ChemSearch Journal 15(1): 86 – 94, June, 2024
Publication of Chemical Society of Nigeria, Kano Chapter

Received: 20/02/2024 Accepted: 29/03/2024
http://www.ajol.info/index.php/csj

Mnium Hornum Hedw Moss as Bioindicator of Atmospheric Pollution of Heavy Metals in the University of Lagos, Akoka Campus

[1,3]*Aramide Dolapo Igbari, [2,3]Oluwafemi Daniel Amusa, [2]Divine Favour Orisejobor and [1,3]Oluwatoyin Temitayo Ogundipe
[1]Department of Botany, University of Lagos, Lagos, Nigeria
[2]Department of Cell Biology and Genetics, University of Lagos, Lagos, Nigeria
[3]TETFund Centre for Biodiversity Conservation and Ecosystem Management, University of Lagos, Lagos, Nigeria
***Correspondence Email:** aoshingboye@unilag.edu.ng

ABSTRACT
This study investigated the presence of heavy metals pollutants in the University of Lagos, Akoka campus using the moss (*Mnium hornum* Hedw.) as a bioindicator. Samples of *M. hornum*. were collected in 2019 from four different locations within the University of Lagos campus: Faculty of Engineering (FE), Lagoon Front (LF), Main Library (ML) and Akintunde Ojo Library (AKT). A control sampling was done at First Estate, Amuwo-Odofin LGA (CL). The concentrations of cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) were determined using the Atomic Absorption Spectrophotometer (AAS). Results confirmed the presence of heavy metals in the following order Fe > Zn > Mn > Cu > Pb > Ni > Co > Cr > Cd. The concentrations of the examined heavy metals across the locations were lowest in CL except Ni which was lowest in FE and LF (0.03mg/kg). While there were no significant differences in the concentrations of Cd, Co, Cr, Cu, Mn, Ni, and Pb among the locations, both Fe (66.00mg/kg) and Zn (64.33mg/kg) were significantly higher in ATK than in the other locations. The contamination factor suggests that ML (C2), FE (C3) and LF (C3) were moderately contaminated while AKT (C5) was highly contaminated. The index of geo-accumulation revealed that FE (I_{geo}4) and ML (I_{geo}4) are moderate to severely polluted, LF (I_{geo}5) was severely polluted while AKT (I_{geo}7) was extremely polluted with the assayed metals. The difference in the occurrence of anthropogenic activities was believed to be the major factor responsible for the variations in the concentration of heavy metals accumulated by the mosses.

Keywords: Air pollution, Biomonitoring, Contamination factor, Geo-accumulation index, Heavy metal

INTRODUCTION
The presence of contaminants that can affect the natural composition and chemistry of indoor or outdoor environments can be referred to as air pollution; such contaminants can be in form of particulate matter, gases, vapour, vehicles and automobiles exhaust, forest fires among others. The effects of air pollution include smog, acid rain, respiratory ailment, and reduced agricultural harvest (Paliulis and Blagnyte, 2010). Poor air quality is one of the most serious environmental hazards globally, contributing up to seven million premature deaths annually (Jiang *et al*., 2018). Inputs of heavy metals unto vegetation and surface soil results in toxicity plausible to constitute public health hazards (Zinicovscaia *et al*., 2021).

Heavy metals are particularly significant as pollutants and they are the major cause of air pollution (Paliulis and Blagnyte, 2010). They are categorized as a group name for metals and metalloids with contamination and eco-toxicity potentials. Heavy metals occur naturally in the lithosphere and thus released into the atmosphere and water bodies (Zinicovscaia *et al*., 2021). Anthropogenic activities such as running power plants and automobiles lead to heavy contamination of the environment (Zinicovscaia *et al*., 2021). Some heavy metals are essential for the normal metabolic functioning of organisms, but when underprovided or excessive, they induce physiological stress with detrimental consequences (Prandan *et al*., 2017). Once heavy metals are introduced into the environment, it becomes difficult to eliminate them and accumulates in the tissues of plants and other organisms via the food chains. Monitoring heavy metal pollution in the environment is a very complex and expensive process, particularly when it comes to airborne pollutants. Thus, the use of biological systems capable of absorbing and accumulating heavy metals in their tissues to account for a quantitatively impact of these pollutants on the biosphere and their distance from the sources (Fernandez *et al*., 2013; Chakraborty and Paratkar, 2006).

