Innovations

Chemometric Evaluation of Moss (Fissidens grandifolius) as a Bioindicator of Heavy Metal Pollution in an Urban-Industrial Environment (Asaba, Nigeria)

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Abstract: *Heavy metal pollution in urban-industrial environments poses critical risks to ecological and public health due to their persistence, toxicity, and bioaccumulative potential. Mosses have been widely employed as biomonitors of atmospheric deposition because of their unique morphological and physiological features. This study evaluated the bioindicator potential of Fissidens grandifolius for assessing heavy metal contamination in Asaba, Delta State, Nigeria. Moss samples were collected from seven sites representing traffic, industrial, and control environments. Atomic Absorption Spectrophotometry (AAS) was used to quantify Pb, Cd, Cr, Zn, Cu, and Ni. Chemometric tools, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), were applied to distinguish pollution sources and classify sites based on contamination profiles. Results showed that Pb and Zn were the dominant metals, with maximum concentrations of 14.22 mg/kg and 12.65 mg/kg, respectively, particularly in industrial and high-traffic areas. PCA extracted two components explaining 76.4% of the total variance, identifying vehicular emissions, paint residues, and petroleum combustion as the primary sources of contamination. HCA grouped sampling sites into three clusters corresponding to highly polluted, moderately polluted, and control zones. The study demonstrates that moss biomonitoring, combined with chemometric evaluation, provides a low-cost, efficient, and reliable approach for environmental monitoring in developing urban-industrial regions.*

Keywords: *Heavy metals, moss biomonitoring, chemometrics, PCA, HCA, Asaba, environmental monitoring*

1. Introduction

Heavy metals are ubiquitous environmental contaminants that persist in ecosystems and accumulate in living organisms, causing both ecological and health risks (Alloway, 2013). Urbanization, industrialization, and vehicular emissions are major contributors of lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), and nickel (Ni) into the atmosphere (Edo et al., 2024). Monitoring atmospheric heavy metals is essential for pollution management, but conventional air monitoring systems are costly and require advanced infrastructure. Mosses, due to their lack of cuticles and vascular tissues, absorb elements directly from atmospheric deposition, making them excellent bioindicators of airborne heavy metals (Ares et al., 2012; Harmenset al., 2015).

Previous studies have demonstrated the applicability of mosses in Europe and Asia for large-scale biomonitoring (Harmenset al., 2015; Gómez-Boleaet al., 2023). However, there are few studies in Nigeria, despite the increasing industrial activities and urban expansion. Incorporating chemometric tools such as Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) improves interpretation of biomonitoring data by distinguishing pollution sources and grouping sampling sites according to contamination levels (Mishra et al., 2024). This study investigates the suitability of Fissidens grandifolius as a bioindicator for heavy metal pollution in Asaba, Delta State, Nigeria, and applies chemometric approaches for source apportionment and pollution classification.

2. Materials and Methods m

2.1 Study Area

The study was conducted in Asaba, Delta State, Nigeria, a fast-growing urban-industrial city characterized by heavy vehicular traffic and emerging industrial activities.

Sample location and characteristics

Site Code	Location Description	Coordinates
+CS	Control Site	6°11'6.6'' N, 6°39'14.3'' E
FS	Fuel Station	6°13'5.8'' N, 6°40'20.2'' E
NPI	Near Paint Industry	6°12'9.7'' N, 6°41'12.1'' E
PI	Paint Industry	6°12'6.3'' N, 6°41'18.3'' E
RH	Roadside near Hotel (Expressway)	6°14'3.5'' N, 6°42'23.9'' E
DOU	DOU Works Environment	6°13'2.8'' N, 6°40'8.7'' E
PWF	Pure Water Factory Environment	6°13'7.9'' N, 6°41'30.4'' E
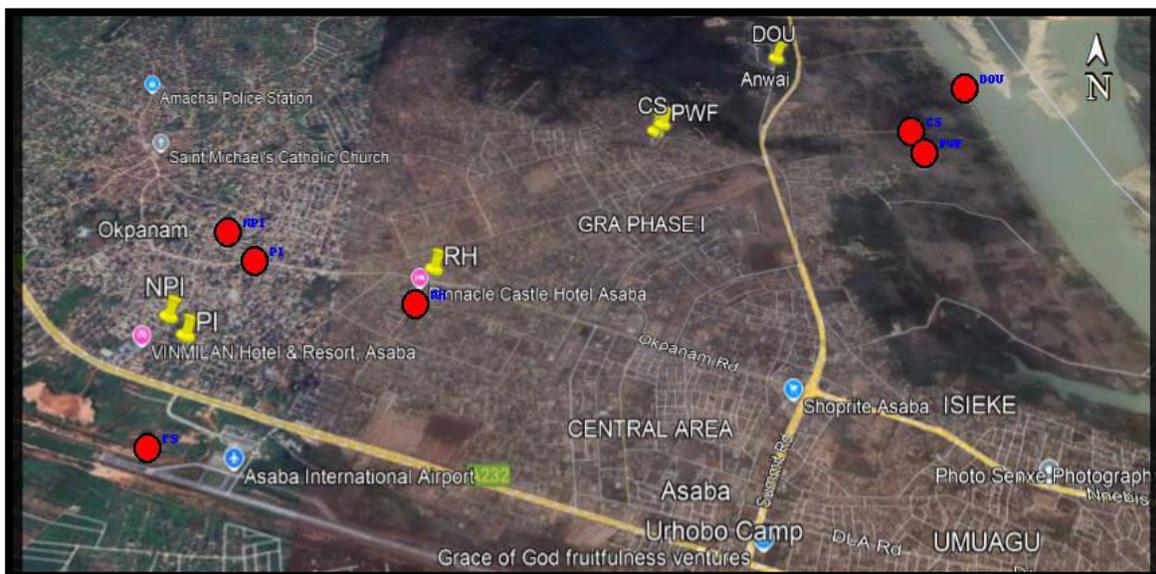
Legend
CS = Control Site
FS = Fuel Station
NPI = Near Paint Industry
PI = Paint Industry
RH = Roadside near Hotel
DOU = DOU Works Environment
PWF = Pure Water Factory

