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Distribution, Levels, Potential Sources and Human Health Risk Assessment of Trace Metals in Atmospheric Particulate Matter in Ogbia communities of Bayelsa State, Niger Delta, Nigeria

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ABSTRACT: The occurrence of toxic metals in atmospheric particulate matter is of high risk to human health. Hence, the objective of this paper was to evaluate the distribution, concentrations, potential sources and human health risk assessment of trace metals in atmospheric particulate matter in Ogbia communities of Bayelsa State, Niger Delta, Nigeria. Samples of atmospheric particulate matter were digested using a mixture of acids, and quantification of trace metals was achieved using atomic absorption spectrophotometry (Model: Buck 230 ATS). The concentration (µg m^{-3}) of trace metals in atmospheric particulate matter ranged as follows: Pb (<0.010 - 0.060), Cd (<0.010 - 0.880), Ni (<0.010 - 0.028), Cu (<0.010 - 0.046), Zn (<0.010 - 0.028), and Co (<0.010 - 0.021). Except nickel (Ni) and cadmium (Cd), other metal concentrations were below the US EPA limits. Principal component analysis indicated a common source of the studied metals and two major factors (gas flaring and uncontrollable fossil fuel combustion) were identified; while non-carcinogenic risk due to inhalation indicated negligible health risk. Therefore, hazardous effects due to inhalation of trace metals in atmospheric particulate matter in the study area is minimal.

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Keywords: Atmospheric particulate matter; toxic metals distribution; risk assessment; principal component analysis.

For several decades, oil exploration and production in the Niger Delta region of Nigeria remains a dominant industrial activity. Consequently, a significant quantity of natural gas is being flared daily. Gas flaring and several other associated combustion processes have negatively impacted the environment, especially on air quality (Uzoekwe *et al*; 2021; Uzoekwe and Ajayi, 2018; Seiyaboh and Izah, 2017). Also, an increase in urbanization, modernization and industrialization has exacerbated air pollution to a level that is of public health concern. Atmospheric particulate matter is one of the several air contaminants identified to significantly cause air pollution (Brown *et al.*, 2013). Atmospheric particulate matter (or simply particulate matter/ PM) refers to particle and droplet emitted into ambient air via both natural process (chemical transformation of gaseous pollutants) and artificial means (human actions) (Popoola *et al.*, 2018). They exist in the Earth's atmosphere either as solid particles or liquid droplets (Perrino, 2010). Natural sources of PM include sea salt, volcanic ash, pollen, fungal spores,

soil particles, forest fires and wind-blow dust. Anthropogenic sources consist of fossil fuel combustion products, industrial processes, mining activities, wood stove burning and cigarette smoking. In urban areas, the main source of PM are motor vehicles, especially those derived from diesel fuel combustion (Kelly and Fussell, 2012). They may be identified by the particle's size (aerodynamic diameter) as PM_{10}, $PM_{2.5}$, and UFP - (ultrafine particles); and the smaller the particle diameter, the higher the chances of inhalation and associated deleterious health effects, and vice versa (Englert, 2004). The advent of PM as a result of industrial revolution has caused contemporary atmosphere appear a bit variant from the pre-industrialization and urbanization era (Chowdhury *et al.,* 2001). The concentration of primary particulates (i.e. those directly emitted into the atmosphere) is dependent on their rates of emission, transport/ dispersion, and rate at which they are removed from the atmosphere. Consequently, relating ambient concentrations of secondary particles to sources of precursor emissions is usually more difficult than identifying the former (Popoola *et al.,* 2018).