Air quality can be monitored by measuring pollutants, including heavy metals discharged directly into environmental compartments by constructing models that describe the distribution of pollutants, or by using bio-indicators (Cowden and Aherne 2019). Living organisms such as microbes, planktons, plants and animals useful for assessment of environmental health and biogeographic changes in the environment are known as bioindicators. Naturally occurring bioindicators are used to determine environmental health and are also an important tool for identifying environmental changes, whether positive or negative and their resulting impact on humans (Chakraborty and Paratker, 2006). Bryophytes are important biological indicators due to their widespread distribution and ability to accumulate abundant amounts of heavy metals (Tremper *et al*., 2004). Bryophyte is a collective term for mosses, hornwort and liverwort, they are groups of spore-producing non-vascular plants that mostly grow on substrates. Mosses are a group of bryophytes that lacks or possess a very thin cuticle and rhizoids; small hair-like appendages that facilitates water uptake and anchorage. Mosses are incredibly common, with more than 12,000 species globally. As a result of their extremely reduced or absent cuticular layer, the ability to absorb and retain nutrients, pollutants, and moisture directly from the atmosphere; mosses are one of the best bioindicator species (Radziemska *et al*., 2019). They have an efficient mechanism for absorbing metals from their environment and a great capacity for trace element retention. Over the decades, mosses have been used to monitor pollutants in terrestrial air and aquatic ecosystems, they are cheaper and easy to use throughout the year (Bargagli *et al*., 2002; Adebiyi and Oyedeji, 2012; Sa'idu, 2015; Ojiodu and Olumayede, 2018; Ndlovu *et al*., 2019; Radziemska *et al*., 2019; Yushin *et al*., 2020; Igbari *et al*., 2023; Nurkassimova *et al*., 2024). The analysis of metal content in mosses reflects a corresponding atmospheric metal deposition. Hence, this work was aimed at detecting the level of heavy metal pollution within the University of Lagos campus using moss as bioindicator.

MATERIALS AND METHODS

Study Area

The survey was carried out at the University of Lagos, Akoka campus (6˚31'0" N, 3˚23'10" E), located on 802 acres of land in Akoka, the North-Eastern part of Yaba, Lagos State. It was based on primary data collection which involved the stratification of the sampling area. The four sample sites were selected based on the level of pollutants exposure, accessibility to the moss species as well as availability of open spaces. A control sampling was done in First Estate, Amuwo Odofin LGA; a strictly residential area with minimal vehicular traffic, commercial activities and alternative electricity sources. Georeferencing of the study sites was done using Garmin GPS MAP 76S. Detailed information on the sampling sites is provided in Figure 1 and Table 1.

Description of Locations

1. **Faculty of Engineering (FE) –** A site with staff offices, lecture halls and laboratories. Located beside the main auditorium and adjacent to the senate building of the school. It is also at an intersection.
2. **Main Library (ML) –** A building for quiet study and work area for students and professionals located behind the senate building. Behind this building is a diesel power plant.
3. **Lagoon Front (LF)** – A noticeable spot for picnics, pictures and meditation surrounded by a large body of water and shops for business and commercial activities.
4. **AkintundeOjo Library (AKT) –** A building for study and a work area for students. Beside this building is also a power plant.
5. **First Estate (C)** - A strictly residential area with little or no commercial activities. Behind it is a major busy highway.

Table 1: Sample location and characteristics

Location	Moss Location site	Location	Coordinates
Faculty of Engineering (FE)	Soil	Faculty of Engineering (FE)	6˚ 31' 5" N, 3˚ 23' 58" E
Main Library (ML)	Bare rock	Main Library (ML)	6˚ 31' 11" N, 3˚ 23' 59" E
Lagoon front (LF)	Soil	Lagoon front (LF)	6˚ 31' 8" N, 3˚ 23' 58" E
Akintunde Ojo Library (AKT)	Bare rock	Akintunde Ojo Library (AKT)	6˚ 31' 10" N, 3˚ 24' 1" E
First Estate (CL)	Soil	Amuwo Odofin (C)	6˚ 28´ 31.6" N, 3˚ 18´ 18.7" E