(Figure 1 Map of Sample location)

2.2 Sampling and Sample Preparation
Moss samples (Fissidens grandifolius) were collected from seven sites: control site, paint industry, fuel station, pure water factory, university surroundings, traffic corridor, and an expressway near a hotel. Samples were taken from walls at 1–2 m above the ground, oven-dried, and homogenized.

2.3 Digestion and Analysis
Approximately 0.5 g of dried moss was digested using a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_{+-}$) in a 3:1 ratio. Heavy metal concentrations (Pb, Cd, Cr, Zn, Cu, Ni) were determined using Atomic Absorption Spectrophotometry (AAS). Quality assurance included blanks, replicates, and recovery tests, with recoveries ranging from 95–103% (Ares et al., 2012).

2.4. Statistical and Chemometric Analysis

Data analysis included descriptive statistics, PCA, and HCA performed with SPSS (v25.0). PCA identified major pollution sources, while HCA grouped sampling sites according to similarities in heavy metal concentrations (Mishra et al., 2024).

3. Results and Discussion

3.1 Heavy Metal Concentrations

Table 1 revealed that Lead (Pb) exhibited the highest concentration (2.01–14.22 mg/kg), followed by Zn (3.71–12.65 mg/kg), and Ni (1.83–8.02 mg/kg). Cd, Cu, and Cr occurred at comparatively lower levels. Industrial and traffic-exposed sites had significantly higher accumulations compared to the control site, indicating anthropogenic origins. These findings are consistent with earlier moss biomonitoring studies (Harmenset al., 2015; Ojioduet al., 2021).

Table 1: presents the summary statistics of heavy metal concentrations in moss samples.

Metal	Range (mg/kg)	Mean ± SD	CV (%)	Dominant Sources
Pb	2.01–14.22	8.34 ± 4.47	53.6	Traffic, paint industry
Cd	0.32–1.91	1.10 ± 0.58	52.8	Fuel combustion, waste
Cr	1.64–7.13	4.56 ± 2.05	45.1	Industrial emissions
Zn	3.71–12.65	8.29 ± 3.45	41.6	Tyre wear, lubricants
Cu	0.37–1.58	1.07 ± 0.42	39.3	Paint residues, industry
Ni	1.83–8.02	4.86 ± 2.34	48.2	Petroleum, traffic sources

