SPATIAL MATRIX EVALUATIONOF HEAVY METALS FROM HEAT VENTILATING AIR CONDITIONING FILTER DUST IN BONNY METROPOLIS

ABSTRACT

This study investigates the spatial distribution and concentration of heavy metals in dust collected from heat ventilating air conditioning (HVAC) filters in Bonny Metropolis. The importance of understanding heavy metal contamination lies in its significant health risks and environmental impact, this research is crucial for understanding environmental contamination in enclosed environments. Samples were collected from 15 coordinate points during the dry season (January-February 2024) using sterilized equipment to prevent cross-contamination. Samples were processed in the laboratory, followed by Flame Atomic Absorption Spectrophotometer (Flame AAS) analysis to quantify metal concentrations. Data analysis involved statistical methodsusing SPSS to determine the mean concentrations and standard deviations of the metals and environmental assessment indicators such as Pollution Load Index (PLI) and Enrichment Factor (EF).Results revealed substantial contamination with heavy metals across various sites. Lead (Pb) levels ranged from 1.40±0.01 to 8.70±0.01 mg/kg, Cadmium (Cd) from 0.001±0.00 to 0.97±0.03 mg/kg, and Chromium (Cr) from 2.04±0.04 to 9.39±0.06 mg/kg, among others. Notably, Pb and Cd levels exceeded WHO and DPR recommended values, indicating significant anthropogenic pollution sources. The contamination profiles varied by location, with specific sites showing higher multiple pollution indices, particularly for Pb, Cd, and Cr. Enrichment factors for heavy metals suggested severe enrichment due to human activities, with Pb, Cd, Cr, Cu, Ni, As, Se, Zn, and Hg significantly elevated at most sites.These findings highlight severe environmental and public health risks, emphasizing the need for urgent remediation and regulatory measures, for improved waste management practices and public awareness of the dangers of heavy metal pollution.Regular maintenance and replacement of HVAC filters, as well as minimizing indoor activities that generate heavy metal-laden dust, are recommended to mitigate exposure. Future research should focus on identifying specific anthropogenic sources and developing effective strategies for mitigating heavy metal pollution in urban environments. The study underscores the importance of continuous monitoring and stricter environmental controls to safeguard public health and environmental air quality in Bonny Metropolis.

KEYWORDS: Heavy Metal Contamination, HVAC Filter Dust Analysis, Spatial Distribution of Metals, Environmental Pollution Assessment, Bonny Metropolis Air Quality, Flame Atomic Absorption Spectrophotometry, Anthropogenic Pollution Sources.

INTRODUCTION

Over the decades troubling phenomena such as climate change, ozone layer depletion, increasing intensity and frequency of natural disasters, decrease of biodiversity, deforestation, black soot deposits, progressive soil acidification, salinization, erosion, poor air quality, and water pollution from human activitieswhich were met to improve quality of life has often led to the opposite effect to the deterioration of human health and environment. Heavy metal pollutants are reaching extremely disturbing levels in industrializedareas like Bonny Island.Polluted air contains one or more hazardous

substances to general health (Musilova *et al.,* 2016). The main pollutants found in the air we breathe include particulate matter(heavy metals), ground-level ozone, hydrocarbons, oxides of carbon, sulphur, and nitrogen (EPHA, 2009).
The definition of heavy metals has been based primarily on the specific gravity of the metals (greater than 5g/cm), their location within the periodic table, and specific biochemical responses in animals and plants (Connell, 2005). Although, there is some evidence that nonessential metals such as Hg, Cd and even Pb and As can demonstrate a dual role of essentiality and toxicity; Generally, the following heavy metals and metalloids such as Hg, Cd, Pb, Sb, Sn and As are the major environmental concerns (Manta *et al.,* 2002). Besides these heavy metals, there is a set of trace metals such as V, Cr, Mn, Co, Ni, Cu, Zn and B, Mo, Se, and Ag, which at elevated concentrations or availability may be toxic and their accumulation in biogeochemical cycles leads to acute or chronic poisoning of plant, animal and human organisms (Bashkin, 2002).Heavy metals can emanate from both natural and anthropogenic processes and end up in different environmental compartments (soil, water, air, and their interface) inFigure 1 below and metals naturally emitted in wind-blown dust are mostly from industrial areas.

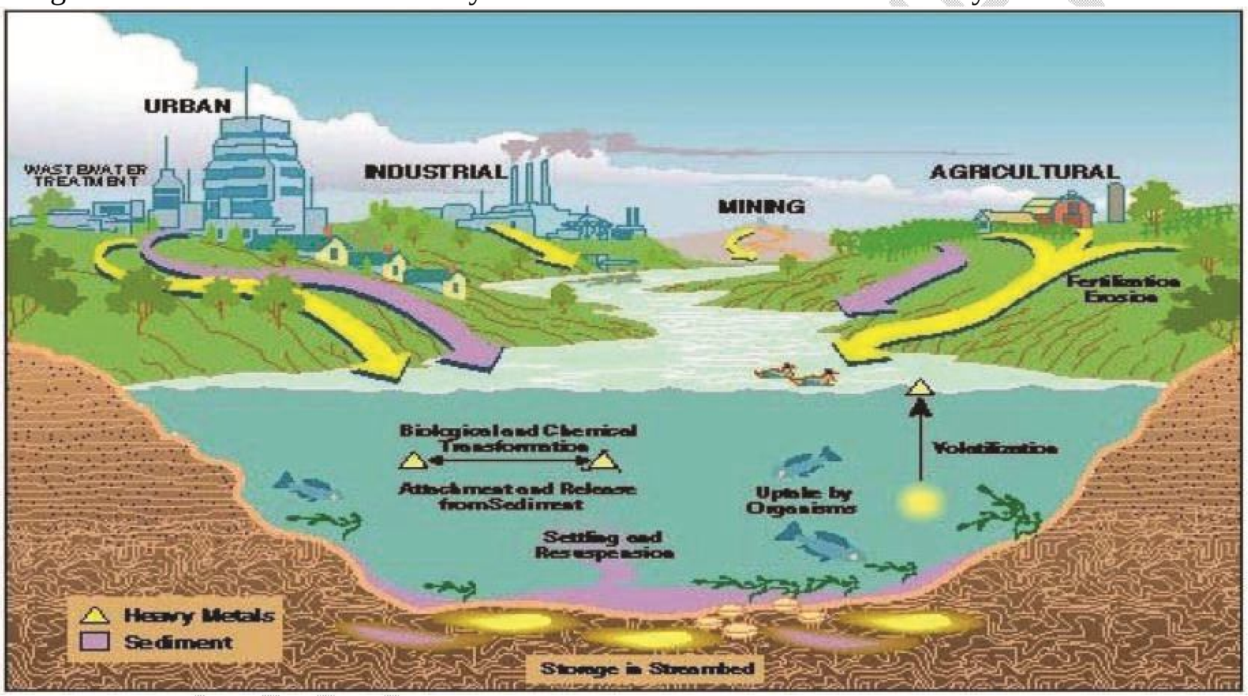

Figure 1: Sources and Sinks of Heavy Metals(Musilova*et al.*, 2016)

Human uptake of metals can occur through inhalation, ingestion of food from household gardens and urban farms with contaminated soils, and recreation in rivers and lakes with polluted waters (Ferreira-Baptista and Miguel, 2005). Siddique *et al.,* (2012) assessed the air quality of Lahore by the elemental analysis of air conditioner (AC) filter dust samples using instrumental neutron activation analysis (INAA). They observed that the concentrations of Ca, Mg, Sn, and Zn were found to be more variable and were found to be dependent on activities such as construction, fruit and vegetable handling, tin plating, and transport, respectively.
Filter forensics (FF) is broadly defined as the use of filters, typically those found in heating, ventilation, and air conditioning (HVAC) systems as long-term passive air samplers. FF has successfully been used to detect a wide range of particle-bound contaminants in a variety of indoor environments even in the same indoor environment; the composition of the air varies. Filters collect many particles and particle-bound contaminants present in indoor air through the ventilation process.

