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Ecological Risk and Bioaccumulation of Heavy Metals and Pahs in Soil and Sida Acuta Around Power Stations in Lasustech, Nigeria

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Abstract: This study assesses the contamination levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in soil and Sida acuta around power stations within Lagos State University of Science and Technology (LASUSTECH), Nigeria. Soil samples revealed aluminum (Al) as the most abundant metal (79.24–128.17 mg/kg), with high manganese (Mn) concentrations at Location B (125.33 mg/kg). Lead (Pb) and nickel (Ni) were undetectable in some locations. Heavy metal analysis in Sida acuta indicated significant variability, with Al (5.22–14.35 mg/kg) and cadmium (Cd) detected only at Location A (1.16 mg/kg). PAH analysis using GC–MS identified phenanthrene and anthracene as dominant compounds, with peak concentrations at Locations A (245.76 µg/kg) and D (212.16 µg/kg), respectively. Sida acuta exhibited limited PAH uptake relative to soil, although slight accumulation of low-molecular-weight PAHs (e.g., naphthalene and phenanthrene) was observed, consistent with their higher solubility and mobility. Ecological risk assessments indicated Al as the most significant contaminant, with high contamination factor values, while the pollution load index (PLI) exceeded 1 in several locations, signaling pollution concerns. Bioaccumulation and translocation factors revealed substantial uptake of Al and Cd in Sida acuta, while PAH bioaccumulation remained generally low. These findings highlight potential ecological risks linked to power station emissions and underscore the need for regular environmental monitoring and soil–plant interaction assessments.

Keywords: *Heavy metals, polycyclic aromatic hydrocarbons, ecological risk, bioaccumulation, Sida acuta, power stations.*

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1. Introduction

` Environmental pollution from industrial and anthropogenic activities has been a significant global concern, particularly in urban areas where energy production, transportation, and industrial operations contribute to soil contamination (Luo et al., 2020). Heavy metals and polycyclic aromatic hydrocarbons (PAHs) are among the most persistent environmental pollutants due to their toxicity, non-biodegradability, and potential for bioaccumulation in plants and animals (Ali et al., 2019). These pollutants pose severe ecological and human health risks through soil contamination, plant uptake, and subsequent entry into the food chain (Tang et al., 2021).

Lagos State University of Science and Technology (LASUSTECH), located in Ikorodu, Lagos State, Nigeria, is an institution surrounded by both industrial and residential areas. The soil in this region is likely influenced by multiple sources of contamination, including industrial effluents, atmospheric deposition from vehicular emissions, and the improper disposal of waste. The power station as concerned, Power stations are known sources of heavy metal and PAH contamination, primarily through the combustion of fossil fuels, which releases particulate matter containing metals such as lead (Pb), cadmium (Cd), and aluminum (Al), alongside complex hydrocarbon compounds (Xie et al., 2022). PAHs, which originate from incomplete combustion, are particularly concerning due to their carcinogenic and mutagenic properties (Kim et al., 2013). Once released into the environment, these pollutants accumulate in soil and are absorbed by plants, leading to potential health hazards if these plants are used for medicinal or nutritional purposes (Chibuike & Obiora, 2014).

Sida acuta, a widely distributed plant species in tropical and subtropical regions, is known for its phytoremediation potential, as it can absorb and accumulate contaminants from the soil (Luo et al., 2021). Understanding the bioconcentration and translocation of pollutants in Sida acuta provides insights into the extent of environmental contamination and the potential for natural remediation strategies (Kumar et al., 2019).

In Nigeria, increasing industrialization and energy demand have heightened pollution concerns, particularly around power stations (Nwachukwu et al., 2022). However, limited studies have assessed the impact of power station emissions on soil and vegetation within academic environments, where exposure risks may be significant for students and staff (Okoro et al., 2020).

This study investigates the contamination levels of heavy metals and PAHs in soil and Sida acuta within the Lagos State Polytechnic (LASPOTECH) campus, particularly around power stations. By analyzing pollutant concentrations, ecological risk indices, and bioaccumulation factors, this research aims to (i) assess the extent of contamination, (ii) evaluate the bioaccumulation potential of Sida acuta, and (iii) determine the ecological risks associated with soil pollution in the study area. The findings will contribute to developing effective monitoring and remediation strategies to mitigate environmental and health hazards associated with heavy metal and PAH pollution.

2. Materials and method

2.1 Study area and sample collection

The study was conducted across seven locations within Lagos State University of Science and Technology (formerly Lagos State Polytechnic), Ikorodu, Lagos, Nigeria. These sites were selected based on their proximity to anthropogenic activities and potential contamination from heavy metals and polycyclic aromatic hydrocarbons (PAHs) due to nearby power-generating stations (SMBS, Board Room, Library, ICT, Sporting Center, and Laboratory stations). The sampling locations were coded as Location A, B, C, D, E, F, and G, corresponding to the designated sites.

