Assessment of heavy metals in air around industrial area of Bonny Island, Rivers State, Nigeria.

ABSTRACT

Heavy metals are naturally found in the environment. However, industrial activities can enhance their concentrations in various environmental media. This is of great concern because of their lethal effects on the ecosystem even in small concentrations. Consequently, the concentrations of Cd, Cr, Pb, Fe, Zn, Cu, Mn and As in $PM_{2.5}$ around industrial area of Bonny Island were investigated. Air samples were collected using the Environmental Monitoring Systems (EMS) High Volume Air Sampler (HVAS). The instrument was set to operate at the specified flow rate for each monitoring period. The filter collected from each of the study stations was prepared for Flame Atomic Absorption Spectrophotometer (FAAS) analysis. The results showed that the concentrations of Cadmium (Cd), Copper (Cu), Lead (Pb) and Arsenic were generally low across the study stations. Whereas Fe, Zn, Cr and Mn had mean concentrations of 36.04 µg/m^3, 15.57 µg/m^3, 1.51 µg/m^3 and 0.60 µg/m^3 respectively. The heavy metals investigated in this study were distributed in this order: Fe>Zn>Cr>Mn>Cd≥Pb≥Cu≥As. The enrichment factor (EF) of Cd, Cu, Pb, Zn and As, ranged between <1 and <10, the EF of Mn was >100 but <1000 while the EF of Cr was >1000. The concentrations of Cr and Mn obtained in $PM_{2.5}$ exceeded their thresholds of 1.1 µg/m^3 and 0.15 µg/m^3 respectively by the World Health Organization. This implies that the residents of Bonny, especially those who live around the industrial area, might be exposed to high concentrations of Cr and Mn. Hence, regular monitoring of heavy metals around industrial areas is strongly recommended for a healthy environment.

Comment [p1]: From the figure in methodology, you did not use HVAS, It is only mini pump Should write according to you action

Comment [p2]: Should specific averaging time

KEYWORDS

Heavy Metals, Pollution, Air Quality, Industrial Area, Bonny Island, Enrichment Factor.

1. INTRODUCTION

Pollution of environmental media by heavy metals has been a major global concern. This is due to their numerous sources, widespread distribution and effects on the ecosystem. Heavy metals are naturally occurring elements characterized by their high atomic mass and density. More recently, the definition has been broadened to include naturally occurring elements with atomic numbers greater than 20 (Ali and Khan 2018; Ali *et al.*, 2020). They occur in low concentration and can be found all through the crust of the planet. Some heavy metals like copper, iron, zinc, cobalt, nickel, manganese and molybdenum are broadly grouped into essential trace elements, whose functions are indispensable for various biological processes and driving the entire human metabolism. For example, cobalt acts as the central atom in vitamin B12 complex, it is a key player in the reductive branch of the propionic acid fermentation pathway (Stowers *et al.*, 2014). Iron is an essential element of various metabolic processes in humans, including DNA synthesis, electron transport, and oxygen transport (Ems *et al.,* 2023). Zinc, a constituent of more than 200 enzymes, plays an important role in nucleic acid metabolism, cell replication, tissue repair and growth through its function in nucleic acid polymerases (Ursula *et al*., 1999; Halstead and Smith, 1970). Copper is an essential nutrient that is widely distributed in food and water and a component of several metalloenzymes that are required for oxidative metabolism, including cytochrome oxidases, ferroxidases, amino oxidases, superoxide dismutase, ascorbic acid oxidase and tyrosinase. Manganese functions both as a cofactor activating many enzymes that form metal-enzyme complexes and as an integral part of certain metalloenzymes. It is also involved in the metabolism of biogenic amines and participates in the regulation of carbohydrate metabolism (Hurley and Keen, 1987). Despite these functions, trace elements are toxic at high concentrations. On the other hand, metals like mercury, cadmium, arsenic, chromium, lead, etc., are