Heavy metals are elements with inherent toxicities, high densities or high atomic weights (Duffus, 2002). They are of environmental importance primarily due to their non-biodegradability, bioaccumulative natures and their potential harmful effects. Both natural (volcanic eruptions, bubble bursting of water bodies, dust re-suspension, etc.) and anthropogenic processes increase metal levels in the atmosphere. Although a minute percentage of heavy metals contribute to PM, the health impacts can be significant through inhalation and dermal contact. The need to ensure good air quality cannot be overemphasized, since, according to World Health Organization (WHO), a decline in air pollution levels from ambient (outdoor) can reduce disease burden, especially cardiovascular and respiratory ailments, on both short and long term basis (WHO, 2018). Due to the toxic nature of heavy metals, their levels and potential health risk in atmospheric PM is necessary. The aim of this study therefore, was to assess heavy metals levels and distribution in atmospheric particulate matter and associated impact on selected semi- urban communities in Ogbia Local Government areas of Bayelsa State, Southern Nigeria.

MATERIALS AND METHOD

Study Area: This study was conducted at different locations in Ogbia Local Government Area of Bayelsa State, Nigeria, bounded by Latitude 4°39′00″N 6°16′00″E. It has an area of 695 km^2 and a population of 179,926. Among the neighbouring communities within the environs, are Imiringi, Otuasega, Ibelebiri, Otuoke, etc. Its boundary in the North is surrounded by Elebele Community, in the East by Emeyal I and Kolo, in the West by Onuebum and Otuogori, and in the South by Otuaba and Ewoi Communities; all in Ogbia Local Government Area of Bayelsa State. Otuoke assumes a central position within the Niger Delta region of Nigeria. The surface majorly drained by Otuoke Creek drainage system, cuts through the community from Elebele in the North, to Otuaba in the South, and empties into Kolo Creek at Otuogidi/Ogbia town the down South. Its soil, forestlands and extended territories are drained by Ekole Creek in the West through Atubu sub – creek and swamp drainage system; in the East by Kolo Creek drainage system, and South East by Akoloman Creek drainage system (Allison *et al.,* 2007). Figure 1 is a map of the study area, while Table 1 gives meteorological details of the sampled locations

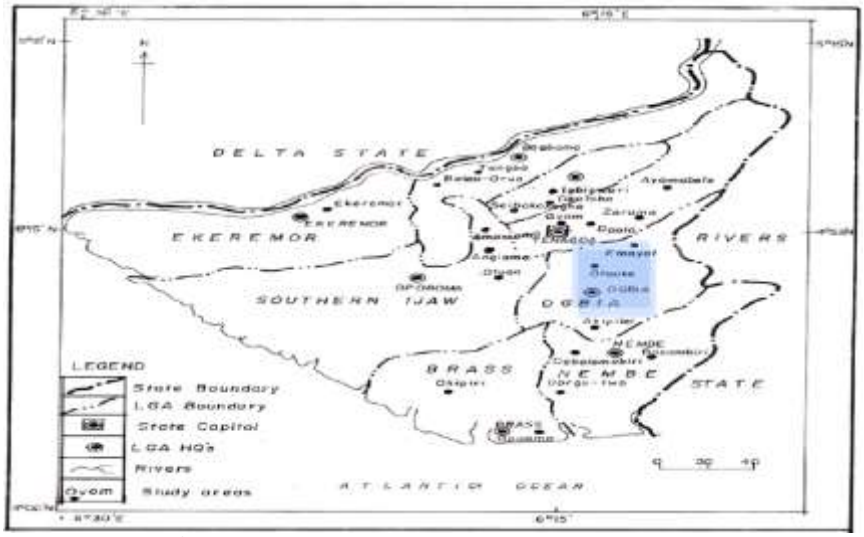

Fig 1: The Map of Bayelsa State, showing the locations in Ogbia L.G.A. (generated by authors)