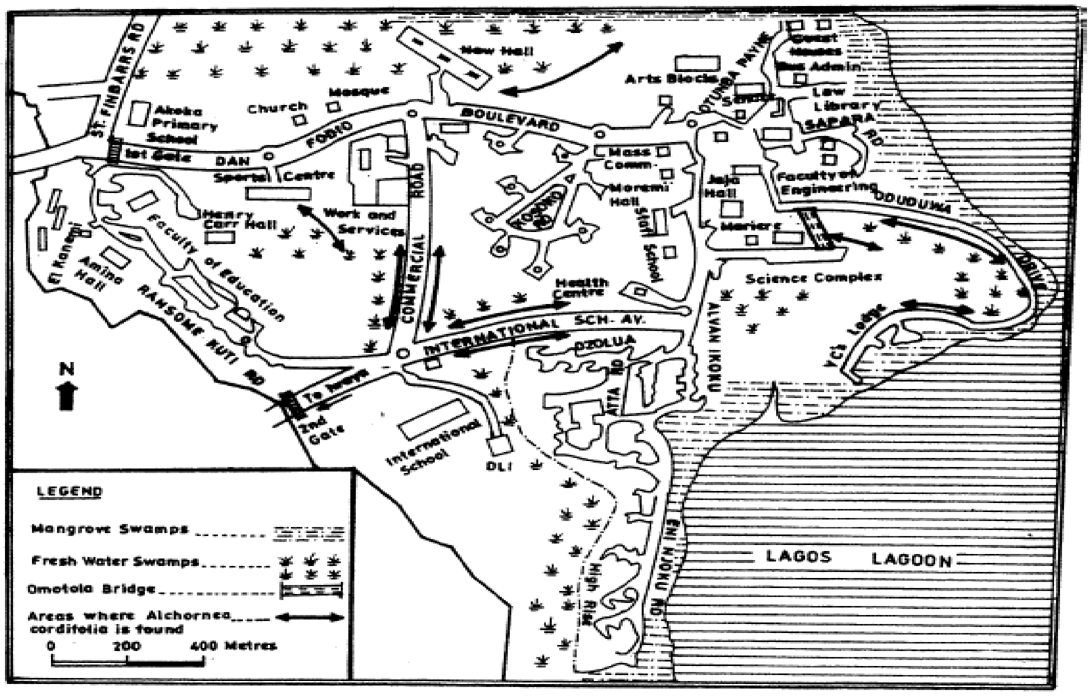

Figure 1: Map of the University of Lagos; location and sampling sites; A= Location of research, Δ= Sampling sites

Sample collection and identification

Samples of *M. hornum* (Plate 1) were collected from the selected sites within the studied area at least 10 metres apart, from July to November 2019. Moss sample collection was carried out using a stainless-steel trowel and gently placed in a Petri dish to prevent excessive heat and condensation. Samples were collected in triplicate, sealed with masking tape, labelled accordingly and transported to the laboratory for analysis. Georeferenced coordinates, as well as the date of the collection, were documented on the masking tape label on each collection. Collected moss samples were taken to the laboratory and identified by a bryologist at the University of Lagos.

Plate 1: The Moss plant (*Mnium hornum*)

Sample preparation and analysis

Moss samples were prepared for laboratory analysis by trimming the life-green portions of the total amount of moss harvested. The moss was dried in a thermostatic dry machine for 24 hrs at 40 ℃ to remove its excess moisture content and ground it into a homogenous powder. Mineralization of moss tissue was done by dissolving 1g of powdered moss into 10 ml of concentrated nitric acid (HNO_3) and digesting at 180 ºC for 5 minutes. After mineralization, samples were left to cool to room temperature for one hour and poured into 50 ml flasks and finally made up to the mark with distilled water (Baltrenaite *et al*., 2011). Determination of the level of heavy metal contamination was done using the Buck Scientific Atomic Absorption Spectrometer Model 210 VGP at the University of Lagos Central Research Laboratory.

Statistical Analysis

The data for heavy metal accumulation in *M. hornum* was evaluated using descriptive analysis. Analysis of Variance was performed to deduce significant differences in the heavy metal concentration among the study areas. Statistical difference was established at $p < 0.05$. All analysis was done using IBM SPSS v. 27 (IBM Corp., NY, USA).

The anthropogenic influence of the pollutants on the environment was calculated using the contaminant factor and geo-accumulation index.

The contamination factor was calculated using equation 1:

$$\mathrm{CF} = \frac{\mathrm{C_{moss}}}{\mathrm{C_{background}}} \quad (1)$$

Where C_{moss} is the measured concentration of the metal in the plant sample in a sample site while $C_{background}$ is the plant samples collected from a clean site (control site). The scale for interpretation of results consisted of various categories according to the CF values as described by Jiang *et al*. (2018): C1 (CF < 1) indicating none contaminated; C2 (CF: 1–2) indicating contamination suspected; C3 (CF: 2–3.5) indicating slightly contaminated; C4 (CF: 3.5–8) indicating moderately contaminated; C5 (CF: 8–27) indicating seriously contaminated; C6 (CF > 27) indicating extremely contaminated.

The index of geo-accumulation, I_{geo}, was calculated using equation 2:

$$I_{geo} = \frac{C_{moss}}{1.5C_{background}} \quad (2)$$

Where $C_{moss}/C_{background}$ is the contamination factor. The factor of 1.5 is introduced to minimize the effect of possible variations in the background (Okedeyi *et al*., 2014). The scale for interpretation of results consisted of various categories according to the I_{geo} values as described by Yushin*et al*. (2020): I_{geo} <0 no contamination (I_{geo}1); 0–1 slightly polluted (I_{geo}2); 1–2 moderately polluted (I_{geo}3); 2–3 moderately to severely polluted (I_{geo}4); 3–4 severely polluted (I_{geo}5); 4–5 severely to extremely polluted (I_{geo}6); and I_{geo} > 5 extremely polluted (I_{geo}7).