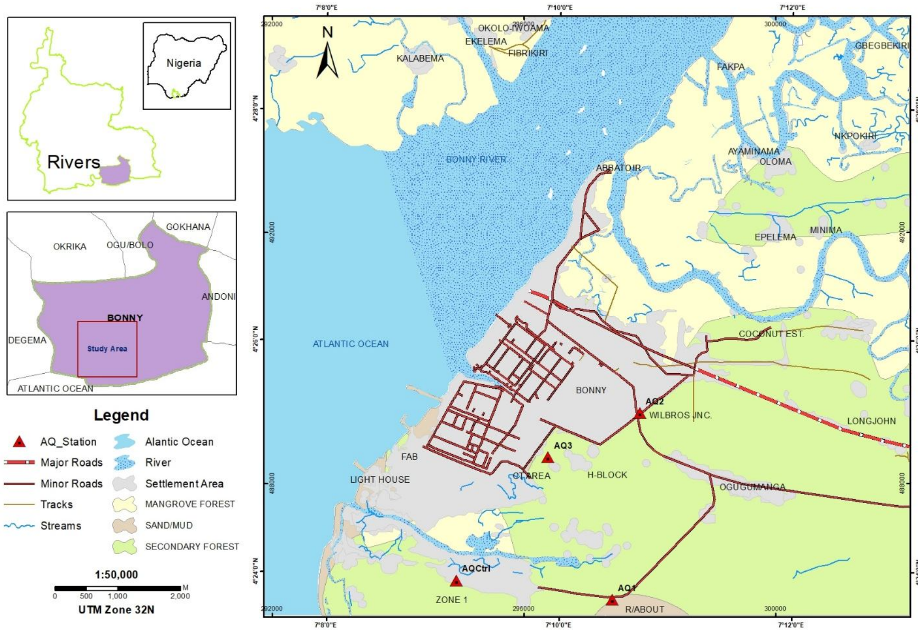

Fig. 1: The map of Nigeria showing the study area in Bonny Island, Rivers State, Nigeria.

Sampling station AQ1 (Plate 1), was at Finima Roundabout with relatively high vehicular density. Adjacent to the roundabout is a car park where passengers board vehicles to different parts of the Island. Activities around this study station included movements of vehicles, restaurants and bakery operations, black market sales of petroleum products such as AGO, PMS, etc. Sampling station AQ2 (Plate 2), was at Wilbros, a popular Junction with high density of vehicles. The major activities around this station included vehicular movements, automobile workshop, welding workshop, automobile spare parts shops, restaurants operations, flaring of gases from nearby flare stacks, etc. Sampling station AQ3 (Plate 3), was in an industrial area with high vehicular movements. Other activities in the area included welding and fabrication, pipe grinding, steel structure erection, civil works, flaring of gases from nearby flare stacks, etc. Control station AQ4 (Plate 4), is a residential area with an assemblage of plant species

Comment [p3]: Can not find AQ4 in the map

Plate 1: AQ1 (Finima Roundabout)

Plate 2: AQ2 (Wilbros Junction)

Plate 3: AQ3 (Construction site)

Plate 4: AQC (Control station)

2.3 DATA COLLECTION

Sampling Equipment

Air samples for the determination of heavy metals in the atmosphere were collected using the Environmental Monitoring Systems (EMS) High volume Air sampler (HVAS). This is a device that consists of an assemblage of a rotameter, an electrical air pump, a flexible hose and filter cassette. The EMS pump draws a precision-controlled volume of air and airborne contaminants through collection media during the sampling period. It is a high flow rate pump of 1 L/min – 20 L/min. A flowmeter model VFB manufactured by Dwyer Instruments Inc. USA was used to calibrate the flow. The Series Visi-Float VF Flowmeter is a line of direct reading, precision machined, clear acrylic body flowmeter suitable for both gas and liquid applications. The air samples were collected on a 37 mm diameter 3-piece pre-loaded filter cassette with 0.8 µm mixed-cellulose ester filter (MCEF) according to the Occupational Safety and Health Administration (OSHA-21). The filter is a mixture of cellulose nitrate/acetate fibres. It is a 3-piece press-fit cassette which helps prevent leakage around the filter as this will result in a loss of dust that should have been collected on the filter, resulting in a measurement that underestimates the concentration of the aerosol sampled. The membrane filter pore size is 0.8µm to retain even the inhalable aerosols. The inlet and outlet sides of the cassette are marked. MCEF sample cassette was chosen because they can retain particles smaller than their nominal pore size. MCEF membranes are naturally low in metal background and are compatible with dilute bases and acids and aromatic and aliphatic hydrocarbons. The filters are hydrophilic and autoclavable. It meets National Institute for Occupational Safety (NIOSH) and OSHA method specifications for monitoring airborne metals. MCEF is easily digested by dilute nitric acid which makes it ideal for atomic absorption spectroscopic analysis.