3.2 Principal Component Analysis (PCA)

PCA extracted two principal components accounting for 76.4% of the total variance. PC1 was strongly correlated with Pb, Zn, and Cu, attributed to traffic and paint industries. PC2 was associated with Ni and Cr, reflecting fossil fuel combustion and industrial processes (Mishra et al., 2024).
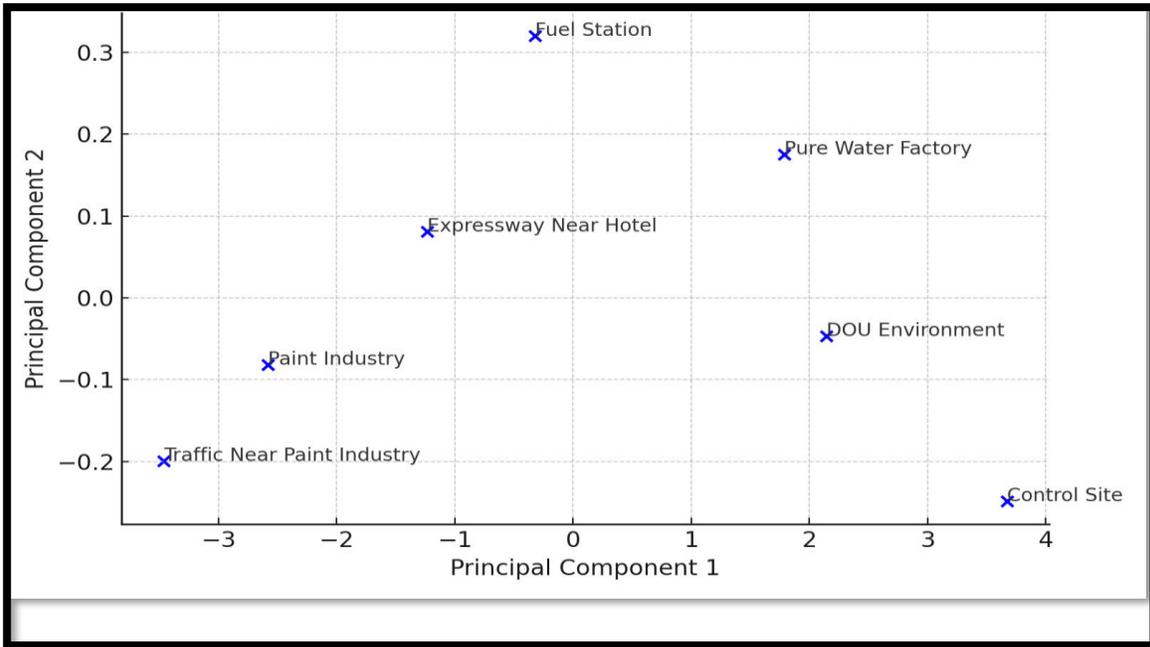
Figure 2: PCA biplot of heavy metals in moss samples

3.3 Hierarchical Cluster Analysis (HCA)

HCA grouped the sites into three clusters: Cluster 1 (traffic corridor, paint industry, expressway – highly polluted), Cluster 2 (fuel station, university, pure water factory – moderately polluted), and Cluster 3 (control site – least polluted). This confirmed spatial variability in heavy metal pollution and supported PCA findings.
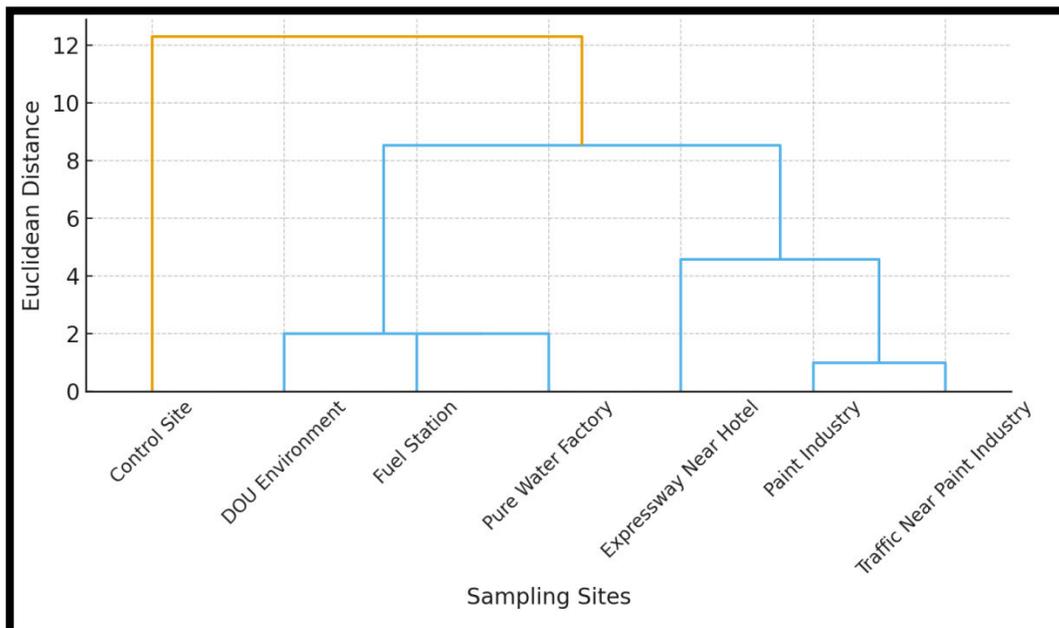

