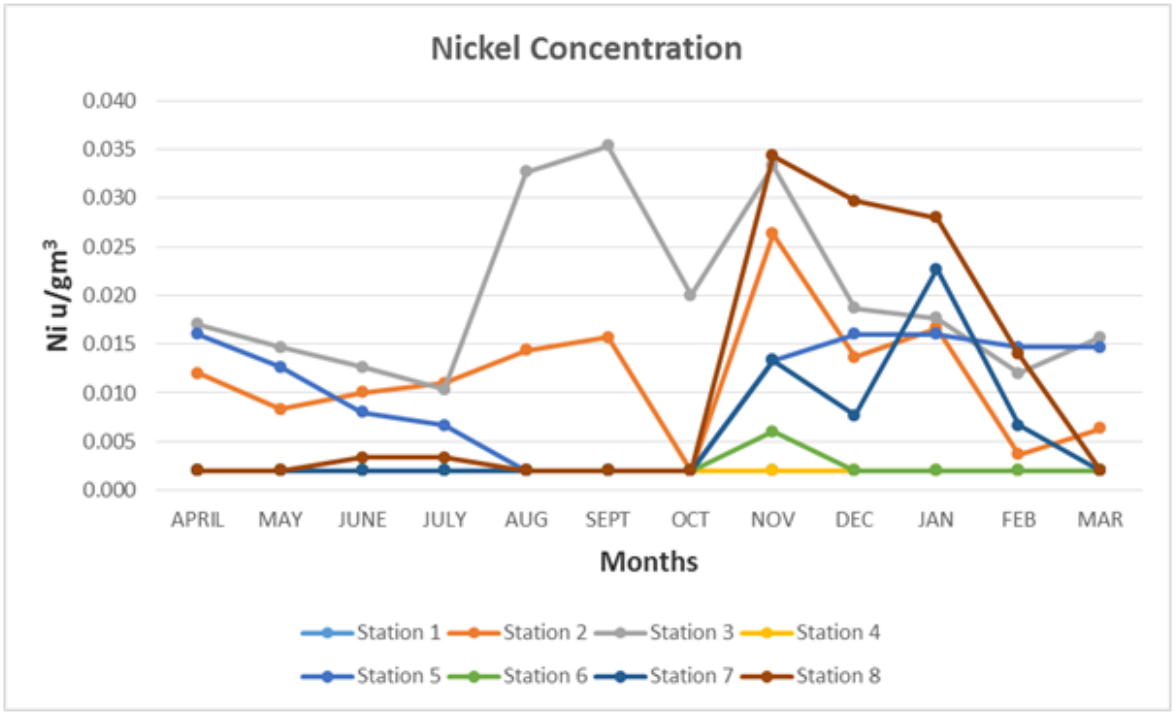

Fig 4. Monthly Variations in Ni Concentrations at the Study Area

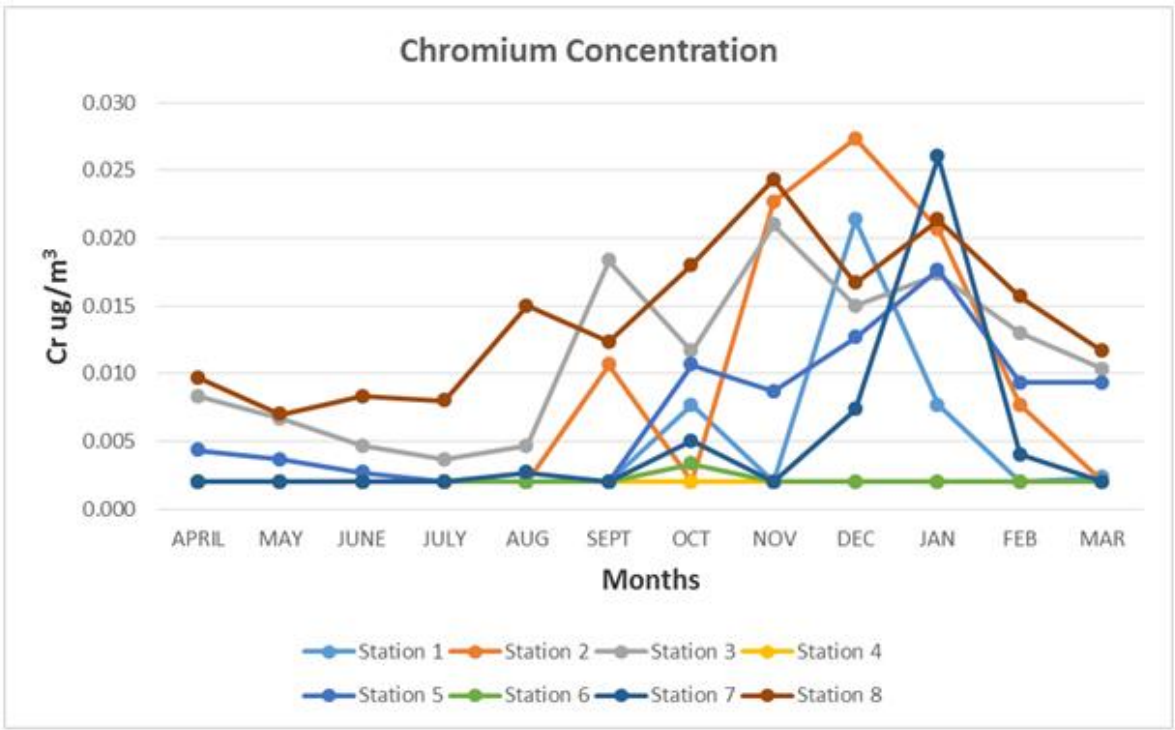

Fig 5. Monthly Variations in Cr Concentrations at the Study Area

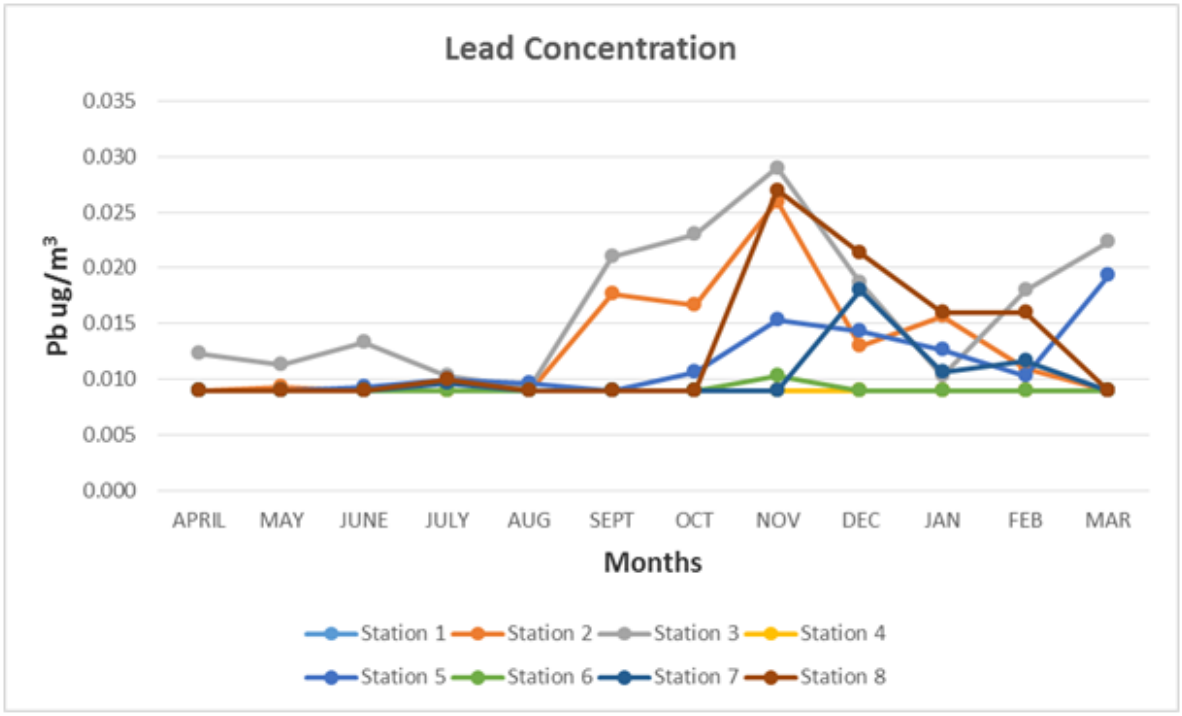

Fig 6. Monthly Variations in Pb Concentrations at the Study Area

Health Risk Assessment of Heavy Metals in the Study Area

The results of the human health risk assessment of the heavy metal concentrations in air at the study area for both children and adults as evaluated in the three main pathways (oral ingestion (DD_{ing}), inhalation (DD_{inh}) and dermal contact (DD_{der})) are presented in Tables 3 and 4. .