Modern HVAC units have a ventilation system that brings in outside air to replace indoor air with the basic principle of refrigeration cycle for effective control of temperature, and humidity in determination of the overall indoor air quality. By examining the amount, size, distribution, and composition of particles present in filter dust,an assessment of the indoor air quality of a building can be established as depicted in Figure 2. Background levels of naturally occurring heavy metals vary due to local sources and weather patterns (Manta *et al.*, 2002).

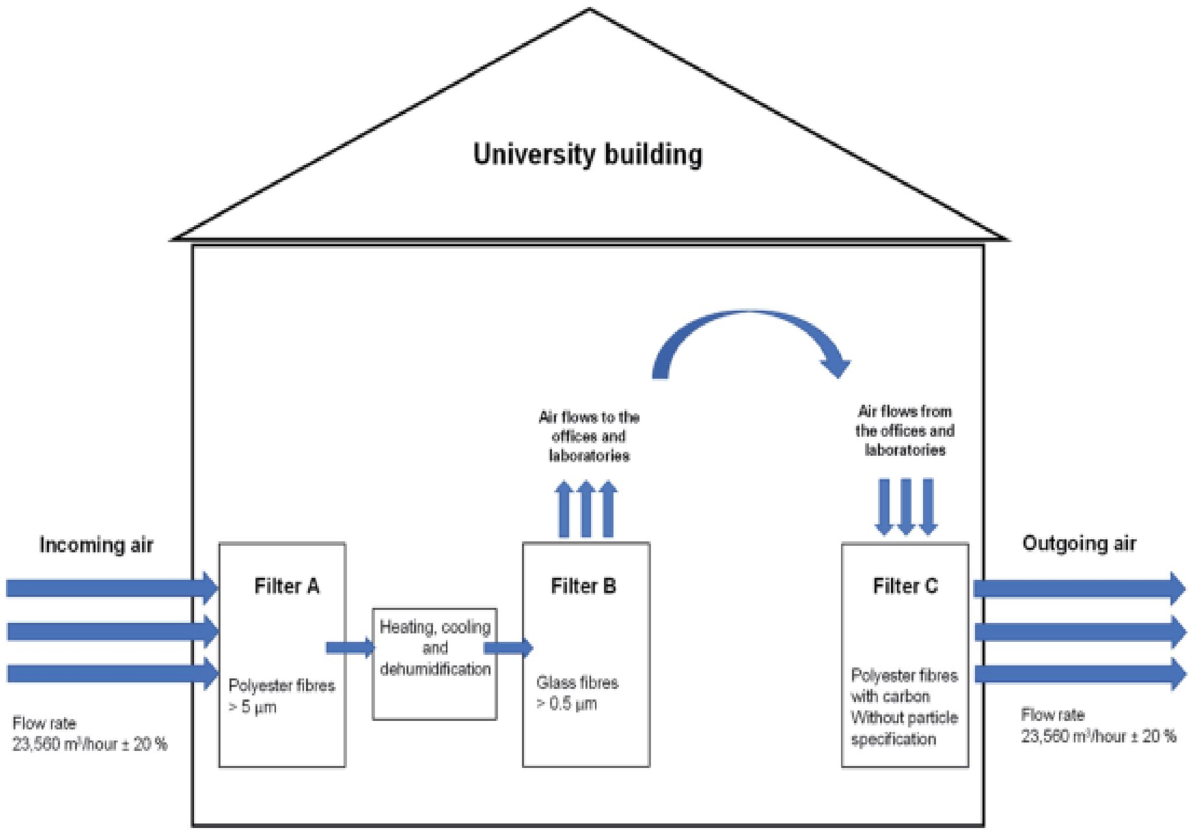

Figure 2: Schematic of an HVAC Unit in a Building(Abbey *et al*., 2021)

The heat ventilating and air conditioning (HVAC) system is equipped with an air filter that traps particulate matter from both in and out direction of the air for cooling/heating purposes through two distinct designs outdoor and indoor strategies. Air enters the system from the outside through an air duct and is mixed just before the filters with return air from the space. The mixed air is pulled through a set of filters (A) where impurities like particulates and gaseous pollutants are removed. As the air moves forward, it passes over a set of cooling coils (B), where the air is cooled, and depending on the dew point of the passing air, may be dehumidified. The air then passes over a set of heating coils where it is heated to the required temperature if necessary. Following the heating coil the air will pass over a set of humidification tubes. If the relative humidity of the passing air is too low these tubes will add moisture to the air as it passes. After the humidifier, the air is pulled into the supply fan, which then pushes it through the supply ductwork, through the diffusers (C) and into the space. The return fan pulls air from the space and pulls it through the return ductwork. Finally, the air is either exhausted to the outside or returned to the unit to be mixed with new outside air and start the cycle all over again (HVAC BASICS, 2017)

Figure 3: HVAC System

The relative contribution of anthropogenic sources compared to natural sources can be higher for metals in urban areas, due to economic growth, advancements of technologies, and industrialization, which have all led to a greater magnitude of natural resource harvesting, changes in the amount, rate of deposition, and type of heavy metal pollution in urban areas have occurred (Pilecka *et al.*, 2017).Other factors such as poor environmental regulation, less efficient technology of production, congested roads, and age and poor maintenance of automobiles also contributed to the reduction in air quality. Exposure to heavy metals in house dust can lead to neurotoxicity, immunotoxicity, hepatic toxicity, haematological toxicity, renal toxicity, endocrine disruption, reproductive and developmental defects, and a variety of cancers, cardiovascular diseases, and skin diseases (Hensley, 2007). Heavy metals can also be found in the form of hydroxides, oxides, sulphides, sulphates, phosphates, silicates, and organic compounds. The most common heavy metals in particulate matterare lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd), arsenic (As), mercury (Hg), zinc (Zn), and copper (Cu). Even in traceamounts, they still cause serious health problems to humans and other mammals (Herawati *et al.*, 2000). Shinggu et al., (2007) reported the heavy metal pollution in Adamawa state, Nigeria. Their finding revealed that heavy metals showed a variation that indicated that Fe>Zn>Pb>As>Cu>Ni>Cr>Cd. It implied that the heavy metal pollutants in the street dust samples of Yola did not originate from common anthropogenic sources. Automobile emission, welding of metal and exhaust from generators may have contributed as one of the major sources of these elements. Heavy metal pollutants in urban street dust have become a growing concern in recent years (Shinggu et al., 2007).According to Mishra (2003), rapid growth in urban population, increasing industrialization, and rising demands for energy and transportation media are worsening air pollution levels. In recent times, indoor air quality has become an increasing environmental and public health issue due to the wide range of physicochemical and biological agents present in the air which cause health/comfort problems (Burge, 2004). Indoor air in most developed settlements contains a mixture of inorganic-organic gaseous species and nonviable particles (Petrick et al., 2011). The sources of indoor pollutant species vary. Incremental amounts of local indoor sources are derived through indoor activities such as cooking (nitrogen oxides – NOX), and smoking (carbon monoxide – CO, particulate matter, NOX, and volatile organic compounds – VOCs). Furniture, building interior surface materials and cleaning products also contribute to indoor emissions (Huang et al., 2011). Usually, outdoor dust infiltrates the indoor environment by advection and diffusion through the vents, doors, open windows, and other passive ventilation portals (Riederer et al., 2005). These dust pathways into living areas are considered passive and are dangerous for residents who may be exposed to larger volumes of dust with high levels of metals and fine particles (Davis and Gulson, 2005). Understanding the nature of each dust pathway, and quantitative assessment of its dust conduction is very important and essential for the development of an effective mitigation strategy (Riederer et al., 2005). A metal-laden particle in an urban area can be mobilized, distributed, immobilized, and scattered. These particles will remain in the air until deposition which is dependent upon many factors, mainly the particle size and properties of the depositional surface (Wong et al., 2006). Recently, atmospheric fallout of pollutants from commonly used products and incineration of trash has led to non-point source pollution in urban areas (Migon et al., 2008). The contamination attributed to the accumulation of heavy metals in street dust is one major way through which heavy metals may find their way into soils and subsequently living tissues of plants, animals, and humans This atmospheric fallout can accumulate in soils, plants, roadways street dust, and waterways.