RESULTS

Distribution of Heavy metals in the study area

A total of nine heavy metals were found in all the moss plants analysed and varied from location to location. Iron has the highest concentration in all the locations evaluated. This was followed by zinc while the least heavy metal concentration from the locations varied. The concentration of heavy metals across the study locations revealed that all the examined metals were lowest at the CL except Ni which was lowest in FE and LF (0.03mg/kg). The concentration of Ni at CL was 0.07mg/kg. All the heavy metals were highest at AKT except Cr, which was lowest at CL and AKT but highest at ML and LF. The concentrations of Cu, Co, Mn, Fe and Zn were significantly different across the study locations (Figure 2). These values are higher than the recommended limits of World Health Organization (WHO 1996) and Federal Ministry of Environment (FME) threshold permissible levels of heavy metals with exception to Cr that is below 1.5mg/kg. Ni (0.03±0.01 mg/kg) was the least heavy metal obtained at the FE location, Cd (0.00±0.03 mg/kg) was found the least at the ML location, Co (0.03±0.02 mg/kg) and Ni (0.03±0.04 mg/kg) were observed least at LF location, while Cr (0.03±0.02 mg/kg) was the least found at ATK location. While there was no significant difference in the concentrations of Cd, Co, Cr, Cu, Mn, Ni, and Pb among locations, Mn, Fe and Zn were significantly higher than the other heavy metals in all locations examined (Figure 3).

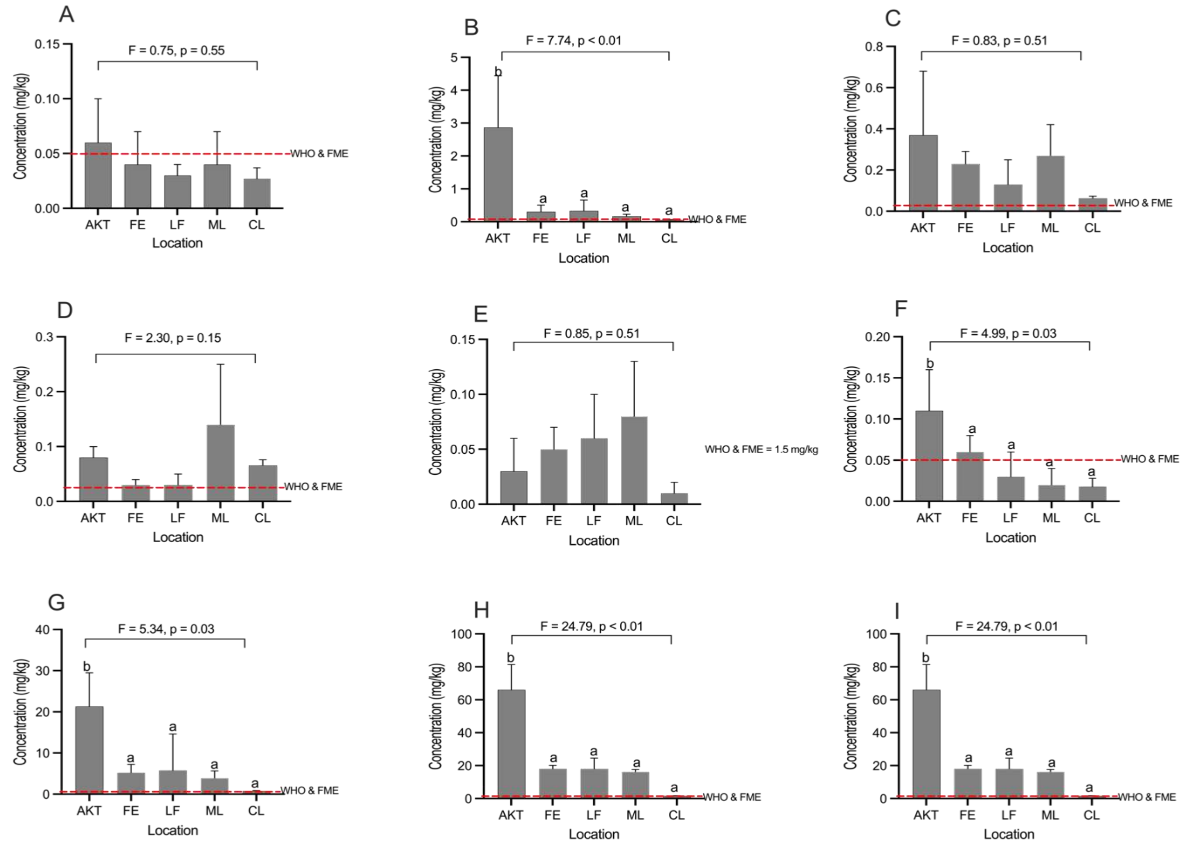

Figure 2: Concentration of heavy metals in mosses across the collection sites (A) Cadmium (B) Copper (C) Lead (D) Nickel (E) Chromium (F) Cobalt (G) Manganese (H) Iron (I) Zinc.