Daily Dose of Exposure

The DD_{ing} values for zinc in children ranged from 1.99×10^{-9} to 8.15×10^{-9} while the value for adults ranged from 8.53×10^{-10} to 3.49×10^{-9}. The values for copper in children ranged from 1.46×10^{-9} to 8.06×10^{-9} while the value for adults ranged from 6.27×10^{-10} to 3.46×10^{-9}. The DD_{ing} values for Nickel in children ranged from 1.09×10^{-10} to 1.09×10^{-9} while the values for adults ranged from 4.66×10^{-11} to 4.66×10^{-10}. The value for Arsenic in children was 1.09×10^{-10} while the value for adults was 4.65×10^{-11}. Chromium values in children ranged from 1.09×10^{-10} to 7.61×10^{-10} while the values for adults ranged from 4.66×10^{-11} to 3.26×10^{-10}. The DD_{ing} values for Cadmium in children ranged from 1.09×10^{-10} to 1.23×10^{-9} while the values for adults ranged from 4.66×10^{-11} to 5.25×10^{-10}. Barium DD_{ing} value in children was 1.90×10^{-8} while the value for adults was 8.14×10^{-9}. The value for mercury in children was 5.43×10^{-11} while the value for adults was 2.33×10^{-11}. The DD_{ing} value for lead in children ranged from 4.89×10^{-10} to 9.01×10^{-10} while the value for adults ranged from 2.09×10^{-10} to 3.86×10^{-10}.

The DD_{inh} value for zinc in children ranged from 5.56×10^{-14} to 2.28×10^{-13} while the value for adults ranged from 1.25×10^{-13} to 5.14×10^{-13}. The value for copper in children ranged from 4.08×10^{-14} to 2.25×10^{-13} while the value for adults ranged from 9.21×10^{-14} to 5.08×10^{-13}. The DD_{inh} value for Nickel in children ranged from 3.04×10^{-15} to 3.04×10^{-14} while the value for adults ranged from 6.85×10^{-15} to 6.85×10^{-14}. The value for Arsenic in children was 3.04×10^{-15} while the value for adults was 6.84×10^{-15}. Chromium value in children ranged from 3.04×10^{-15} to 2.13×10^{-14} while the value for adults ranged from 6.85×10^{-15} to 4.79×10^{-14}. The DD_{inh} value for Cadmium in children ranged from 3.04×10^{-15} to 3.45×10^{-14} while the value for adults ranged from 6.85×10^{-15} to 7.78×10^{-14}. Barium DD_{inh} value in children was 5.31×10^{-13} while the value for adults was 1.20×10^{-12}. The value for mercury in children was 1.52×10^{-15} while the value for adults was 3.42×10^{-15}. The DD_{inh} value for lead in children ranged from 1.37×10^{-14} to 2.52×10^{-14} while the value for adults ranged from 3.08×10^{-14} to 5.68×10^{-14}.

The DD_{der} value for zinc in children ranged from 5.57×10^{-11} to 2.28×10^{-10} while the value for adults ranged from 2.60×10^{-10} to 1.06×10^{-9}. The value for copper in children ranged from 4.09×10^{-11} to 2.28×10^{-10} while the value for adults ranged from 1.91×10^{-10} to 1.05×10^{-9}. The DD_{der} value for Nickel in children ranged from 3.04×10^{-12} to 3.04×10^{-11} while the value for adults ranged from 1.42×10^{-11} to 1.42×10^{-10}. The value for Arsenic in children was 3.04×10^{-12} while the value for adults was 1.42×10^{-11}. Chromium value in children ranged from 3.04×10^{-12} to 2.13×10^{-11} while the value for adults ranged from 1.42×10^{-11} to 1.61×10^{-10}. The

DD_{der} value for Cadmium in children ranged from 3.04×10^{-12} to 3.45×10^{-11} while the value for adults ranged from 1.42×10^{-11} to 1.61×10^{-10}. Barium DD_{der} value in children was 5.32×10^{-10} while the value for adults was 2.48×10^{-9}. The value for mercury in children was 1.52×10^{-12} while the value for adults was 7.09×10^{-12}. The DD_{der} value for lead in children ranged from 1.37×10^{-11} to 2.52×10^{-11} while the value for adults ranged from 6.38×10^{-11} to 1.18×10^{-10}.