Table 1: Meteorological parameters of the various locations understudied

Locations	GPRS	Temp. (°C)	Wind speed	Wind direction	Noise	Humidity (%)
SS1	N40 55" 7.6 E60 25" 1.7	35.4	0.30	East	65.5	72.5
SS2	N40 55" 8.2 E60 25" 2.5	38.5	0.20	N/East	58.5	70.9
SS3	N40 55" 7.1 E60 25" 4.7	38.6	0.20	East	60.1	71.2
SS4	N40 51" 37.3 E60 22" 16.3	39.9	0.20	East	64.5	69.8
SS5	N40 51" 37.3 E6022" 16.3	33.7	0.70	/East	39.5	72.6
SS6	N40 57" 53.1 E60 26" 8.7	32.5	0.50	N/East	41.5	75.8
SS7	N40 57" 8.4 E6025" 56.2	30.1	1.20	West	61.5	81.5
SS8	N40 53" 6.4 E6022" 26.4	31.8	0.60	North	50.7	79.9
SS9	N4047" 40.4 E60 19" 7.9	32.5	0.10	East	65.6	72.6
SS10	N40 4"I 38.5 E60 19" 13.1	31.7	0.10	S/East	58.2	73.4

***Keys**: SS1 = Otuasega Jetty; SS2 = Otuasega Residential Area 1; SS3 = Otuasega Residential Area 2; SS4 = at Bridge; SS5 = Imiringi Junction; SS6 = Ibelebiri 1; SS7 = Ibelebiri 2; SS8 = Imiringi Road; SS9 = School Park; SS10 = School Gate; SS11 = Control*

Sampling: Airborne particulate matter (PM) was collected monthly from various locations in Otuasega, Imiringi, Ibelebiri and Otuoke communities in three seasonal periods: October to December 2021, February to April 2022, and June to August 2022. Samples were on a respirable fine particulate pre-weighed polytetrafluoroethylene (PTFE) filter paper of 47mm diameter, fixed on a plastic holder with stainless mesh support of a sampler, at a flow rate of 16.5 L min^{-1}. The sampler was calibrated and positioned at 1.9 meters above the ground with a protective base; this was done to avoid being blown away by wind, and to debilitate the risk of dust infiltration via underlying surfaces. The filters were conditioned in a dessicator before and after sampling. The exposed filters and blank filters were stored in properly labeled polyethylene bags and stored in a refrigerator maintained at 4^0 C. The mass of particulate matter was determined gravimetrically as a difference in mass of the filter paper before and after sampling.

Sample Preparation and Analysis: The methods of Batterman *et al.* (2014) was employed in this study. Each collected sample was first spiked with 2 µL of an isotopically labeled internal standard. This was followed by careful addition of 5.5 cm^3 boiling concentrated HNO_3 inside a beaker, and 3.0 cm^3 of 70% $HClO_4$. The mixture was heated at 120 °C, until a clear solution was obtained. Heating was continued until the volume of the mixture reduced to about 1.0 cm^3. Upon cooling, 5 cm^3 of distilled water was added; the mixture was filtered in a 50 cm^3 volumetric flask and made to mark with distilled water. The concentration of Pb, Cd, Ni, Cu, Zn, Cr, Cd and Co was measured using Flame Atomic Absorption Spectrophotometer (AAS Model: Buck 230 ATS) using the expression:

$$\text{Concentration of metal } (\mu g\ m^{-3}) = \frac{\text{instrument reading (mg/L) x } 1000\ \mu g/mg}{\text{volume of air sampled } (m^3)} \quad (1)$$

Quality Control: Quality Control measures were carried out as replicates of samples were digested before running a blank to correct the measurements and appraise all reagents for cross contamination and interference.

Statistical Analysis: All determinations were done in replicates and the results were reported as mean ± standard deviation.

Health risk assessment: The average daily intake (ADI) of metals via inhalation of soil particulates is estimated as follows:

$$\text{ADIInh} = \frac{C_s\ x\ IR_{air}\ x\ EF\ x\ ED}{BW\ x\ AT\ x\ PEF} \quad (2)$$

Where: ADI_{inh} = average daily intake of metals inhaled from soil in mg/kg-day, C_S = heavy metal concentration in soil in mg/kg, IR_{air} = inhalation rate in m^3/day, PEF = particulate emission factor in $m^3\ kg^{-3}$.