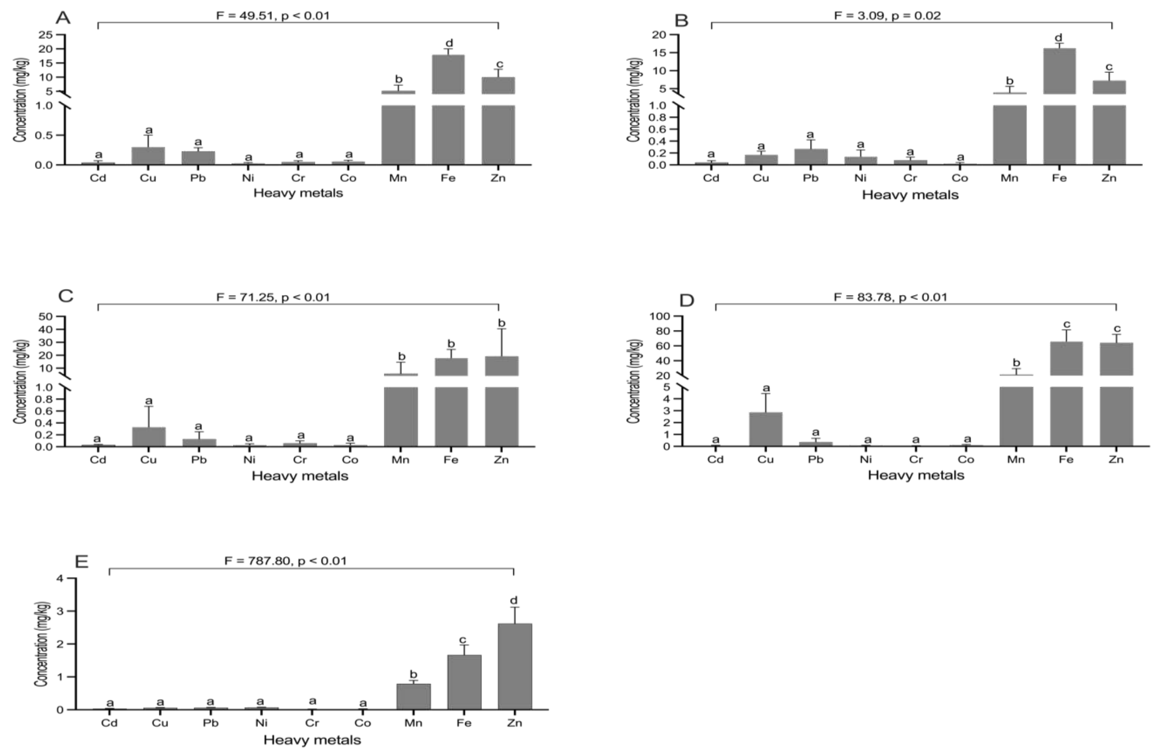

Figure 3: A comparison of heavy metals concentration within study locations (A) FE, (B) ML, (C) LF, (D) AKT, (E) CL: control location; Cd: Cadmium; Cu: Copper; Pb: Lead; Ni: Nickel; Cr: Chromium; Co: Cobalt; Mn: Manganese; Fe: Iron; Zn: Zinc

Contaminant Factor

The contaminant factor (CF_{moss}) of each metal in the studied locations is summarized in Table 2. Results revealed that Cd (1.57mg/kg) and Ni (1.17mg/kg) were suspected contaminants in the campus and Co (3.06mg/kg) is in the slightly contaminated category. Cr (5.00 mg/kg) and Pb (4.09mg/kg) are in the moderately contaminated category while Cu (15.82mg/kg), Fe (17.69mg/kg), Mn (11.46mg/kg) and Zn (9.86mg/kg) are in the seriously contaminated category. In a comparison of these CF values with the different study locations, ML, FE and LF are moderately contaminated (C4 category) while AKT has a CF value in the C5 category, indicating serious contamination.

Index of Geo-accumulation

The I_{geo} results indicate different levels of contamination in the different study locations (Table 3). Cd (1.05mg/kg) and Ni (0.78mg/kg) are the least contaminants while Co (2.04mg/kg), Cr (3.33mg/kg) and Pb (2.72mg/kg) are moderately pollutants in the Akoka campus. Cu (10.55 mg/kg), Fe (11.80mg/kg), Mn (7.64mg/kg) and Zn (6.57mg/kg) are severe pollutants in the study locations. In comparison, the index of geo-accumulation of heavy metal pollution in the Akoka campus of the University of Lagos revealed that FE and ML are moderate to severely polluted, LF is severely polluted while AKT is extremely polluted with the determined elements.