Figure 3: HCA dendrogram of study sites

3.4 Comparative and Health Implications

Pb and Zn were dominant contaminants as revealed in figure 4 below, consistent with global urban-industrial studies (Harmenset al., 2015; Gómez-Boleaet al., 2023). Pb exposure is linked to neurotoxicity, especially in children (Edo et al., 2024), while Ni and Cr are potential carcinogens. Moss biomonitoring thus provides early-warning signals for pollution-related health risks.
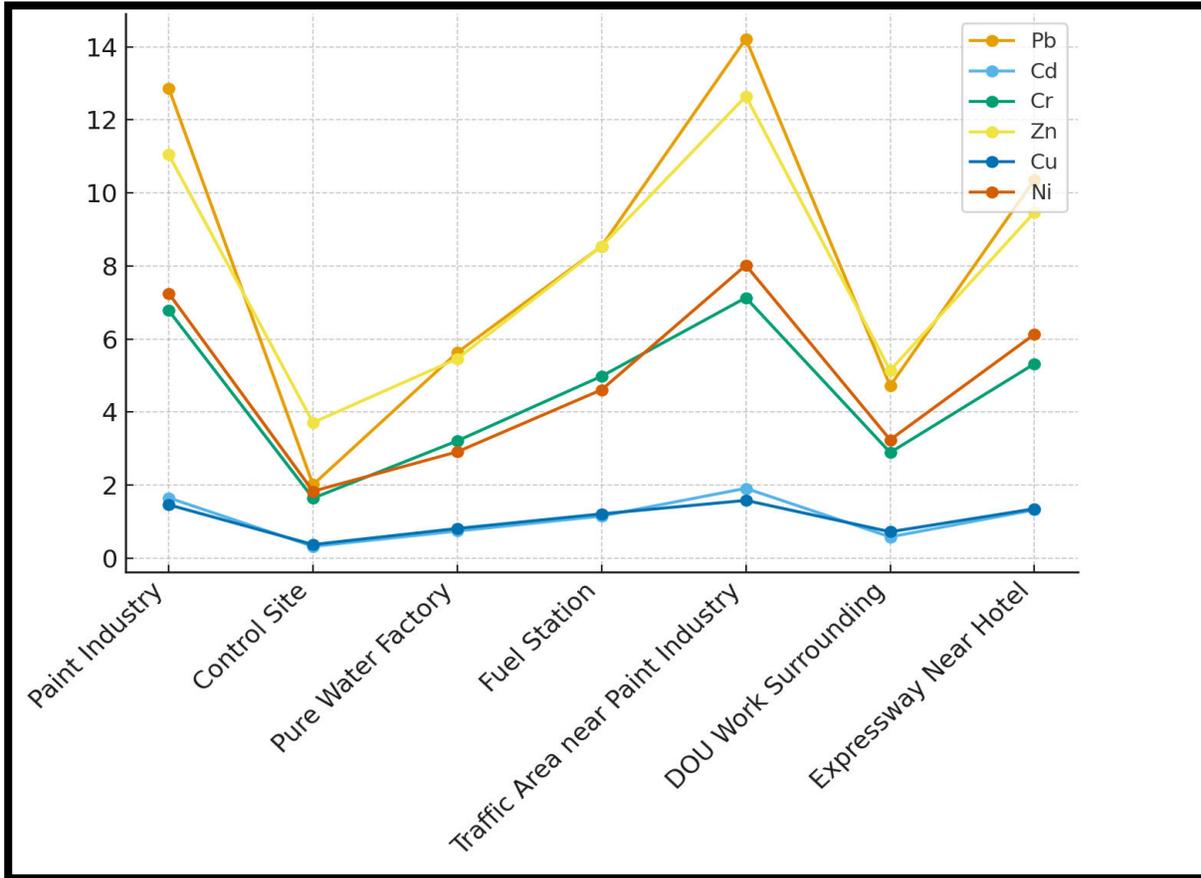

Figure 4: Comparative concentrations of Pb, Cd, Cr, Zn, Cu, and Ni across the seven sampling

4. Conclusions

This study demonstrates the potential of Fissidens grandifolius as a bioindicator of atmospheric heavy metals in Asaba. Pb and Zn were the most abundant pollutants, reflecting contributions from traffic and industrial activities. PCA and HCA provided clear evidence of pollution source apportionment and spatial clustering of sampling sites. Moss biomonitoring coupled with chemometrics is a cost-effective and reliable tool for environmental assessment in developing regions. Future studies should expand temporal coverage and integrate additional pollutants to strengthen monitoring frameworks.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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