Tble 3: Daily Intake of Heavy Metals in Children

	Children					
	DD_{ing}		DD_{inh}		DD_{der}	
Parameter	Min	Max	Min	Max	Min	Max
ZN	1.99×10^{-9}	8.15×10^{-9}	5.56×10^{-14}	2.28×10^{-13}	5.57×10^{-11}	2.28×10^{-10}
Cu	1.46×10^{-9}	8.06×10^{-9}	4.08×10^{-14}	2.25×10^{-13}	4.09×10^{-11}	2.28×10^{-10}
Ni	1.09×10^{-10}	1.09×10^{-9}	3.04×10^{-15}	3.04×10^{-14}	3.04×10^{-12}	3.04×10^{-11}
As	1.09×10^{-10}	1.09×10^{-10}	3.04×10^{-15}	3.04×10^{-15}	3.04×10^{-12}	3.04×10^{-12}
Cr	1.09×10^{-10}	7.61×10^{-10}	3.04×10^{-15}	2.13×10^{-14}	3.04×10^{-12}	2.13×10^{-11}
Cd	1.09×10^{-10}	1.23×10^{-9}	3.04×10^{-15}	3.45×10^{-14}	3.04×10^{-12}	3.45×10^{-11}
Ba	1.90×10^{-8}	1.90×10^{-8}	5.31×10^{-13}	5.31×10^{-13}	5.32×10^{-10}	5.32×10^{-10}
Hg	5.43×10^{-11}	5.43×10^{-11}	1.52×10^{-15}	1.52×10^{-15}	1.52×10^{-12}	1.52×10^{-12}
Pb	4.89×10^{-10}	9.01×10^{-10}	1.37×10^{-14}	2.52×10^{-14}	1.37×10^{-11}	2.52×10^{-11}

Table 4: Daily Intake of Heavy Metals in Adults

	Adults					
	DD_{ing}		DD_{inh}		DD_{der}	
Parameter	Min	Max	Min	Max	Min	Max
ZN	8.53×10^{-10}	3.49×10^{-9}	1.25×10^{-13}	5.14×10^{-13}	2.60×10^{-10}	1.06×10^{-9}
Cu	6.27×10^{-10}	3.46×10^{-9}	9.21×10^{-14}	5.08×10^{-13}	1.91×10^{-10}	1.05×10^{-9}
Ni	4.66×10^{-11}	4.66×10^{-10}	6.85×10^{-15}	6.85×10^{-14}	1.42×10^{-11}	1.42×10^{-10}
As	4.65×10^{-11}	4.65×10^{-11}	6.84×10^{-15}	6.84×10^{-15}	1.42×10^{-11}	1.42×10^{-11}
Cr	4.66×10^{-11}	3.26×10^{-10}	6.85×10^{-15}	4.79×10^{-14}	1.42×10^{-11}	1.61×10^{-10}
Cd	4.66×10^{-11}	5.25×10^{-10}	6.85×10^{-15}	7.78×10^{-14}	1.42×10^{-11}	1.61×10^{-10}
Ba	8.14×10^{-9}	8.14×10^{-9}	1.20×10^{-12}	1.20×10^{-12}	2.48×10^{-9}	2.48×10^{-9}
Hg	2.33×10^{-11}	2.33×10^{-11}	3.42×10^{-15}	3.42×10^{-15}	7.09×10^{-12}	7.09×10^{-12}
Pb	2.09×10^{-10}	3.86×10^{-10}	3.08×10^{-14}	5.68×10^{-14}	6.38×10^{-11}	1.18×10^{-10}

Non-Carcinogenic Risk Assessment of Heavy Metals in the Study Area

The non-carcinogenic risks for children and adults associated with the daily dose intake of the heavy metals were assessed for each exposure pathway as their Hazard Quotients (HQs) and Hazard Indexes (HIs).

The highest HI for zinc in children was 1.99×10^{-9} while the highest value for adults was 8.53×10^{-10}. The highest HI for copper in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for nickel in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for arsenic in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for chromium in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for cadmium in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for barium in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for mercury in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$ The highest HI for lead in children was 1.99×10^{-9} while the highest value for adults was $8.53 \times 10^{-10.}$

Carcinogenic Risk Assessment of Heavy Metals in the Study Area

The Lifetime Cancer Risks (LCR) and Total Lifetime Risk (TLCR) in the study area were assessed for arsenic, chromium, cadmium, lead, nickel and mercury which have been identified as carcinogens (USEPA, 2002). The cancer slope factor for nickel and mercury are zero (0.00). The TLCR value for arsenic in children was 1.68 x10-10 while in adults was 9.11×10^{-11}. The highest value for chromium in children was 2.35×10^{-12} while the value for chromium in adults was 1.28×10^{12}. The highest value for cadmium for children was 7.99×10^{-9} while the value for cadmium for adults was 4.35×10^{-9}. The highest value for lead in children was 1.61×10^{-11} while the value for chromium in adults was 1.61×10^{-12}.

IV. Conclusion

The control station generally showed significantly higher levels of the elements than the study stations. Thus the major sources of the elements are vehicular and other automobile activities than petroleum industry activities. The results also indicated spatial variation of the heavy elements; although they did not constitute any

health risks both in adults and children. However, Life time cancer risk was 10 times higher in children than in adults in the communities.

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