Non-carcinogenic risk assessment: The non-carcinogenic hazard is characterized by the "Hazard quotient (HQ)". It is the measure of dose or ADI per the threshold value (chronic reference dose, R*f*D) of a given metal as shown in the equation below:

$$\text{HQ} = \frac{ADI}{R_fD} \quad (3)$$

For "n" metals, the non-carcinogenic effect is thus the sum of all HQs by individual metals (called the "Hazard Index (HI)") (USEPA, 1989).

HQ values > 1 suggest level of concern for potential non-carcinogenic effects while HQ values < 1 suggest unlikely adverse health effects (Luo *et al.*, 2012).

Total lifetime carcinogenic risk assessment: Carcinogenic risk assessment approximates the increasing prospects of an individual getting cancer over a lifetime due to exposure to the identified carcinogen. It is calculated as:

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k \,.\, CSF_k \qquad (4)$$

Where: ADI_k (mg/kg/day) and CSF_k (mg/kg/day^{-1}) are the average daily intake and cancer slope factor respectively for the kth heavy metal for n number of metals. The slope factor converts the estimated daily intake of metals averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer (USEPA, 1989). The carcinogenic risk assessment is calculated using the R*f*D and CSF values derived from the USEPA and the Department of Environmental Affairs, South Africa. In general, the total cancer risk lower than 10^{-6} (i.e. the carcinogenic target risk, which is the probability of 1 individual in every 1,000,000 developing cancer) are negligible, while cancer risks above 10^{-4} are considered unacceptable by most international regulatory agencies (USEPA, 1989; Luo *et al.*, 2012).

RESULTS AND DISCUSSION

Toxic Metal levels and Distribution: The concentration range of heavy metals in particulate matter for the three seasonal periods are shown in Table 2 below. The average metals concentration across the sampling sites followed the order: Cr < Ni < Co < Pb < Cu = Zn < Cd. None of the analysed metals was detected in the control site, while the lowest concentrations were recorded in samples from the University's gate which served as the control. There was no defined pattern of metals distribution in PM with regards to location and anthropogenic activities in the studied area. Generally, the determined levels of Ni and Cd (except one site) exceeded their permissible limit, while the concentration of other metals determined in this study were found to be within their respective permissible limits. The concentration of Pb in PM ranged from 0.003 to 0.026 µg m^{-3}, with an average concentration of 0.016 µg m^{-3}. The highest concentrations were detected in sites 8, 7 and 5, respectively. Site 5 is characterized by the presence of oil exploration facilities, while site 5 is a busy junction, characterized by