Air Sampling

Pump flow calibrations were performed before the commencement of sampling. The flow rate for the pump with a blank sample cassette was measured and recorded as 5 L/min. A constant flow rate of 20 L/min that did not deviate more than ±0.2 L/min was then maintained throughout the sampling period. The exposure time at each sampling station was 2 hours. The filter was attached to the pump that drew air into a 37mm diameter MCE sample cassette. The plug was removed from the cassette inlet and the pump started sampling. The start time was recorded. The pump and sampling train were checked as frequently as practical. At the end of the recording time, the pump was turned off and the end time was also recorded. The filter cassette was removed from the sampling train and the plugs in the inlet and outlet openings of the cassette were replaced. The instrument was set to operate at the specified flow rate for each monitoring period. The filter cassette was replaced after each sampling period and sealed in a Ziploc bag (Plate 5). The filter cassette was weighed before and after sampling to determine the mass of particulate matter collected.

Comment [p4]: You did not use HVAS, these are minipump
Change name of equipment to the right name

Comment [p5]: This reference for indoor air

Comment [p6]: You mentioned PM2.5, but the equipment did not attach with cyclone, That mean you collect Total dust,
And this equipment is for indoor air not for ambient air

Plate 5: Collected filter cassettes sealed in Ziploc bag after the sampling period

Meteorology

Information on the regional climatic conditions of the study area was obtained from the Nigerian Meteorological Agency (NiMet) and complemented with microclimatic data which were collected using Davis wireless weather station. Davis wireless weather station was installed and allowed to measure various meteorological parameters during the study. The Davis Weather Station has an integrated sensor suite that consists of a rain gauge, temperature, humidity, barometric pressure, wind speed and direction sensors. The integrated sensor suite was carefully mounted on approximately 10 meters pole to represent the average height of cloud formation in the study area.

2.3 Analytical Method

The filter collected from each of the study station was placed into a clean digestion vessel, and a combination of acids (HNO_3 and HCl) was added to digest the particulate matter. The sample was heated gently on a hot plate until complete digestion of the particulate matter was achieved. After digestion, the sample was allowed to cool, filtered and diluted to 100 ml using deionized water to prepare it for Flame Atomic Absorption Spectrophotometer (FAAS) analysis. The FAAS instrument (PerkinElmer AAnalyst 400) was powered on and allowed to stabilize. Then the hallowed cathode lamp for the metal of interest was installed and the wavelength was selected. A calibration blank, followed by calibration standards, was aspirated to establish a calibration standard curve. A reagent blank was carried out to ensure method compliance. The digested sample was aspirated into the flame, where the metal ions were atomized to measure the absorption of light at the selected wavelength. The FAAS instrument provided the concentrations for each metal in the sample after analysis. The metal concentration in the digested solution was converted to mass per volume of air sampled. This was done using the following formula:

$$Conc.\ of\ metal\ in\ Air\ \left(\frac{\mu g}{m3}\right) = \frac{Conc.\ in\ digest\ \left(\frac{\mu g}{ml}\right)\ \times Dilution\ Volume\ (ml)}{Volume\ of\ air\ sampled\ (m3)}$$