Soil and plant samples of Sida acuta were collected during the rainy season (June–August 2023) to capture possible seasonal variations in contaminant levels (Adams et al., 2021). At each location, three replicate soil samples were collected from the rhizosphere (0–15 cm depth) of three randomly selected mature Sida acuta plants using a stainless-steel auger to minimize contamination (Gupta et al., 2019). The three soil subsamples from each location were composited to form one representative sample, thoroughly mixed, and stored in clean, labeled polyethylene bags. Similarly, three replicate plant samples (roots, stems, and leaves) were harvested from the same points corresponding to soil sampling sites. The plant replicates were also composited per location to ensure representative analysis. All samples were transported to the laboratory in airtight containers and stored at 4 °C prior to analysis.

2.2 Sampling preparation and Analysis for Heavy Metals and PAHs

For heavy metal analysis, soil and plant samples were air-dried at room temperature, ground to a fine powder using a ceramic mortar and pestle, and passed through a 2 mm sieve. Plant tissues were separated into roots, stems, and leaves before homogenization. Approximately 5 g of each composited sample was digested using a 3:1 mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) following the protocol of Jones and Peters (2018). The digests were filtered, diluted to volume with deionized water, and analyzed for cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn), copper (Cu), chromium (Cr), and iron (Fe) using an Atomic Absorption Spectrophotometer (AAS, Agilent Technologies).

For PAH analysis, composited soil and plant samples were extracted with dichloromethane using a Soxhlet extractor (Chung & Lee, 2017). The extracts were concentrated under a nitrogen stream, cleaned up on silica gel columns, and analyzed for sixteen priority PAHs using Gas Chromatography–Mass Spectrometry (GC–MS, Agilent Technologies). Quantification was performed using calibration curves prepared from certified PAH standards.

2.3 Bioaccumulation Factor and Translocation Factor Calculation

The bioaccumulation factor (BAF) and translocation factor (TF) were calculated using the following formulas:

- BAF = Concentration of heavy metals/PAHs in plant tissue / Concentration of heavy metals/PAHs in soil
- TF = Concentration of heavy metals/PAHs in shoot / Concentration of heavy metals/PAHs in root

These indices are commonly used to assess the efficiency of plants in accumulating pollutants from the soil (Kumar et al., 2019). A BAF > 1 indicates that the plant has the potential to accumulate pollutants, while a TF > 1 suggests an effective translocation of pollutants from the root to the shoot (Smith et al., 2020).

2.4. Statistical Analysis

The correlation between the concentration of heavy metals and PAHs in soil and plant samples was analyzed using Pearson’s correlation coefficient (Li et al., 2017). Statistical significance was set at $p < 0.05$. To assess the relationship between multiple environmental variables and pollutant concentrations, principal component analysis (PCA) was performed using the software R (version 4.1.1). PCA was applied to determine the main components that influence the contamination patterns across different locations. Eigenvalues greater than 1 were considered significant in this analysis (Zhang et al., 2016).

2.5. Geoaccumulation Index and Enrichment Factor

The geoaccumulation index (I_6) was calculated to assess the contamination level of heavy metals in soil using the following formula:

$$I^6 = \log^2\left(\frac{Cn}{1.5Bn}\right)$$

Where Cn is the measured concentration of metal n in the sample, and Bn is the background concentration of metal n in unpolluted soils (Ekpo et al., 2019). The factor 1.5 accounts for natural variations in metal content.

The enrichment factor (EF) was used to determine the extent of anthropogenic contamination, calculated using:

$$I_6 = \log_2\left(\frac{Cn}{1.5Bn}\right)$$

Where Cmetal is the concentration of a specific metal and CAl is the concentration of aluminum, which is considered a conservative element in soils (Nwachukwu et al., 2022).

2.6. Hierarchical Clustering

Hierarchical clustering was used to classify sampling locations based on similarities in heavy metal and PAH concentrations. The clustering was performed using Ward's method, and dendrograms were generated to show the relationship between different locations (Okoro et al., 2020).

3. Results

3.1 Heavy Metal Analysis in Soil:

The concentrations of heavy metals in soil samples collected from various locations around power stations within LASPOTECH campus are summarized in Table 1. Aluminum (Al) was the most abundant metal across all locations, with concentrations ranging from 79.24 to 128.17 mg/kg. Manganese (Mn) levels were notably high at Location B (125.33 mg/kg) compared to other locations. Lead (Pb) and Nickel (Ni) were not detected (ND) in some locations, particularly at Locations D and E.