high volume of vehicular movements. When compared with the US EPA (US EPA, 2016) and WHO (WHO, 2018) limits, all determined concentrations of Pb were below the limit concentration of 1.5 µg m^{-3}. The results obtained in this study are relatively low, compared with those of Izah *et al*. (2021) who recorded a concentration range of 0.32 - 1.02 for Pb in PM around a gas flaring area in Bayelsa State, but comparable with those of Soleimani *et al*. (2018) with Pb concentrations ranging from 0.041 - 0.062 µg m^{-3} in Isfahan City Iran, Kermani *et al*., 2017), with a reported average concentration of 0.03 µg m^{-3} for Pb in PM in Tehran, and Uzoekwe and Ajayi (2018) with an average concentration of 0.00053 µg m^{-3} for Yenagoa and its environs. The concentration of Ni detected in this study ranged from 0.003 - 0.028 µg m^{-3}, with an average concentration of 0.009 µg m^{-3} across the sampled sites. The highest concentration was at site 1, which is a boat jetty. However, the concentration of Ni in all samples except the control, exceeded the USEPA and WHO limit concentrations of 0.00024 µgm^{-3}. Nickel is a group 1 carcinogen, and its health effects are well documented in literature. When compared with related studies, the results obtained in this study are similar to those of Soleimani *et al*. (2018), but slightly lower than Izah *et al*. (2021), and higher than Uzoekwe and Ajayi (2018). For Cd, the concentration in PM ranged from 0.0003 - 0.087 µgm^{-3}, with an average concentration of 0.025 µg m^{-3}. With exception of the control site, all determined Cd concentrations exceeded the WHO and USEPA limit concentrations of 0.0006 µgm^{-3}. High concentration of Cd in PM could be attributed to emissions from automobiles in high traffic density areas (Wong *et al.* 2019). The concentration of Cu ranged from ND to 0.046 µgm^{-3}. The presence of Cu in PM has been linked with heavy traffics of public transportation and increasing use of diesel fuel (Soloemani *et al*., 2018). Zn concentrations ranged from 0.0003 - 0.034 µgm^{-3}, with an average concentration of 0.018 µgm^{-3}., while Cr recorded very low concentrations, ranging from ND - 0.0446 µgm^{-3}, with all concentrations below the 0.1 µg m^{-3} limit by USEPA and WHO. The origin of heavy metals in PM are reported to generally include re-suspended particulate matter, fuel oil combustion, mining, traffic emissions, etc. (Mukherjee and Agrawal, 2017). Some elements such as Pb, Cd and Cu have been reported to be associated with debris of wearing of tyres and brake pads associated with road dust and old automobile combustion systems (Adachi and Tainosho, 2004), while burning of biomass and crustal dust from raging fire were important sources of Pb (Kayee *et al*., 2020). As a result, Sakunkoo *et al*. (2022) suggested that the