Bonny residents are aware that outdoor air pollution is a worldwide recognized threat to human health even at low doses evidenced by the large amount of black soot deposits in Bonny Island resulting from the continuous industrial and gas flaring activities released into the surroundings daily. Hence, all residents in residential, and commercial buildings, even 'batcher' houses within the study area are all equipped with centralized HVAC systems (benefit of the steady power supply) which gives rise to the question, does staying indoors tend to air pollution, masterminds the need for urgent evaluation of the quality of air inhaled at industrial and residential areas sincethe quality of life/health on earth is inextricably linked to the overall quality of air within the environment (air is life). The principal mechanism of the HVAC system, installed for a long period allows the application of this dust sampling technique, as long-term high-volume samplers for indoor environments. Therefore, retained or trapped dust collected on the HVAC filters should provide information concerning the indoor air quality of the study area.Hence, identifying the complex matrix of SHD (settled house dust) in HVAC filter dust is a promising area for future research which is vital for protecting human health.

The study aim to investigate the composition of dust particles trapped in HVAC filters from offices and residential homes within the Bonny metropolis for heavy metals (Iron (Fe), Zinc (Zn), Lead (Pb), Arsenic (As), Copper (Cu), Nickel (Ni), Chromium (Cr), Cadmium (Cd), Mercury (Hg) and Selenium (Se) concentrations and determination of the quality of indoor air.

Highlights

1. Evaluation ofdust samplesfrom 15 coordinate points comprising offices andresidential homes in Bonny Island.
2. Determination of heavy metal pollution indices.
5. Determination of indoor air quality, overruling confidence of pollution-free enclosed surrounding disdain.

STUDY AREA

The study area covers offices and residential areas in Bonny Local governments in Rivers State due to the presence of major multinational companies operating within the Island. Bonny Island lies about 40 kilometres south of Port Harcourt, located between latitudes 4°52' N and 5°02' N, and longitudes 6°56' E and 7°04' E, with a population of 270,000 people as shown in Figure 3 (NPC, 2006). The Island has a flat topography, with an elevation of 3.05 atmospheric mean sea level and a total land area of 214.52 m^2 (NLNG, 2005), with tidal floods and land subsidence affecting around 70% of its size. Ibani is the local language on Bonny Island. The Island is connected directly to the Atlantic Ocean where giant oil tankers export crude oil from different oil and Gas Companies. According to previous studies, the seasonal fluctuation of rainfall (mm) in the Niger Delta ranges from 2301 to 3670 mm during the wet season (March to November) and 43 to 97 mm during the dry season

(December to March) (Adejuwon, 2012). Report toEludoyin*et al.*, (2012), Bonny Island lost about 1,793.24 km^2 of coastline between 1986 and 2006, with the majority of this loss (76.62 percent) occurring between 1986 and 2001, coinciding with the massive construction of the Nigerian Liquefied Natural Gas Company (NLNG), expansion of the Shell export terminal, other oil company facilities such as tank farms, and other anthropogenic influence as a result of influx to the small Island. On the banks of the Bonny River and its tributaries, Bonny Island is a rainforest vegetation area with brackish mangrove forest flora. The greater northern part of the island, up to the east of Bonny Town, along the Opobo Channel, is mostly mangroves and is slightly above sea level. Bonny Island's southern Atlantic coast features a beach ridge barrier and a sandy beach.

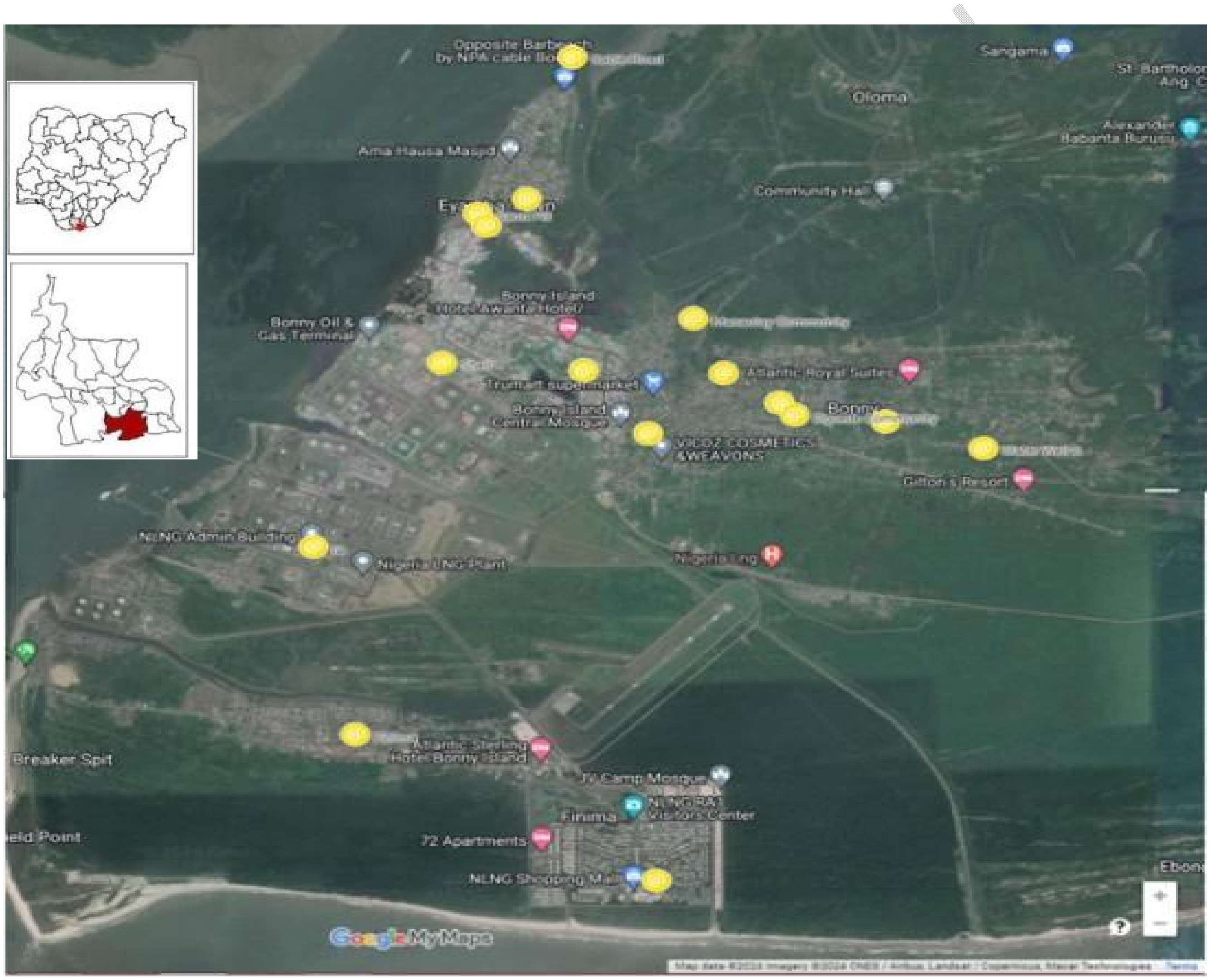

Figure 4: Map of Samples Locations within Bonny Metropolis:yellow oval shapes show the sample collection sites.