2.4 Enrichment Factor (EF)

Enrichment factor was used to determine the source of the elements in the study area, whether natural or anthropogenic, and it was calculated according to Liu *et al.*, 2018; Turekian and Wedepohl, 1961 as follows:

$$EF = \frac{[Cx/C_{ref}]Sample}{[Cx/C_{ref}]Background}$$

where the concentration of the element of interest is C_x, and the concentration of a reference element for the purpose of normalization is C_{ref}. The selection of reference elements should meet certain criteria, such as having stable chemical properties which are less influenced by human activity (Liu *et al.*, 2018). For this reason, Fe, Mn, Al and Se can be used as reference elements. In this study, Fe being one of the most abundant elements with relatively stable chemical properties, was used as the reference element. The standard of enrichment factor is presented in Table 1.0.

Table 1.0: The Standard of Enrichment Factor

Level	EF	Degree of Enrichment	Source
1	<1	No enrichment	Crust and Soil
2	>1<10	Minimal enrichment	Natural & Anthropogenic factors
3	>10<100	Moderate enrichment	Anthropogenic factors
4	>100<1000	Significant enrichment	Anthropogenic factors
5	>1000	Extremely high enrichment	Anthropogenic factors

Source: (Liu *et al.*, 2018)

Comment [p7]: This mean 1-10? Your symbol is very confuse

2.5 Quality Assurance and Control

Quality assurance and quality control (QA/QC) measures were adopted and applied consistently throughout all phases of the data gathering in accordance with OSHA requirements to ensure a high level of reliability of results. The QA/QC measures adopted are as stated below:

- The equipment was correctly calibrated and checked prior to use.
- The collection device inlet was oriented in a downward vertical position to avoid gross contamination from airborne debris falling into the collection device.
- Blank and duplicate analyses were carried out to ensure analytical integrity.
- Written analytical standard operating procedures (SOPs) were followed during analysis.

The results obtained from the Laboratory analysis were compared with national standards (Federal Ministry of Environment and Environmental Guidelines and Standards for the Petroleum Industry in Nigeria) as well as the World Health Organization (WHO) guidelines (Table 2.0).

Table 2.0: National and WHO Air Quality Guidelines

Metals	EGASPIN Guidelines for Ambient Air (µg/m^3) (2018)	WHO Guidelines (µg/m^3)	FMEnv Guidelines for Ambient Air (µg/m^3) (2001)
Cd	NS	0.005	0.005
Cr	NS	1.1	NS
Cu	NS	NS	NS
Fe	NS	NS	NS
Mn	NS	0.15	NS
Pb	1.0	0.5	1.00
Zn	NS	NS	NS
As	NS	NS	NS

Legend: EGASPIN = Environmental Guidelines and Standards for the Petroleum Industry in Nigeria; WHO = World Health Organization; FMEnv = Federal Ministry of Environment; NS = Not Stated

Comment [p8]: If you mention ambient air, your methodology is wrong
Your sampling method and your sampling time can not compare to ambient air quality standard

3.0 RESULTS AND DISCUSSION

3.1. Results

The concentrations of Cadmium (Cd), Copper (Cu), Lead (Pb) and Arsenic were generally low. Whereas Fe and Zn concentrations were obtained across the three study stations and at the control. Cr concentration was relatively high at AQ1 and AQ3 but very low at AQ1. Moreover, Mn had relatively high concentration at AQ2 and AQ3 but was very low at AQ1. Apart from Fe and Zn, the concentration of Cd, Cr, Cu, Mn, As and Pb obtained at the control was generally below equipment detection limit of <0.001 (Table 3.0).