concentration of metals in PM may vary with meteorological factors and topology.

Table 2: Average Heavy Metal concentration (range in parenthesis) in the ambient Particulate Matter

Sampling stations	Concentration of $PM_{2.5}$ (μg m^{-3})						
	Ni	Cr	Cu	Pb	Zn	Co	Cd
SS1	**0.022±0.0049^a** (0.016-0.028)	0.001± 0.0012^a (ND-0.003)	0.043± 0.0034^a (0.038-0.046)	0.015±0.0029^a (0.011-0.018)	0.023±0.0041^a (0.018-0.028)	0.018±0.0012^a (0.0016-0.019)	**0.005±0.0009^a** (0.004-0.006)
SS2	**0.017±0.0025^a** (0.014-0.020)	0.001±0.0008^a (ND-0.002)	0.027±0.0029^b (0.023-0.030)	0.015±0.0017^a (0.013-0.017)	0.020±0.0012^a (0.018-0.021)	0.007±0.0016^b (0.005-0.009)	**0.004±0.0008^a** (0.003-0.005)
SS3	**0.007±0.0009^b** (0.006-0.008)	0.001±0.0008^a (ND-0.002)	0.021±0.0021^b (0.018-0.023)	0.012±0.0016^a (0.010-0.014)	0.024±0.0017^a (0.022-0.026)	0.007±0.0009^b (0.006-0.008)	**0.004±0.0009^a** (0.003-0.005)
SS4	**0.006±0.0012^b** (0.005-0.008)	0.001±0.0014^a (ND-0.003)	0.019±0.0019^c (0.018-0.022)	0.022±0.0012^b (0.021-0.024)	0.031±0.0025^b (0.028-0.034)	0.021±0.0054^a (0.015-0.28)	**0.086±0.0168^b** (0.064-0.105)
SS5	**0.006±0.0016^b** (0.004-0.008)	0.004±0.0024^b (0.001-0.007)	0.025±0.0025^b (0.022-0.028)	0.025±0.0024^b (0.022-0.028)	0.024±0.0053^a (0.018-0.031)	0.022±0.0014^a (0.021-0.24)	**0.003±0.0012^a** (0.001-0.004)
SS6	**0.012±0a.0016^c** (0.010-0.014)	0.004±0.0021^b (0.002-0.007)	0.019±0.0017^c (0.0170-0.021)	0.024±0.0029^b (0.020-0.027)	0.016±0.0033^c (0.012-0.020)	0.019±0.0017^a (0.017-0.021)	**0.070±0.0344^b** (0.022-0.101)
SS7	**0.014±0.0012^c** (0.012-0.015)	0.005±0.0008^b (0.004-0.006)	0.016±0.0012^c (0.0140-0.017)	0.025±0.0033^b (0.021-0.029)	0.018±0.0029^c (0.014-0.021)	0.018±0.0016^a (0.016-0.020)	**0.087±0.0037^b** (0.082-0.091)
SS8	**0.006±0.0021^b** (0.003-0.008)	0.006±0.0016^b (0.004-0.008)	0.028±0.0029^b (0.025-0.032)	0.026±0.0016^b (0.024-0.028)	0.027±0.0029^a (0.023-0.030)	0.018±0.0021^a (0.016-0.021)	**0.011±0.0099^c** (0.003-0.025)
SS9	**0.003±0.0008^d** (0.002-0.004)	0.012±0.0014^c (0.010-0.013)	0.008±0.0043^d (0.004-0.014)	0.015±0.0037^a (0.011-0.021)	0.015±0.0043^c (0.011-0.020)	0.005± 0.0037^b (0.001-0.010)	**0.004±0.0050^a** (ND-0.011)
SS10	**0.003±0.0017^d** (0.001-0.005)	0.0003±0.0005^d (ND)-0.001	0.001±0.0008^e (ND-0.002)	0.003±0.0012^c (0.002-0.005)	0.0003± 0.0005^d (ND-0.001)	0.001±0.0005^c (ND-0.001)	0.0003± 0.0005^c (ND-0.001)
SS11	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND
Max	0.028	0.013	0.046	0.026	0.034	0.028	0.105
Overall mean	0.009	0.003	0.018	0.016	0.018	0.012	0.025

ND - not detected. Superscripts with different superscripts on a column indicates significant difference in concentration. Bolded values indicate concentrations exceeding permissible limits

Health Risk assessment: The total carcinogenic risk values are presented in Table 3. For adult scenario, the average risk values for all studied metals ranged from $2.09x10^{-9}$ to $2.23x10^{-7}$ for adult scenario, and from $3.70x10^{-9}$ to $3.95x10^{-7}$ for children scenario, respectively. The average carcinogenic risk values for the individual metals followed the order: Cd > Cr > Ni > Co for both adult and children exposure scenarios. However, the total carcinogenic risk was slightly above the USEPA lower limit of 10^{-6} in sampling locations 4 and 6 for children exposure scenario, while the total risk was below the limit in adult exposure scenario. This suggests that children exposed in the study area (except two locations) are not expected to experience health risk due to inhalation of carcinogenic heavy metals in PM. The non-carcinogenic risk, represented by the hazard quotient (HQ) for the individual metals, shown in Table 4.