Table 1:Sample Details

S/N	Sampling sites	Weight in gram(g)	Temp.(°C)	GPS Coordinate
1	Y-BNY	04.24	173	NL-4º24 ′59″ EL-7º9′21″South (S)

2	C-BNY	8.60	227	NL-4º25′48″EL-7 º9′21″South-West (SW)
3	G-BNY	03.91	34	NL-4º25′33″EL-7 º12′17″North-East (NE)
4	K-BNY	04.44	239	NL-4º25′42″EL-7º11′51″South-West (SW)
5	M-BNY	03.94	118	NL-4º26′51″EL-7º10′3″South-East (SE)
6	V-BNY	03.84	93	NL-4º25′38″EL-7º10′48″East (E)
7	J-BNY	04.47	59	NL-4º26′47″EL-7º10′5″North-East (NE)
8	U-BNY	05.85	274	NL-4º27′43″EL-7º10′28″West (W)
9	O-BNY	05.06	18	NL-4º26′16″EL-7º11′0″North (N)
10	T-BNY	03.77	247	NL-4º25′85″EL-7º11′8″North-West (NW)
11	H-BNY	04.08	197	NL-4º25′44″EL-7º11′27″South (S)
12	N-BNY	04.17	206	NL-4º25′59″EL-7º10′31″North-South (NS)
13	R-BNY	04.99	144	NL-4º26′1.392″EL-7º9′53.279″
14	I-BNY	04.86	36	NL-4º23′56.472″EL-7º9′32.256″
15	E-BNY	05.14	233	NL-4º23′7.836″EL-7º10′52.391″

MATERIALS AND METHODS

Samples were collected from 15 cardinal points (fig 3) in the dry season from January to February 2024. Used an oral hygiene soft bristle toothbrush to sweep the inner and outer surface of the filter unit of the HVAC systemon muti-purpose, plain white paper (210mm by 297mm) into a moisture-proof, biodegradable, disposableantistatic polypropylene press-lock bags bought from Bonny Pharmaceutical shop. Before sample collections, the multi-purpose paper, toothbrush and nylon bags were conditioned in desiccators for a day before and during sample collections to avoid sampling error. Note, that each toothbrush, glove and multipurpose paper used were discarded after each sample collection to eliminate cross-pollution. Safety gadgets such as nose masks, goggles, gloves, and lab cloth were properly kited and precursory measures of ensuring no wind/rotations of fan, power switch of appliances, rain or water splash were observed. After sampling, samples were sieved inthe laboratory with a polystyrene sieve, weighed and dried at room temperature and stored at 4°C in a refrigerator before analysis.