Table 2: Contamination factor (CF) and different categories of contamination (as defined by the mean CF) for each of the heavy metal

Metals (mg/kg)	FE	ML	LF	AKT	Mean CF	Category
Cadmium	1.48	0.00	2.59	2.22	1.57	C2
Cobalt	3.33	1.11	1.67	6.11	3.06	C3
Chromium	4.00	7.00	6.00	3.00	5.00	C4
Copper	5.17	2.93	5.17	50.00	15.82	C5
Iron	10.78	9.70	10.78	39.52	17.69	C5
Manganese	6.58	4.94	7.34	26.96	11.46	C5
Nickel	0.45	2.58	0.45	1.21	1.17	C2
Lead	3.65	4.29	2.06	6.35	4.09	C4
Zinc	3.85	3.78	7.37	24.43	9.86	C5
Mean CF	4.37	4.04	4.83	17.76	7.75	
Category	C4	C4	C4	C5		

KEY: FE: Faculty of Engineering, ML: Main Library, LF: Lagoon front, AKT: Akintunde Ojo library.

Table 3: Index of geo-accumulation values of the studied locations

Metals (mg/kg)	FE	ML	LF	AKT	Mean	Category
Cadmium	0.99	0.00	1.73	1.48	1.05	$I_{geo}2$
Cobalt	2.22	0.74	1.11	4.07	2.04	$I_{geo}3$
Chromium	2.67	4.67	4.00	2.00	3.33	$I_{geo}4$
Copper	3.45	1.95	3.45	33.33	10.55	$I_{geo}7$
Iron	7.19	6.47	7.19	26.35	11.80	$I_{geo}7$
Manganese	4.39	3.29	4.89	17.97	7.64	$I_{geo}7$
Nickel	0.30	1.72	0.30	0.81	0.78	$I_{geo}1$
Lead	2.43	2.86	1.38	4.23	2.72	$I_{geo}3$
Zinc	2.57	2.52	4.91	16.28	6.57	$I_{geo}7$
Mean	2.91	2.69	3.22	8.69	5.16	
Category	$I_{geo}4$	$I_{geo}4$	$I_{geo}5$	$I_{geo}7$		

KEY: FE: Faculty of Engineering, ML: Main Library, LF: Lagoon front, AKT: Akintunde Ojo library

DISCUSSION

Some organisms are used as active or passive bioindicators for environmental stress, which might result from the exposure of such organisms to contaminants (Pesch and Schroeder, 2006). The presence or absence of some moss species can indicate the presence of certain pollutants. According to Cowden and Aherne

(2019), specific moss presence or absence can indicate the presence or absence of some pollutants. Certain species are highly pollutant prone, while others are immune.

This study explored the heavy metal pollution of the University of Lagos, Akoka campus using moss as a bioindicator. The study revealed that Fe, Mn and Zn were the most accumulated heavy metals in all the locations examined. The study also confirmed that the control location is a clean environment with low concentrations of heavy metals. In comparison with the locations surveyed, the University of Lagos Main Library and Lagoon Front locations were the least polluted site while the Akintunde Ojo Library site is the most polluted location within the Akoka campus. AKT had the highest concentration of all the metals excluding Ni and Cr. This could be attributed to the diesel power plant fumes while metallurgical plants and machinery companies can emit Ni, Cu, Mo and W (Vergel *et al*., 2019). The Faculty of Engineering location had average contamination levels. These results clearly show the effect of some anthropogenic activities such as emissions from industries, energy generation, vehicular traffic and combustion of fossil fuel on the quality of air in the atmosphere. Locations that have the highest rate of deposits either from a power plant or automobiles recorded a relatively high heavy metal deposit and vice versa. This result agrees with the work of Jiang *et al*. (2018) who reported that Huazhong Agricultural University (HZ) out of the five locations studied is the least polluted, as the campus was exposed to minimal anthropogenic emission, surrounded by clear lakes and green hills with high vegetation cover. This also confirms the higher accumulation capabilities of heavy metals by mosses as compared to tree leaves. These results are similar to previous studies by Graciela *et al*. (2013), Cowden *et al*. (2015), and Jiang *et al*. (2018), indicating that mosses accumulate heavy metals 4 to 51 times more than tree leaves. The concentrations of heavy metals recorded in this study is far greater than the recommended limits of World Health Organization (WHO) and Federal Ministry of Environment (FME) threshold permissible levels of heavy metals (Musa *et al*., 2017). This supports similar studies on heavy metal contamination around Lagos metropolis of the State (Ojiodu *et al*., 2016; Ojiodu and Olumayede 2018).