Table 3: Carcinogenic risk values of heavy metals in ambient particulate matter

Sampling location	Carcinogenic risk values							
	Children exposure				Adult exposure			
	Pb	Cd	Cr	Ni	Pb	Cd	Cr	Ni
SS1	$1.19x10^{-10}$	$7.82x10^{-8}$	$3.12x10^{-8}$	$1.13x10^{-8}$	$6.73x10^{-11}$	$4.41x10^{-8}$	$1.76x10^{-8}$	$6.37x10^{-9}$
SS2	$1.25x10^{-10}$	$6.70x10^{-8}$	$2.34x10^{-8}$	$9.04x10^{-9}$	$7.04x10^{-11}$	$3.78x10^{-8}$	$1.32x10^{-8}$	$5.09x10^{-9}$
SS3	$9.77x10^{-10}$	$7.26x10^{-8}$	$2.34x10^{-8}$	$3.47x10^{-9}$	$5.51x10^{-11}$	$4.09x10^{-8}$	$1.32x10^{-8}$	$1.96x10^{-9}$
SS4	$1.82x10^{-10}$	$1.43x10^{-6}$	$2.34x10^{-8}$	$3.30x10^{-9}$	$1.03x10^{-10}$	$8.09x10^{-7}$	$1.32x10^{-8}$	$1.86x10^{-9}$
SS5	$2.04x10^{-10}$	$4.47x10^{-8}$	$9.38x10^{-8}$	$3.12x10^{-9}$	$1.15x10^{-10}$	$2.52x10^{-8}$	$5.29x10^{-8}$	$1.76x10^{-9}$
SS6	$1.93x10^{-10}$	$1.17x10^{-6}$	$1.01x10^{-7}$	$6.25x10^{-9}$	$1.09x10^{-10}$	$6.61x10^{-7}$	$5.73x10^{-8}$	$3.52x10^{-9}$
SS7	$2.01x10^{-10}$	$1.45x10^{-6}$	$1.17x10^{-7}$	$7.12x10^{-9}$	$1.13x10^{-10}$	$8.22x10^{-7}$	$6.61x10^{-8}$	$4.01x10^{-9}$
SS8	$2.12x10^{-10}$	$1.84x10^{-7}$	$1.40x10^{-7}$	$2.95x10^{-9}$	$1.19x10^{-10}$	$1.03x10^{-7}$	$7.94x10^{-8}$	$1.66x10^{-9}$
SS9	$1.22x10^{-10}$	$6.70x10^{-8}$	$2.81x10^{-7}$	$1.56x10^{-9}$	$6.89x10^{-11}$	$3.78x10^{-8}$	$1.58x10^{-7}$	$8.82x10^{-10}$
SS10	$2.71x10^{-11}$	$5.58x10^{-9}$	$7.82x10^{-9}$	$1.39x10^{-9}$	$1.53x10^{-11}$	$3.15x10^{-9}$	$4.41x10^{-9}$	$7.84x10^{-10}$
SS11	-	-	-	-	-	-	-	-
Min.	$2.71x10^{-11}$	$5.58x10^{-9}$	$7.82x10^{-9}$	$1.39x10^{-9}$	$1.53x10^{-11}$	$3.15x10^{-9}$	$4.41x10^{-9}$	$7.84x10^{-10}$
Max.	$2.11x10^{-10}$	$1.45x10^{-6}$	$2.81x10^{-7}$	$1.13x10^{-8}$	$1.19x10^{-10}$	$8.22x10^{-7}$	$1.58x10^{-7}$	$6.37x10^{-9}$

For children scenario, the HQ values ranged from $3.19x10^{-9}$ to $2.49x10^{-8}$ for Pb, $3.72x10^{-10}$ to $9.72x10^{-8}$ for Cd, $1.82x10^{-8}$ to $6.70x10^{-7}$ for Cr, $1.65x10^{-9}$ to $1.34x10^{-8}$ for Ni, $1.67x10^{-10}$ to $7.15x10^{-9}$ for Cu, $7.50x10^{-11}$ to $7.15x10^{-9}$ for Co, and $3.70x10^{-10}$ to $3.50x10^{-8}$ for Zn. For adult scenario, the HQ values ranged from $1.89x10^{-9}$ to $1.40x10^{-8}$ for Pb, $2.10x10^{-10}$ to $5.48x10^{-8}$ for Cd, $1.05x10^{-8}$ to $3.71x10^{-7}$ for Cr,

$9.33x10^{-10}$ to $7.58x10^{-9}$ for Ni, $9.45x10^{-11}$ to $4.03x10^{-9}$ for Cu, $4.20x10^{-11}$ to $1.38x10^{-9}$ for Co, and $2.10x10^{-10}$ to $2.00x10^{-8}$ for Zn. Expectedly, children had an increased exposure to non-carcinogenic risk to heavy metals in PM, compared to adults. However, the total non-carcinogenic hazard, (i.e hazard index values) were less than 1, indicating that there would be no potential adverse non-carcinogenic risk to both children and adult population in the study area. Similar low non-carcinogenic risk values via inhalation of PM has been previously reported around gas flaring sites in Yenagoa area of Bayelsa State.