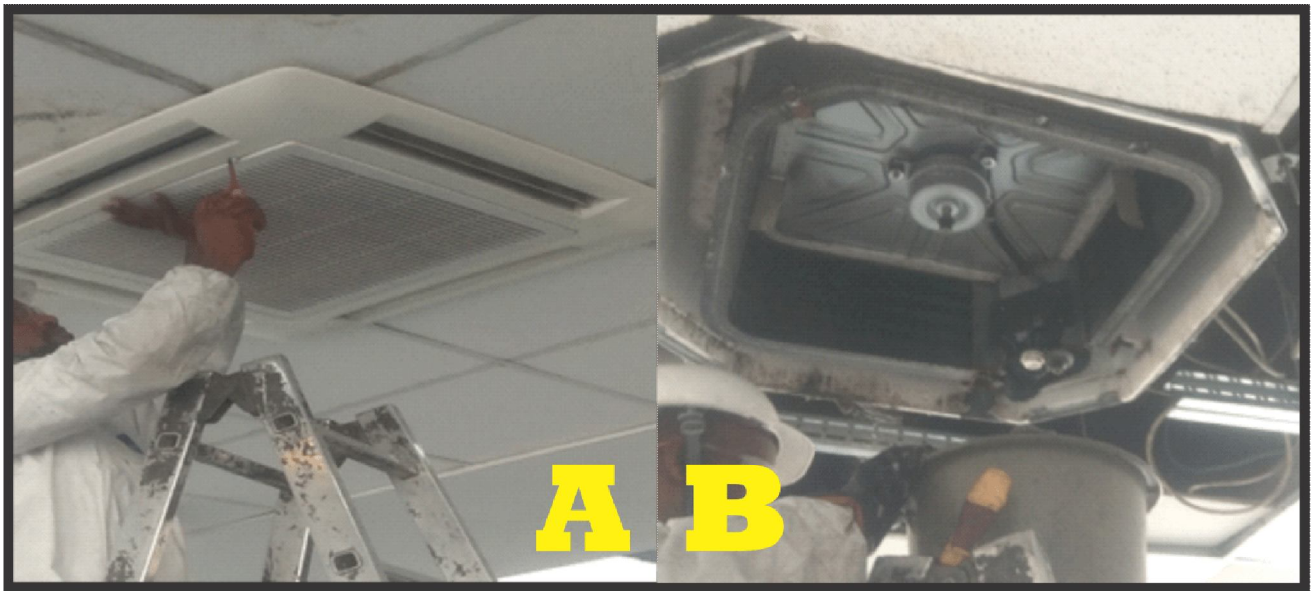

Figure 5: Industrial Sample Collection Steps

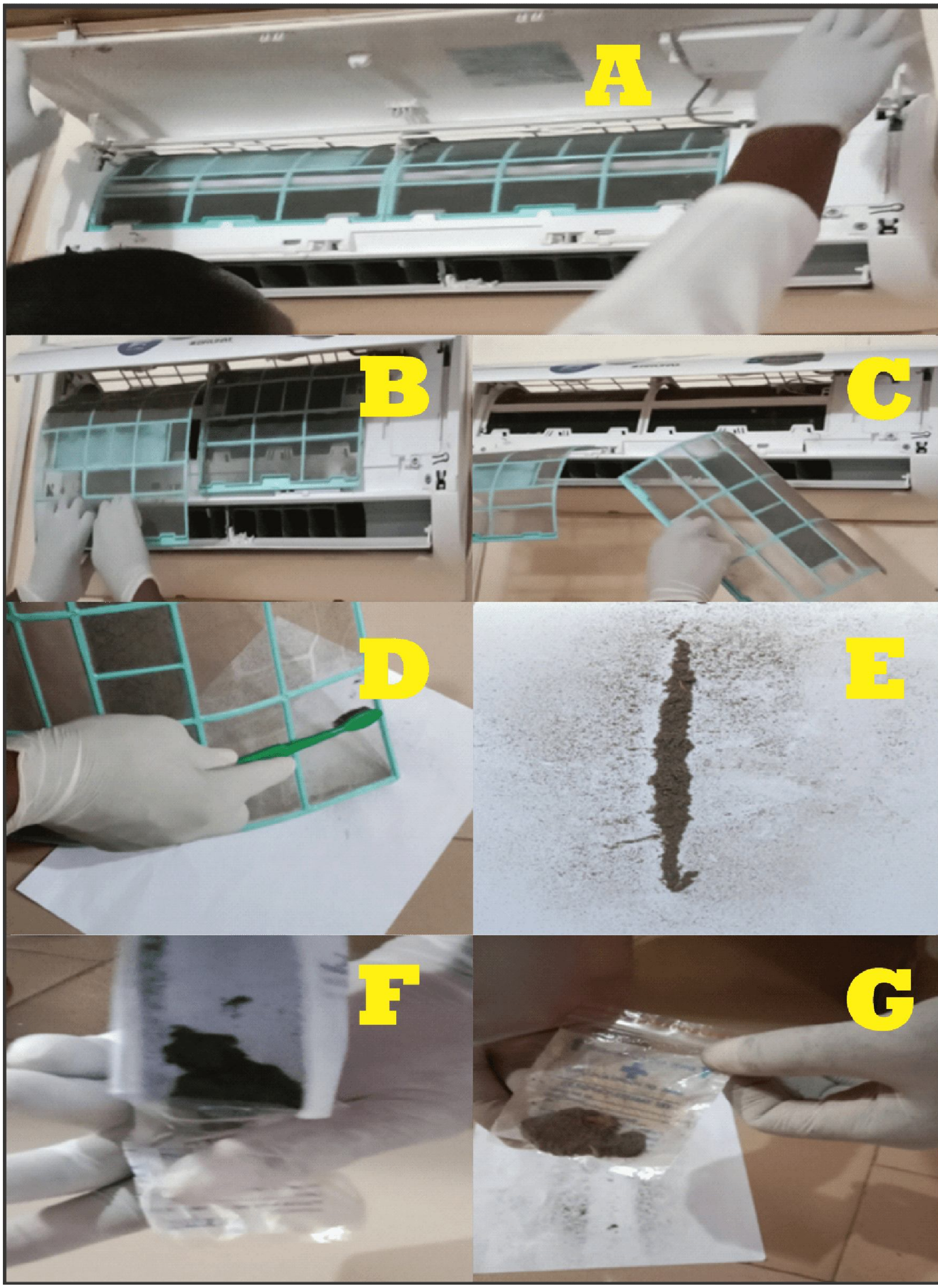

Figure 6: Homes/Offices Sample Collection Steps

The research lasted for about six (6) months via a strategic work plan on relevant approvals from Authorities and Host Communities, Sample Collection, Storage, laboratory and instrumental analysis and data analysis phase with the followingglassware and instruments: Different-sized beakers, glass pipettes, spatula, digestion bottles,Pipets (microliter with disposable tips), filter paper,measuring cylinders, Volumetric flask of suitable precision and accuracy, Erlenmeyer flasks,Funnels, Fume hood, conical flasks, vinyl gloves, Oven, Flame Atomic Absorption Spectrophotometer (Flame AAS) model:S4=71096, Pressure-reducing valves, Block digester, Analytical balance, hot plate, distilled water**,**Acetylene**,** Metal free water**,** Stock metal solution, Potassium chloride solution**,** Hydrogen tetraoxosulphate (vi) acid (H_2SO_4)**,** Trioxonitrate (v) acid (HNO_3)**,** Perchloric acid ($HClO_4$), hydrochloric acid (HCl), Nitrogen gas (Ng) & Air.Weighed 1-3g of the sample into a 100ml conical flask, forthe wet digestion method in a total volume OF 100ml of H_2SO_4, HNO_3, and HClO in a ratio of 40%:40%:20% were mixed. 5ml of the mixed acid was added to each of the samples in 100ml conical flask placed in a fume cupboard with hot plate for digestion process until white fumes appeared, allowed digest to cool and filtered into another 100ml volumetric flask, making up volume with distilled water beforeinjection to Flame Atomic Absorption Spectrophotometer (Flame AAS), Manufacturer's procedures were followed as specified by (ASTM D1971, 2016). observations and records were noted by sample absorbance with that of standards. Read concentration directly from the instrument in milligrams per litre according to calibration and multiply concentration readout by the appropriate dilution factor.All samples wereanalyzed in triplicate, and statistical analysis of means and standard deviations were determined with SPSS.The overall air quality was determined using the mean value of the metal concentration from each location for environmental assessment indicators like pollution load index (PLI) and enrichment factor (EF).

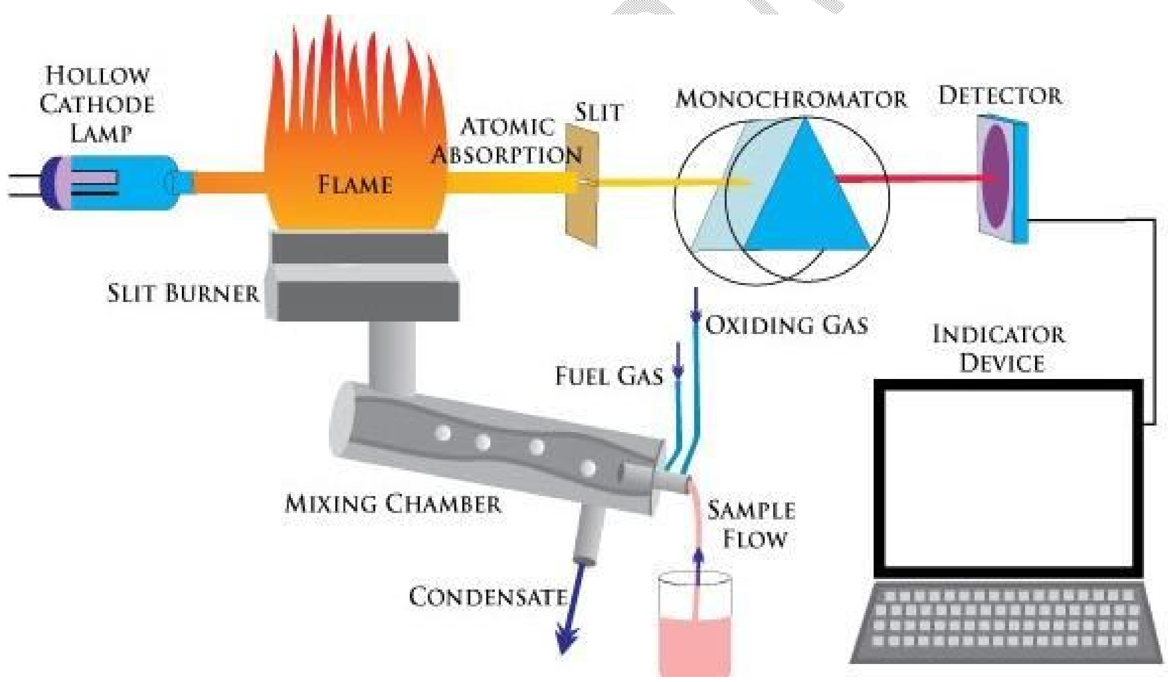

Figure 7: The principle of AAS instrumentation

The reference value was taken from the crusta abundance value of respective sampled metals (1961). A C/PI (Contamination/pollution index) value >1 shows the pollution range while values <1 show the contamination range. Multiple pollution index (MPI) was calculated from the sum of respective metals from sampled dust's C/PI values greater than 1.

Table 2: Significance of indices for contamination/pollution, and Index of geo-accumulation.

C/PI[21]	Significance
<0.1	Very slight contamination
0.10–0.25	Slight contamination
0.26–0.5	Moderate contamination
0.51–0.75	Severe contamination
0.76–1.0	Very severe contamination
1.1–2.0	Slight pollution
2.1–4.0	Moderate pollution
4.1–8.0	Severe pollution
8.1–16.0	Very severe pollution
>16.0	Excessive pollution

PRESENTATION OF RESULT

The results of the heavy metal contents from heat ventilating air conditioning (HVAC) filter dust in Bonny Island are shown in Table 3. Results obtained showed Pb 1.40±0.01(at G) to 8.70±0.01 (E), Cd 0.001±0.00(at G) to 0.97±0.03 (at Y), Cr 2.04±0.04 (at R) to 9.39±0.06 (at K), Cu 3.70±0.02 (at G) to 11.62±0.01 (at K), Ni 0.08±0.0(at J) to 4.22±0.02 (at K), As 0.003±0.0 (at V) to 1.23±0.03(at Y) Se 0.001±0.0(at E) to 0.33±0.02(at Y), Zn 1.86±0.02(at H) to 5.40±0.01 (at Y) Fe 1.05±0.04 (at G) to 7.52±0.08(at I), Hg 0 (at G, N & R) to 0.003±0.0 (at Y) all in mg/Kg^{-1}. The values obtained were above WHO and DPR recommended values for all metals except Zn and Fe which were quite minimal compared to recommended standards.From the mean results, Cadmium (Cd) metal is present at all sample sites in decreasing order M>R>Y>J>I>H>V>T>E>K>U>C>N>O>G and had its highest value of 9.54mg/kg-1 to 3.88 lowest value. Table 3. also indicates Chromium (Cr) metal levels in 12 sites except for sites G,R & V, with similar occurrence applied for Lead (Pd) outside sites C & G, others in high values. Iron (Fe) is also predominant leaving only site Y,K,G & H. Zinc (Zn) metal had its highest value at site Y. All other metals at their mean value were insignificantly low levels.