The use of geochemical indices such as contamination factor and geo-accumulation index is important for the assessment of the contamination status of an environment (Vergel *et al*., 2019; Rutkowski *et al*., 2020). The contamination factor (CF) helps to determine the contamination level of each metal in the location. The different categories of CF values indicate the level of pollutants in the environment. In this study, CF values ranged between C1 and C6 categories. Ni in LF, Co in ML, and Ni in LF were less than 1 indicating that these sites experienced no contamination. Suspected contamination of Cd, Co, and Ni was observed in all the study sites while other metals are contaminated at different levels. This supports Qarri *et al*. (2015) who reported a then CF value of 2 indicates no contamination with As, Mn, Ni, and Cd, since CF is less than 2 as these metals can easily be obtained from natural variation (Vergel *et al*., 2019). A moderate contamination range of C4 was recorded for Cr, Mn, Zn, Pb and Cu in FE, LF and ML while Fe is the only extremely contaminated metal in these three study locations. The high CF of Cu, Fe, Mn and Zn in AKT shows extreme contamination. These results are at variance with Fernandez and Carballeria (2001) which indicated that Cu, Mn, Cd, Fe, Ni and Zn are associated with the C1 and C2 categories of contamination scales in Galicia North Spain. Vergel *et al*. (2019) reported that the CF value of heavy metals deposition in Moscow, Russia obtained for Pb indicates slightly moderate pollution supporting results of this study. The I_{geo} data are in good correlation with CF values depicting moderate to extreme pollution in the moss samples evaluated. It reiterated the pollution scales of the study locations, FE and ML of the Akoka campus are moderate to severely polluted, LF is severely polluted while AKT is extremely polluted.

CONCLUSION

This study has proven the efficacy of *Mnium hornum* moss as an environmental pollution indicator. A high concentration of Fe, Zn and Mn were present in all locations. AKT had the highest concentration of all the metals excluding Ni and Cr. Based on the contamination assessment done in 2019 using CF and I_{geo} values, the selected sample locations of the University of Lagos, Akoka campus was characterized to be moderate to severely (FE, ML, LF) and extremely polluted (AKT).

REFERENCES

Adebiyi, A. O. and Oyedeji, A. (2012): Comparative studies on mosses for air pollution monitoring in suburban and rural towns in Ekiti State. *Ethiopian Journal of Environmental Studies and Management*, 5(4): 408 – 421.http://dx.doi.org/10.4314/ejesm.v5i4.10

Baltrenaite, K, Buktus, D. and Both, C. A. (2011): Comparison of Three Tree Ring Sampling Methods for Trace Metal Analysis. *Journal of Environmental Engineering and Landscape Management*, 18: 170 - 177.

Bargagli, R., Monaci, F., Borghini, F., Bravi, F. and Agnorelli, C. (2002): Mosses and lichens as biomonitors of trace metals: A comparison study on *Hypnumcu* *pressiforme* and *Parmelia caperata* in a former mining district in Italy. *Environmental Pollution*, 116(2): 279 – 287.

Chakrabortty, S. and Paratkar, G. (2006): Biomonitoring of trace element air pollution using Mosses. *Aerosol and Air Quality Research*,**6**(3): 247-258.

Cowden, P. and Aherne, J. (2019): Assessment of atmospheric metal deposition by moss biomonitoring in a region under the influence of a long-standing active aluminium smelter. *Atmospheric Environment*, 201: 84-91.

Cowden, P., Liang, T. andAherne, J. (2015): Mosses as bioindicators of air pollution along an urban-agricultural transect in the Credit River watershed, Southern Ontario, Canada. *Annali di Botanica*,**5**: 63-70.

Fernandez, J. and Carballeira, A. (2001). A comparison of indigenous mosses and top soils for use in monitoring atmospheric heavy metal deposition in Galicia (Northwest Spain). *Environmental Pollution*, 114: 431-441.

Fernandez, J., Perez-Llamazares, A., Carballeira, A. and Aboal, J. (2013): Temporal variability of metal uptake in different cell compartments in Mosses. *Water, Air, and Soil Pollution*, 224(3): 1481-1490.

Graciela, Z., Josefina, P., Samuel, T., Pedro, A., Carmen, Z., Huemantzin, O. and Guadalupe, M. (2013): Assessment of Spatial Variability of Heavy Metals in Metropolitan Zone of Toluca Valley, Mexico, Using the Biomonitoring Technique in Mosses and TXRF Analysis. *The Scientific World Journal*,Article ID 426-492. https://doi.org/10.1155/2013/426492

Igbari, A.D. Amusa, O.D. Ihejimba, A.J. and Ogundipe, O.T. (2023): Biomonitoring of Heavy Metals Pollution in the University of Lagos, Akoka Campus Environment using the Moss *Dicraniumscorparium* Hedw. *Science World Journal*, 18(3): 445-451. https://dx.doi.org/10.4314/swj.v18i3.

Jiang, Y., Fan, M., Hu, R., Zhao, J. and Wu, Y. (2018): Mosses Are Better than Leaves of Vascular Plants in Monitoring Atmospheric Heavy Metal Pollution in Urban Areas. *International Journal of Environmental Research and Public Health*, 29: 15(6):1105. doi: 10.3390/ijerph15061105

Musa, J., Mustapha, j., Ibrahim, Y., Akos, M., Daniel, S., Oguche, M. andKuti, A. (2017): Heavy metals in agricultural soils in Nigeria. *Arid Zone Journal of Engineering, Technology and Environment*,13(5): 593 – 603.