Table 3.0: Metal concentration at different locations

	Sample Stations				
Metals	**AQ1 (μg/m^3)**	**AQ2 (μg/m^3)**	**AQ3 (μg/m^3)**	**mean (μg/m^3)**	**AQC (Control)**
Cd	0.001	0.001	0.001	0.001	<0.001
Cr	2.33	0.001	2.21	1.51	<0.001
Cu	0.001	0.001	0.001	0.00	<0.001
Fe	17.13	50.25	40.75	36.04	22.38
Mn	0.001	0.875	0.92	0.60	<0.001
Pb	0.001	0.001	0.001	0.001	<0.001
Zn	12.38	15.13	19.21	15.57	15.13
As	0.001	0.001	0.001	0.001	<0.001

Comment [p9]: Your sample only one time? You have only one value

Table 4.0: Enrichment Factor of Heavy Metals in the Study Area

Heavy Metal	**AQ1**	**AQ2**	**AQ3**
Cd	1.306	0.4454	0.5492
Cr	3044.1	0.4454	1213.7
Cu	1.306	0.4454	0.5492
Fe	1	1	1
Mn	1.306	389.7	505.4
Pb	1.306	0.4454	0.5492
Zn	1.069	0.4454	0.6973
As	1.306	0.4454	0.5492

4.0 Conclusion

This study validates the claim that industrial activities have the potential of exposing man to high concentrations of heavy metals via food chain. The concentrations of Cr and Mn obtained in $PM_{2.5}$ exceeded their thresholds of 1.1 µg/m^3 and 0.15 µg/m^3 respectively by the World Health Organization. This implies that the residents of Bonny, especially those who live around the industrial area, might be exposed to high concentrations of Cr and Mn. The EF of Cd, Cu, Pb, Zn, and As on the whole showed no enrichment indicating natural origin of the metals in the study area (especially at AQ2 and AQ3). However, the EF of Mn and Cr showed significant enrichment and extremely high enrichment indicating anthropogenic sources. Regular monitoring of heavy metals around industrial areas is strongly recommended for a healthy environment. Moreover, further research into the health risk estimation of heavy metals around industrial areas in Bonny Island is recommended.

Comment [p10]: From your result and sampling location, you can not conclude that heavy metal came from industrial
It look like came from traffic

REFERENCES

Abbey, D.M., Awuhe, T. T., Ogunyemi, T. C. and Abbey, M. E. (2024). Spatial matrix evaluation of heavy metals from heat ventilating air conditioning filter dust in Bonny metropolis. *Asian Journal of Advanced Research and Reports.* 7(24): 283-302.

Abdullah, A. (2015). Sources of metal pollution in the urban atmosphere of Tuzla, Istabul. *Journal of Environmental Health Science and Engineering.* 13:79 – 87.

Adani, M., Mircea, M., D'Isidoro, M., Costa, M. P., and Silibello, C. (2015). Heavy metal modelling study over Italy: Effects of grid resolution, lateral boundary conditions and foreign emissions on air concentrations. *Water, Air & Soil Pollution*, 226(46): 1-10.

Ali, H and Khan, E (2018) What are heavy metals? Long-standing controversy over the scientific use of the term' heavy metals'-proposal of a comprehensive definition. Toxicology and Environmental Chemistry. 100(1):6–19.

Ali, S., Awan, Z., Mumtaz, S., Shakir, S.H.A., Ahmad, F., Ulhaq, M., Tahir, H.M., Awan, M.S., Sharif, S., Irfan, M. and Khan, M.A. (2020). Cardiac toxicity of heavy metals (cadmium and mercury) and pharmacological intervention by vitamin C in rabbits. Environmental Science and Pollution Research. 27(23): 29266 – 29279.

Azham U.A., Fina B.M., Septian H.S., Minoru Y. and Yasuto M. (2024). Heavy metal air pollution in an Indonesian landfill site: Characterization, sources, and health risk assessment for informal workers. *Environmental Advances.* 15: 100512 – 100523.

Baltas, H., Sirin, M., Gökbayrak, E., Ozcelik A., (2020). EA Case Study on Pollution and a Human Health Risk Assessment of Heavy Metals in Agricultural Soils Around Sinop Province, Turkey, *Chemosphere*, 241: 125015

Barceloux, D.G. (1999). Zinc. *Journal of Toxicology and Clinical Toxicology*. *37*, 279–292.

California Environmental Protection Agency (CEPA) (2004). Air Resources Board Fact Sheet. www.arb.ca.gov.

De, A., and Roy, N. (2023). Consequences of Arsenic in the Environment. IntechOpen. doi: 10.5772/intechopen.1001476.