The results of the Contamination/Pollution Index (C/PI) of Heavy Metals in the Samples from heat ventilating air conditioning (HVAC) filter dust in Bonny Island are shown in Table 5. Results obtained showed Pb 0.02 (at G) to 0.1 (E), Cd 0.001 (at G) to 1.21 (at Y), Cr 0.02 (at R) to 0.09 (at K), Cu 0.04 (at G) to 0.08 (at K), Ni 0.0001 (at J) to 0.04 (at Y), As 0.1 (at G) to 0.32 (at M) Se 0.004 (at E) to 1.35 (at Y), Zn 0.01 (at H) to 0.04 (at Y) Fe 5.2E-05 (at G) to 70.0004 (at I), Hg 0 (at G, N & R) to 0.04 (at K). The multiple pollution index ranged from 0 to 2.57.The results of the Heavy Metal Enrichment Factor (EF) of Samples from heat ventilating air conditioning (HVAC) filter dust in Bonny Island are shown in Table 6. Results obtained showed highly enriched samples with Pb 862 (C) to 2239.02 (at G), Cd 171.84 (at G) to 63248.66 (at Y), Cr 190.8742 (at R) to 2277.912 (at K), Cu 9.18 (at J) to 1130.813 (at K), Ni 3.11 (at V) to 1790.3 (at Y), As 840.8602 (at U) to 4354.941 (at G) Se 13.24 (at E) to 9879.21 (at Y), Zn 219.31 (at E) to 1547.40 (at G) Fe 1, Hg 0 (at G, N & R) to 893.47 (at K). From the mean results, Cadmium (Cd) metal is present at all sample sites in decreasing order M>R>Y>J>I>H>V>T>E>K>U>C>N>O>G and had its highest value of 9.54mg/kg-1 to 3.88 lowest value. Table 1 also indicates Chromium (Cr) metal levels in 12 sites except for sites G,R & V, with similar occurrence applied for Lead (Pd) outside sites C & G, others in high values. Iron (Fe) is also predominant leaving only sites Y,K,G & H. Zinc (Zn) metal had its highest value at site Y. All other metals at their mean value were insignificantly low levels

Table 3: Heavy Metal Contents of Samples (mg kg^{-1})

S/M	Pb	Cd	Cr	Cu	Ni	As	Se	Zn	Fe	Hg
Y	3.65±0.02^{a}	0.97±0.03^{a}	5.89±0.05^{a}	8.09±0.04^{a}	1.98±0.03^{a}	1.23±0.03^{a}	0.33±0.02^{a}	5.40±0.01^{a}	2.78±0.05^{a}	0.003±0.0^{a}
C	1.73±0.09^{a}	0.08±0.00^{a}	8.0±0.05^{a}	4.06±0.05^{b}	1.02±0.02^{a}	0.07±0.00^{a}	0.13±0.01^{a}	2.71±0.03^{a}	3.40±0.01^{a}	0.002±0.0^{a}
G	1.40±0.01^{a}	0.001±0.00^{a}	2.72±0.01^{b}	3.70±0.02^{b}	1.42±0.02^{a}	0.01±0.00^{a}	0.014±0.0^{a}	3.51±0.02^{a}	1.05±0.04^{a}	BDL
K	4.93±0.09^{a}	0.15±0.01^{a}	9.39±0.06^{a}	4.97±0.06^{b}	3.09±0.05^{a}	0.004±0.0^{a}	0.25±0.00^{a}	2.08±0.02^{a}	1.84±0.01^{a}	0.01±0.00^{a}
M	4.40±0.06^{a}	0.34±0.02^{a}	6.78±0.06^{a}	11.62±0.01^{a}	4.22±0.02^{a}	0.02±0.00^{a}	0.08±0.01^{a}	3.98±0.02^{a}	6.41±0.01^{b}	0.002±0.0^{a}
V	3.70±0.01^{a}	0.04±0.00^{a}	2.80±0.01^{b}	6.21±0.03^{a}	0.82±0.01^{a}	0.003±0.0^{a}	0.02±0.00^{a}	3.05±0.04^{a}	3.92±0.07^{a}	0.002±0.0^{a}
J	6.21±0.06^{b}	0.02±0.00^{a}	3.99±0.02^{b}	7.18±0.03^{a}	0.08±0.06^{a}	0.04±0.00^{a}	0.15±0.00^{a}	2.39±0.08^{a}	5.00±0.02^{b}	0.001±0.00^{a}
U	8.33±0.16^{b}	0.04±0.00^{a}	8.99±0.02^{a}	4.80±0.05^{b}	1.13±0.03^{a}	0.02±0.00^{a}	0.04±0.00^{a}	4.94±0.06^{a}	7.09±0.04^{b}	0.002±0.0^{a}
O	5.99±0.02^{a}	0.01±0.00^{a}	5.95±0.09^{a}	3.88±0.02^{b}	2.79±0.04^{a}	0.08±0.00^{a}	0.08±0.06^{a}	3.09±0.06^{a}	5.00±0.01^{b}	0.01±0.01^{a}
T	7.00±0.01^{b}	0.03±0.00^{a}	8.24±0.06^{a}	5.98±0.03^{a}	1.73±0.01^{a}	0.02±0.00^{a}	0.03±0.00^{a}	2.79±0.03^{a}	4.98±0.02^{a}	0.002±0.0^{a}
H	4.0±0.01^{a}	0.17±0.01^{a}	3.74±0.02^{b}	6.50±0.0^{a}	3.54±0.04^{a}	0.11±0.00^{a}	0.04±0.0^{a}	1.86±0.02^{a}	3.01±0.05^{a}	0.02±0.0^{a}
N	6.59±0.00^{b}	0.03±0.00^{a}	4.13±0.04^{a}	4.041±0.01^{b}	1.97±0.03^{a}	0.23±0.01^{a}	0.06±0.00^{a}	4.97±0.03^{a}	5.73±0.07^{b}	BDL
R	8.17±0.05^{b}	0.09±0.00^{a}	2.04±0.04^{b}	9.54±0.10^{a}	3.78±0.06^{a}	0.14±0.01^{a}	0.11±0.00^{a}	2.40±0.02^{a}	4.77±0.06^{a}	BDL
I	4.31±0.09^{a}	0.37±0.02^{a}	6.31±0.08^{a}	7.09±0.08^{a}	2.05±0.05^{a}	0.49±0.01^{a}	0.04±0.00^{a}	4.07±0.06^{a}	7.52±0.08^{b}	0.002±0.0^{a}
E	8.70±0.01^{b}	0.03±0.00^{a}	7.99±0.01^{a}	5.00±0.02^{a}	1.49±0.13^{a}	0.004±0.0^{a}	0.001±0.0^{a}	3.01±0.01^{a}	6.38±0.07^{b}	0.002±0.0^{a}

Values represent Mean± SEM. At n=3 and $p \leq 0.05$ Mean in the same column with the same superscript alphabet is not significantly different, while the mean in the same column with different superscript alphabets is significantly different at $p \leq 0.05$.