Ndlovu, N., Frontasyeva, M., Newman, R. and Maleka, P. (2019): Moss and Lichen Biomonitoring of Atmospheric Pollution in the Western Cape Province (South Africa). *American Journal of Analytical Chemistry*, 10: 86-102. doi: 10.4236/ajac.2019.103008.

Nurkassimova, M., Omarova, N., Zinicovscaia, I. Chaligava, O. and Yushin, N. (2024): Mosses as bioindicators of air pollution with potentially toxic elements in area with different level of anthropogenic load in Karaganda region, Kazakhstan. *Journal of Radio-analytical Nuclear Chemistry*. https://doi.org/10.1007/s10967-023-09334-0

Ojiodu, C.C., Shittu, A. and Moses, D.U. (2016): Heavy metals presence in the Amosphere of Owode –Onirin, Ikorodu, Lagos - State, Southwestern Nigeria Using *Barbulaindica*(Hook) Spreng as bioindicator. *Nigeria Journal of Scientific Research*, 15(3): 546 -552.

Ojiodu, C.C. and Olumayede, E.G. (2018): Biomonitoring of heavy metals using *Polytrichum commune* as a bioindicator in a macro environment, Lagos state, South-Western Nigeria. *FUW Trends in Science and Technology Journal*, 3: 287 – 291

Okedeyi, O.O., Dube, S., Awofolu, O.R. and Nindi, M.M. (2014): Assessing the enrichment of heavy metals in surface soil and plant (*Digitariaeriantha*) around coal-fired power plants in South Africa. *Environmental Scientific Pollution Research*, 21: 4686–4696.

Paliulis, D. and Blagnyte, R. (2010): Research into heavy metals pollution of atmosphere applying Moss as bioindicator: a literature review. *Environmental Research, Engineering and Management*,4: 26-33.

Pesch, R. and Schroeder, W. (2006). Mosses as bioindicators for metal accumulation: Statistical aggregation of measurement data to exposure indices. *Ecological Indicators*,6: 137-152.

Prandan, A., Kumari, S., Dash, S., Biswal, D., Dash, K. and Panigrahi, K. (2017): Heavy metal absorption efficiency of two species of Mosses (*Physcomitrella patens* and *Funariahygrometrica*) studied in mercury treated culture under laboratory condition. *IOP Conference Series: Materials Science and Engineering*,225(12): 22-28.

Qarri F., Lazo P., Bekteshi L., Stafilov T., Frontasyeva M. and Harmens H. (2015): The effect of sampling scheme in the survey of atmospheric deposition of heavy metals in Albania by using moss biomonitoring. *Environmental Scientific Pollution Research*, 22: 2258–2271.

Tremper, A., Agneta, M., Burton, S. and Higgs, D. (2004): Field and laboratory exposures of two Moss species to low level metal pollution. *Journal of Atmospheric Chemistry*, 49: 111-120.

Radziemska, M., Mazur, Z., Bes, A., Majewski, G., Gusiatin, Z.M. and Brtnicky, M. (2019): Using Mosses as Bioindicators of Potentially Toxic Element Contamination in Ecologically Valuable Areas Located in the Vicinity of a Road: A Case Study. *International Journal of Environmental Research in Public Health*,16(20): 3963. https://doi.org/10.3390/ijerph16203963

Rutkowski, P., Diatta, J., Konatowska, M., Andrzejewska, A., Tyburski, Ł. And Przybylski, P. (2020): Geochemical Referencing of Natural Forest Contamination in Poland. *Forests*, *11*: 157. https://doi.org/10.3390/f11020157

Sa'idu, A. (2015):*Assessment of moss species as biomonitors of atmospheric pollutants in some towns of North -Western Nigeria*, Department of Biological Sciences, Ahmadu Bello University, Zaria Nigeria, pp. 27- 50.

Vergel, K., Zinicovscaia, I., Yushin, N., Frontasyeva, M. and Marina V. (2019): Heavy Metal Atmospheric Deposition Study in Moscow Region, Russia. *Bulletin of Environmental Contamination and Toxicology*, 103: 435-440. https://doi.org/10.1007/s00128-019-02672-4

World Health Organization (WHO) (1996). Permissible Limits of Heavy Metals in Soil and Plants. Geneva, Switzerland.

Yushin, N., Chaligava, O., Zinicovscaia, I., Vergel, K. andGrozdov, D. (2020): Mosses as Bioindicators of Heavy Metal Air Pollution in the Lockdown Period Adopted to Cope with the COVID-19 Pandemic. *Atmosphere*, *11*:1194. https://doi.org/10.3390/atmos11111194

Zinicovscaia, I., Hramco, C., Chaligava, O., Yushin, N., Grozdov, D., Vergel, K. andDuca, G. (2021): Accumulation of Potentially Toxic Elements in Mosses Collected in the Republic of Moldova. *Plants*, 10(3): 471.