Duruibe, J. O., Ogwuegbu, M. O. C. and Egwurugwu, J. N. (2007). Heavy Metal Pollution and Human Biotoxic Effects. International Journal of Physical Science, 2: 112-118

Ebong, G. A., Etuk, H. S. and Johnson, A. S. (2007). Heavy metals accumulation by Talinum triangulare grown on waste dumpsites in Uyo metropolis. *Journal of Applied Science*, 7(10),1404 – 1409.

Edopka, D. O. and Ede, P. N. (2013). Challenge of Associated Gas Flaring and Emissions Propagation in Nigeria. *Academia Arena*. 5(4),1-8

Ems T., Lucia, K. and Huecker, M.R. (2023). Biochemistry, Iron Absorption. [Updated 2023 Apr 17]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK448204/

Engwa, GA., Ferdinand, PU., and Nwalo, FN, (2019). Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the Modern World. Pp136

Erik, S. (2001). Cadmium uptake by plants. *Inter. J. Occupational Med. Environ. Health*. 14(2): 177-183

European Commission (EC) (2001). Abient air pollution by As, Cd and Ni compounds. Position Paper. Pp 318, available at htt://Europa.eu.int/comm/environment/publ/home.htm

Farahmandkia, Z., Mehrasbi, M., Sekhavatjou, M., Hasan, Ama, and Ramezanzadeh, Z. (2010). Study of heavy metals in the atmospheric deposition in Zanjan, Iran. *Iranian Journal of Health and Environment*. 4(2): 240-249.

Ferner, D.J. (2001). Toxicity of heavy metals. *Med. J*., 2:1

Halstead, J.A and Smith, J.C. (1970). Plasma zinc in health and disease. Lancet.1:322-5.

Hasanein, P., Emamjomeh, A., (2019). Beneficial effects of natural compounds on heavy metal-induced hepatotoxicity. Dietary Intervention in Liver Disease. *Foods, Nutrient and Dietary Supplement*. 345–355.

Hurley, L.S., and C.L. Keen. (1987). Manganese. Pp. 185-223 in W. Mertz, editor., ed. Trace Elements in Human and Animal Nutrition, Vol. I. Academic Press, New York.

Iyebor, E. W., Ngah, S. A., Abam, T. K. S., Ubong, I., and Ule, O. (2020). Assessment of Heavy metals in soil around leaking underground petroleum facilities in Rivers State. *International Journal of Scientific and Technical Research in Engineering (IJSTRE)*, 5(2), 12-27.

Kalagbor, I.A., Dibofori-Orji, A.N and Ekpete, O.A. (2019). Exposure to heavy metals in soot samples and cancer risk assessment in Port Harcourt, Nigeria. *Journal of Health & Pollution*. 9(24): 102 – 114.

Kampa, M., and Castanas, E. (200). Human health effects of air pollution. *Environmental Pollution*, 151(2): 362-367.

Kim, Y.H., Fazlollahi, F., Kennedy, I.M., Yacobi, N.R., Hamm-Alvarez, S.F., Borok, Z., Kim, K.J. and Crandall, E.D. (2010). Alveolar epithelial cell injury due to zinc oxide nanoparticle exposure. *American Journal of Respiratory and Critical Care Medicine. 182*, 1398–1409.

Liati, S.S., Pandurangi, K., Boulouchos, D., Schreiber, Y. and Arroyo R. D (2015). Metal nanoparticles in diesel exhaust derived by in-cylinder melting of detached engine fragments. *Atmospheric Environment*. 101: 34 – 40.

Liu, J., Liu, YJ., Liu, Y., Liu, Z., and Zhang, A.N. (2018). Quantitative contributions of the major sources of heavy metals in soils to ecosystem and human health risks: A case study of Yulin, China. *Ecotoxicolgical and Environmental Safety*; 164: 261-269.