Table 4: Contamination/Pollution Index (C/PI) of Heavy Metals in the Samples

MET SAM	Pb	Cd	Cr	Cu	Ni	As	Se	Zn	Hg	Fe	MPL
Y	0.043	1.214	0.05885	0.056514	0.04231	0.224639	1.354167	0.038593	0.01	0.0001	2.57
C	0.020	0.101	0.07995	0.029229	0.002414	0.112861	0.558333	0.019386	0.007	0.0002	
G	0.016	0.001	0.02718	0.040457	0.000483	0.102639	0.058333	0.025079	0	5.2E-05	
K	0.058	0.188	0.0939	0.088143	0.000138	0.138028	1.054167	0.014871	0.043	9.09E-05	1.05
M	0.052	0.421	0.06784	0.120514	0.000586	0.322778	0.3125	0.02845	0.007	0.0003	
V	0.044	0.05	0.02796	0.023543	0.000103	0.172361	0.066667	0.021814	0.007	0.0002	
J	0.073	0.023	0.03993	0.001943	0.001379	0.199361	0.629167	0.017079	0.003	0.0003	
U	0.098	0.044	0.08989	0.032171	0.000586	0.133417	0.166667	0.035307	0.007	0.0004	
O	0.070	0.008	0.05953	0.079686	0.002862	0.107917	0.341667	0.022093	0.04	0.0003	
T	0.082	0.035	0.08242	0.049343	0.000793	0.166028	0.129167	0.019914	0.01	0.0003	
H	0.047	0.21625	0.03736	0.101029	0.003862	0.1805	0.170833	0.013257	0.053	0.0002	
N	0.078	0.04125	0.04133	0.056286	0.007931	0.11225	0.258333	0.035471	0	0.0003	
R	0.096	0.1125	0.02036	0.107886	0.004724	0.264861	0.466667	0.017121	0	0.0002	
I	0.051	0.4575	0.0631	0.057943	0.016931	0.196944	0.1625	0.029057	0.007	0.0004	
E	0.102	0.0375	0.07987	0.042429	0.000138	0.139	0.004167	0.021529	0.007	0.0003	

Where C/PI - <0.1(Very slight contamination), 0.10–0.25 (Slight contamination) 0.26–0.5, (Moderate contamination), 0.51–0.75 (Severe contamination), 0.76–1.0 (Very severe contamination), 1.1–2.0 (Slight pollution), 2.1–4.0(Moderate pollution), 4.1–8.0(Severe pollution), 8.1–16.0(Very severe pollution), >16.0 (Excessive pollution). MPI – multiple pollution index

Table 5: Heavy Metal Enrichment Factor (EF) of Samples

MET SAM	Pb	Cd	Cr	Cu	Ni	As	Se	Zn	Hg	Fe
Y	2215.983	63248.66	947.1329	481.0112	1790.295	3612.862	9879.211	902.6137	136.7891	1
C	862.602	4317.274	1052.871	203.5621	83.5739	1485.263	3333.007	370.996	74.61955	1
G	2239.021	171.8446	1154.032	908.4395	53.89048	4354.941	1122.718	1547.397	0	1
K	4517.756	14727.54	2277.912	1130.813	8.797252	3346.107	11592.21	524.2695	893.4709	1

M	1160.106	9517.865	473.3995	444.747	10.75491	2250.856	988.5023	288.506	39.54009	1
V	1594.87	1848.339	319.2208	142.1496	3.10521	1966.506	345.0233	361.9308	64.69187	1
J	2096.343	651.0381	356.8334	9.182048	32.40723	1780.363	2548.693	221.7932	25.31815	1
U	1984.07	893.4031	566.9217	107.3037	9.720225	840.8602	476.4816	323.5973	35.73612	1
O	2023.152	217.2733	532.627	377.0512	67.32574	964.8902	1385.721	287.2564	304.1826	1
T	2376.326	1091.17	740.6895	234.5095	18.73903	1491.03	526.1866	260.0752	76.38192	1
H	2243.617	10407.17	555.2975	794.1372	150.922	2681.008	1151.005	286.3514	673.759	1
N	1942.798	1042.68	322.6524	232.3808	162.7845	875.7051	914.1883	402.4192	0	1
R	2892.254	3414.912	190.8742	534.8916	116.4409	2481.359	1983.179	233.2598	0	1
I	968.6111	8812.852	375.4024	182.3056	264.8286	1170.883	438.2347	251.2182	33.71036	1
E	2302.694	851.1402	559.8812	157.2907	2.542072	973.7086	13.23996	219.3097	39.71988	1

EF values less than 2 refer to deficiency to minimal enrichment, between 2 & 10 indicate moderate enrichment, whereas higher than 10 shows severe enrichment.

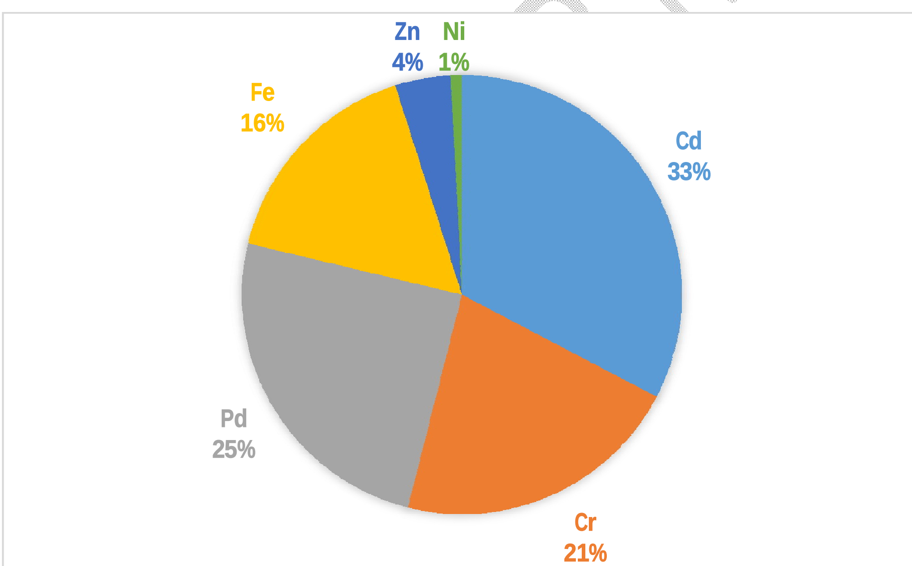

Figure 8: Percentage of Preeminent Heavy Metals

RESULTS&DISCUSSION

The level of these metals obtained from different sample sites as shown in Table 3revealed notable differences when compared with known standards.

The results of the heavy metal contents from heat ventilating air conditioning (HVAC) filter dust in Bonny Island are shown in Table 3. Revealed heavy metals contamination with a range as follows; Pb 1.40±0.01(at G) to 8.70±0.01 (E), Cd 0.001±0.00(at G) to 0.97±0.03 (at Y), Cr 2.04±0.04 (at R) to 9.39±0.06 (at K), Cu 3.70±0.02 (at G) to

11.62±0.01 (at K), Ni 0.08±0.0(at J) to 4.22±0.02 (at K), As 0.003±0.0 (at V) to 1.23±0.03(at Y) Se 0.001±0.0(at E) to 0.33±0.02(at Y), Zn 1.86±0.02(at H) to 5.40±0.01 (at Y) Fe 1.05±0.04 (at G) to 7.52±0.08(at I), Hg 0 (at G, N & R) to 0.003±0.0 (at Y) all in mg/Kg^{-1}. The values obtained were above WHO and DPR recommended values for all metals except Zn and Fe which were quite minimal compared to recommended standards.

However, different heavy metals were shown to be maximum at different locations, Seregin and Ivaniov, (2001) reported that Pb has the potential to alter membrane permeability, water imbalance, inhibit enzyme activities, and mineral nutrition disturbance with lots other lethal effects at high Pb dosage. A report by Uaboi – Egbenni, (2010) also shows Its toxic effect on kidneys, liver etc. Studies revealed that Cadmium even at Low ingestion is toxic and could on chronic exposure lead to; bone disorders, (Asia *et al.*, 2008; Dan-lin*et al.*, 2011). Dayan and Paine, (2001) reported that Cr(III) exposure could be associated with respiratory diseases, with evidenced wheezing, coughing etc. while High iron content could hamper chlorophyll synthesis in plants hence starving plants of vital nutrients and probable sugars, hence limiting plants from producing their energy from the sunlight (Lacoma, 1999).

Heavy metal contamination and pollution profiling of the same samples show very slight contamination with Pb, Cr, Zn, Ni, Hg and Cu, while Fe shows no contamination at all sampled locations, Cd was shown to contaminate site G, J, U, O, T, N and E very slightly, while slightly contaminating site C, K, H, and R, moderate Cd contamination was seen at location M, and I, while very severe contamination was seen at location Y. Copper, was seen to have contaminated all sites very slightly except at sites M, H, and K which was shown to be slightly contaminated. Arsenic was seen to show slight contamination at all sites except at site M which is seen as moderate contamination. No selenium contamination was seen at site E, however, sites Y and K showed moderate pollution with Se, while sites C, and J, showed severe Se contamination, sites M, O and N were shown to be moderately polluted while the rest of the site were seen to be either very slightly or slightly polluted. In general sites Y and K gave an indication of a high multiple pollution index as shown in Table 4 above.