Table 4: Non-carcinogenic risk of heavy metals in particulate matter

Sampling location	Human group	Average daily intake	Hazard index
SS1		$2.11x10^{-10}$	$8.00x10^{-8}$
SS2		$1.44x10^{-10}$	$6.40x10^{-8}$
SS3		$1.20x10^{-10}$	$6.00x10^{-8}$
SS4		$3.11x10^{-10}$	$1.20x10^{-7}$
SS5		$1.59x10^{-10}$	$1.60x10^{-7}$
SS6	Adult	$2.64x10^{-10}$	$2.10x10^{-7}$
SS7		$2.97x10^{-10}$	$2.40x10^{-7}$
SS8		$1.82x10^{-10}$	$2.30x10^{-7}$
SS9		$8.89x10^{-11}$	$4.00x10^{-7}$
SS10		$1.01x10^{-11}$	$1.40x10^{-8}$
SS11		-	-
SS1		$3.73x10^{-10}$	$1.40x10^{-7}$
SS2		$2.55x10^{-10}$	$1.10x10^{-7}$
SS3		$2.13x10^{-10}$	$1.10x10^{-7}$
SS4		$5.52x10^{-10}$	$2.20x10^{-7}$
SS5		$2.83x10^{-10}$	$2.90x10^{-7}$
SS6	Children	$4.68x10^{-10}$	$3.70x10^{-7}$
SS7		$5.26x10^{-10}$	$4.30x10^{-7}$
SS8		$3.23x10^{-10}$	$4.10x10^{-7}$
SS9		$1.58x10^{-10}$	$7.10x10^{-7}$
SS10		$1.79x10^{-11}$	$2.40x10^{-8}$
SS11		-	-

Source Identification: Factor analysis refers to a group of related mathematical techniques used to examine the hidden or latent structure of a set of variables. In this study, principal component analysis (PCA) was used for source identification and percentage contribution of each source to toxic metals (Ni, Cr, Cu, Pb, Zn, Co and Cd) in ambient air of selected communities in Bayelsa State arising from particulate matter emissions. The results are presented in tables 5 and 6 below. The extraction rate of the toxic metals are 0.593, 0.638, 0.889, 0.878, 0.809, 0.780 and 0.553 for nickel, chromium, copper, lead, zinc, cobalt and cadmium respectively.

The extraction indicates the proportion of each variable's variance that ca be explained by the principal components. Nickel and cadmium showed similar extraction from others. However, the study revealed significant relationship between all the metals in PM.

Table 5: Toxic metal Extraction Communalities

Metals	Initial	Extraction
Ni	1.000	0.593
Cr	1.000	0.638
Cu	1.000	0.889
Pb	1.000	0.878
Zn	1.000	0.809
Co	1.000	0.78
Cd	1.000	0.553

Table 6: Principal Component Analysis

Component	Eigen values	Percentage Variance	Cumulative Percentage
1	3.682	52.600	52.600
2	1.458	20.825	73.426
3	.839	11.979	85.405
4	.719	8.826	94.230

Conclusion: The study showed that the levels of nickel and cadmium in atmospheric particulate matter exceeded US EPA recommended limit. Two major sources of the metals in the particulate matter were identified as gas flaring from various flow stations and uncontrollable fossil fuel combustion from artisanal refineries, and biomass combustion. However, the potential health risk arising from inhalation of the studied metals in particulate matter were negligible.

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