Liu,Y., Li, S., Chunyuan, S., Qi, M., Yu, X., Zhao, W. and Li, X. (2018). Pollution Level and Health Risk Assessment of PM2.5-Bound Metals in Baoding City Before and After the Heating Period. *International Journal of Environmental Research and Public Health*. 15(10): 2286 http://doi.org/10.3390/ijerph15102286

Malakootian, M., Mohammadi, A., Nasiri, A., Asadi A.M.S., Conti, G.O., and Faraji, M, (2021). Spatial distribution and correlations among elements in smaller than 75 µm street dust: ecological and probabilistic health risk assessment. *Environmental Geochemistry Health*. 43(1) 567-583.

Michelle, A.C., Jaime R.J., Vihra, V.G., Cheryl, L.B. Harry, A.R., Danelle, T.L. and Rosemarie M.B. (2015). Characterization of air manganese exposure estimates for residents in two Ohio towns. *Journal of the Air and Waste Management Association.* 8(65):948 – 957.

Michigan Department of Environmental Quality Air Quality Division (MDEQAQD) (2012). Ambient Air Levels of Manganese in Southeast Michigan: Evaluation and Recommendations by the AQD Manganese Workgroup. 55 pp

Ogundele, LT., Owoade, OK., Hopke, PK., and Olise, FS (2017). Heavy metals in industrially emitted particulate matter in Ile-Ife, Nigeria. *Environmental Research*. 156: 320-5

Rahman, MS., Khan, M., Jolly Y., Kabir, J., Akter, S., and Salam, A (2018). Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. *Science of Total Environmental.* 12.425.

Rauf, A.U., Mallongi, A., Lee, K., Daud, A., Hatta, M., Madhoun, W. and Astuti RDP (2021). Potentially Toxic Element Levels in Atmospheric Particulates and Health Risk Estimation around Industrial Areas of Maros, Indonesia. *Toxics*. 2:9(12):328.

Schoofs, H., Schmit, J. and Rink, L. (2024). Zinc Toxicity: Understanding the Limits. *Molecules*. 29(13):3130. https://doi.org/10.3390/molecules29133130

Sloof, J.E. (1999). Lichens as quantitave biomonitors for atmosphere trace elelments deposition, using transplants. *Atmos Environ*. 29:11–19.

Stowers, CC., Cox, BM. and Rodriguez, BA. (2014). Development of an industrializable fermentation process for propionic, acid production. Journal of Industrial Microbiology & Biotechnology.41(5):837-852.

Suvarapu, L. N. and Baek, S. (2017). Determination of heavy metals in the ambient atmosphere: A review. *Toxicology and Industrial Health*, 33(1),79-96.

Tchounwou, P. B., Yedjou, C. G., Patilolla, A. K. and Sutton, D. J. (2012). Heavy Metals Toxicity and the Environment. *National Institute of Health*, 101, 133-164

Turekian, K.K.; Wedepohl, K.H. (1961). Distribution of the elements in some major units of the earth's crust. Geol. Soc. Am. Bull.

Ursula, R.S., Mauro, F. and Fisberg, L.G. (1999). Nutritional assessment and serum zinc and copper concentration in leukemic children. *Sao Paulo Med J/Rev Paul Med*. 117(1):8 – 13.

Uzoekwe, S.A., Izah S.C., Aigberua, A.O. (2021) Environmental and human health risk of heavy metals in atmospheric particulate matter (PM10) around gas faring vicinity in Bayelsa State, Nigeria. *Toxicol Environmental Health Science*, 13,323–335. https://doi.org/10.1007/s13530-021-00085-7

World Health Organization (WHO) (2016). Guidelines for Air Quality, Geneva (Retrieved April 2016) (https://www.epa.gov/risk/regional-screening-levels-rsls generic-tables-may-2016).

World Weather Online (WWO) (2024). Boony Annual Weather Average, Rivers state Nigeria (Retrieved August, 2024) ((https://www.worldweatheronline.com/bonny-weather-averages/rivers/ng.aspx))

Yaman, M. and Erel, E. (2013). Determination of Fe, Zn and Cu in ambient air by combining pre-concentration method and FAAS. *International Journal of Environmental Research.* 7(4): 989 – 994