The enrichment factor (EF) of the heavy metals at the sampled sites was calculated. This is a widely used metric for determining how much the presence of an element in a sampling media has increased relative to average natural abundance because of human activity. Calculation of an EF requires the selection of both a background composition and a reference element. The crustal values and Department of Petroleum Resource (DPR) values were used as the background value for this study while Iron (Fe) was used as the reference element. The EF values less than 2 refer to deficiency to minimal enrichment, while values between 2 & 10 indicate moderate enrichment, whereas higher than 10 shows severe enrichment. This study hence shows that Pb, Cd, Cr, Cu, Ni, As, Se, Zn and Hg were all severely enriched at all sample sites except at sites G, N and R where Hg was shown to be below the detectable limit. Enrichment factor is generally used to designate bodies of minerals and or elements. It is defined as the minimum factor by which the weight percent of a mineral in an orebody is greater than the average occurrence of that mineral in the Earth's crust. This is often used to compare the necessary enrichment of different types of minerals for their recovery to be economically viable. Calculating the most representative EF values is useful for numerical assessment of enrichment, whether anthropogenic or natural (Wei *et al.*, 2010; Wei *et al.*, 2015).

In light of the above, the findings from this study show that these heavy metals have an anthropogenic source that has severely contributed to the pollution of the clouds of dust from heat-ventilating air conditioning (HVAC) filter samples from Bonny Island.

However, it is notable that Pb presence in the dust samples corroborates the findings of Popoola *et al.*, (2012) who reported Pb presence in classroom dusts of schools within Lagos State. It has also been reported that Pb may become toxic to plants and animals if their concentrations exceed certain levels (0.0035) as set by USEPA and WHO (Aydinalp and Marinova, 2009), as Pb has the potential to inhibit water imbalance, alter mineral nutrition, enzyme activities, hormonal status and membrane permeability alteration. Reports have shown that Pb at increased concentrations could inhibit cellular activities thus causing cell death (Seregin, and Ivaniov, 2001). It also has a toxic destructive impact on the kidneys, central nervous system, reproductive system, liver etc with the most severe effect being brain necrosis, which hence poses a dangerous threat to our environment. (Ademoroti, 1996; Asia *et al.,* 2008; Uaboi – Egbenni, 2010). The Pb Levels corroborate with reports by Addo *et al*., 2012 (in Ketu-Ghana), Abbey *et a*l., 2021(Rivers, Nigeria) and Popoola *et al.,* 2012 (Lagos, Nigeria). The low levels of Pb as obtained could be attributable to the ban on leaded gasoline in Nigeria which often time is a vital input of Pb pollution in urban areas as well as the low productivity of most industries in Rivers State.

It's been reported that exposure to Pb can cause damage or reduce children's intelligence and academic performance. It also has the potential to decrease hearing ability and children's sight, and could cause memory loss and attention deficit disorders (Sanborn *et al.,* 2002).

The mean Cd levels seen are of high public health concern as Gough *et al.,* 1979; Adriano, 1986 and Aydinalp and Marinova, 2009; have independently reported that Cd does not have any known beneficial effects and could become toxic to plants and animals on bioaccumulation whereas Asia *et al.,* 2008 reported that Cd is toxic even if absorption by ingestion is low. Chronic exposure to elevated cadmium levels in food causes bone disorders, including osteoporosis and osteomalacia (Asia *et al.,* 2008). The EPA, (1971) accounted for the moderate toxicity of Cadmium to all organisms, with cumulative poisoning in animals concentrating at the liver, kidney, pancreas and thyroid of humans and other mammals (EPA, 1971). Its major route of entrance in humans is through the gastrointestinal tract by consumption of foods grown on contaminated soil, however, smokers may receive a considerable part of their cadmium by inhaling cigarette smoke (Corbett *et al*., 2002 and Iqbal, 2011). Cadmium levels on average as observed in this study were above the average concentration in the earth's crust 0.2µg/g (Lewis, 2004), suggesting an anthropogenic Cd source, most especially at site Y.

Studies have shown that occupational exposure to Cr(III) via inhalation has been associated with respiratory effects with evidenced wheezing, coughing, etc. (Novey and Habib, 1983; Abbey *et al.*, 2021). Other observable symptoms include; hyperemia, asthma,chronic rhinitis, chronic bronchitis, chronic pharyngitis, tracheobronchitis, etc.(Dayan and Paine, 2001). Chromium absorbed via dermal contact could trigger an immune response. Sensitized people will showcase allergic dermatitis when exposed to high chromium levels. Localized vesicular lesions on points of contact or eczematous dermatitis could suggest sensitization (Lewis, 2004; ATSDR, 2000). Lung cancer risk analysis suggests potential excessive death risk from lung cancer amongst U.S. workers exposed to previous permissible limits for Cr(VI) (52 µg m^{-3}) (Braver and Infante, 1985). Recent studies also disclosed excessive mortal lung cancer risk from occupational Cr(VI) compound exposure(Gibb and Lees, 2000; Park and Bena, 2004).

Activities of localized industries within sampled sites might be responsible for the high Chromium levels reported in this study as the result showed that Cr is of a high amount.

The results of this study showed that mean Arsenic (As) could be of worrisome negative impact. The IARC has grouped/classed arsenic and its compounds as carcinogenic agents to humans (IARC, 1987; WHO, 2016) with other potential adverse effects like diabetes, cardiovascular disease, neurotoxicity, pulmonary disease etc (WHO, 2016). However significant high mortality rate could be observed from As-induced myocardial infarction.

The NIOSH (National Institute for Occupational Safety and Health) recommended limit of exposure is 2 $\mu g\ m^{-3}$ of air for not more than 15 minutes, based on the classification of arsenic as a potential human carcinogen.

CONCLUSION

The trapped dust in HVAC air filters was analyzed, revealing significant heavy metal accumulation, distribution, and contamination, serving as a reliable tool for assessing air pollution even in enclosed environments such as residential homes and offices in Bonny Island. Some identified metals are carcinogenic. Source apportionment indicates that the primary contributors are anthropogenic activities within and around the area. Metals like Cd, Pb, Cr, Cu, Ni, As, Se, and Zn are predominantly enriched particulate matter pollutants, posing severe health risks to children, youth, adults, and the elderly in the study areas. The sources of Cadmium, Chromium, Lead, Iron, and Zinc include industrial activities (natural gas refining, fossil fuel combustion, oil burning for energy), vehicle emissions (exhaust, tyres, and brake pads), construction activities, and unregulated waste disposal (industrial/domestic waste). Unfortunately, these activities are prevalent in the rapidly developing urban area of Rivers State, Nigeria.

Exposure to these heavy metals (Cd, Pb, Cr, Ni) through inhalation, ingestion, skin contact, food, water, and occupation poses potential carcinogenic and non-carcinogenic risks, leading to major health problems and even death through oxidative stress, inflammation, and disruption of cellular signalling pathways, depending on the exposure level and duration as well as individual susceptibility. Therefore, there is an urgent need for proper waste management and public awareness regarding the dangers of heavy metal pollution, exposure sources, and associated health risks, even in seemingly safe enclosed environments. Periodical cleaning and replacement of HVAC filters, use of dust-absorbing mats in and out of offices and homes, and reducing indoor activities that generate smoke are recommended to mitigate these risks.

RECOMMENDATION

1. There should be continuous monitoring and research into new technologies and strategies to curb the constant flaring of gas within Bonny Island,
2. Government should set emission standards and encourage the use of scrubbers, filters, catalytic converters,
3. Enforce sustainable policies in monitoring heavy metals concentration levels in air quality within offices and residential homes.

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