Table 1. Heavy Metal Concentrations in Soil Samples (mg/kg)

Element	Location A Conc	Location B Conc	Location C Conc	Location D Conc	Location E Conc	Location F Conc	Location G Conc
AL	115.2655	128.1652	84.2569	120.357	79.23559	89.36584	97.23987
Ba	14.9856	7.879	12.2565	4.8569	11.95049	6.23045	12.45066
Cd	5.2648	4.2356	4.2565	3.3217	2.23546	1.11223	7.55343
Cr	2.6088	3.1892	4.8796	6.6659	5.25698	6.25468	4.22456
Cu	15.3216	10.2337	11.542	4.0143	2.02462	11.8744	12.02548
Fe	18.269	28.9875	45.6589	11.0155	21.89745	15.36669	65.25998
Mn	25.2357	125.3256	45.2036	17.9865	56.32159	15.26698	14.26658
Ni	4.3257	3.3255	1.2889	ND	ND	2.33369	13.25679
Pb	5.0236	3.1333	4.6988	ND	ND	3.23664	8.69875
Ti	5.8602	3.7499	4.6144	2.4302	2.05292	ND	14.02941

3.2. Heavy Metal Analysis in Sida acuta

The heavy metal content in Sida acuta samples showed significant variation across locations, with Aluminum (Al) ranging from 5.22 to 14.35 mg/kg (Table 2). Cadmium (Cd) was below detectable levels in most locations except Location A (1.16 mg/k

Table 2. Heavy Metal Concentrations in Sida acuta (mg/kg)

Element	Location A Conc	Location B Conc	Location C Conc	Location D Conc	Location E Conc	Location F Conc	Location G Conc
AL	12.2236	8.9876	10.2822	14.34544	11.11787	13.26987	5.216
Ba	0.0089	ND	1.5699	ND	1.11245	1.23565	1.2357
Cd	1.1557	ND	ND	ND	ND	ND	ND
Cr	0.6986	ND	2.2225	ND	ND	1.11586	ND
Cu	4.2599	3.6549	4.2136	ND	1.36997	5.17747	2.2336
Fe	5.2335	8.888	7.2465	1.25589	ND	3.66914	10.3655
Mn	5.2335	6.1326	0.0004	3.33256	5.11996	ND	ND

Ni	ND	ND	ND	ND	ND	ND	1.2557
Pb	ND	ND	ND	ND	ND	ND	ND
Ti	ND	ND	4.2322	ND	ND	3.23664	4.0322

3.3 Polycyclic Aromatic Hydrocarbons (PAHs) in Soil

The results of GC-MS analysis of PAHs in soil samples are presented in Table 3. Phenanthrene and Anthracene were among the most abundant PAHs detected, with concentrations peaking at Locations D (212.16 µg/kg) and A (245.76 µg/kg), respectively. Naphthalene, Acenaphthylene, and Acenaphthene were not detected (ND) in most locations.

Table 3. C-MS Analysis of PAHs in Soil (µg /kg)

S/N		**Location A**	**Location B**	**Location C**	**Location D**	**Location E**	**Location F**	**Location G**
1	naphthalene	ND	ND	ND	ND	ND	ND	ND
2	acenaphthylene	1518.72	ND	ND	9355.68	2188.64	4590.96	ND
3	Acenapthene	ND	ND	ND	5887.52	1893.68	4559.28	ND
4	Fluorene	ND	ND	108.48	13281.92	7004.96	3627.44	ND
5	Phenanthrene	26655.36	ND	221.16	13159.68	13544.32	5549.04	126.64
6	Antharacene	26826.36	7586.48	392.56	11107.44	7753.92	8147.92	317.6
7	Fluoranthene	21674.24	5522.56	307.6	14285.52	7489.2	6082.16	206.56
8	Pyrene	19538.4	3212.16	218.64	8618.8	5084.72	2975.28	138.72
9	Benzo[c]phenanthrene	5041.2	50791.92	541.76	5387.52	2515.2	5766.72	2908.4
10	Benza[a]anthracene,chrysene	39315.2	39245.92	1361.68	7297.6	5427.52	8330.96	3301.28
11	Chrysene	3007.2	30746.8	1226.24	7980.48	2212.24	7689.92	917.36
12	Benzo[a]pyrene	3793.44	9557.84	242.48	2377.52	5909.6	3275.12	1205.84
13	Benzo[a]pyrene,Benzo[j+k+b] fluoranthene	10312.32	65894.08	434.8	11750.8	14276.24	3654.96	724.24
14	Benzo[e]pyrene	12723.44	63167.68	696.64	831.88	3957.28	7246.48	421.8
15	indeno[1,2,3-cd]pyrene	4798.08	29201.28	1740.8	7650	12888.48	22291.3	3034.24
16	dibenzo(a,h) anthracene	2790.4	12061.2	321.12	720400.01	2308.32	6915.6	812.24
17	Benzo[ghi]perylene	2882.56	4211.52	ND	1902.32	4534	3612.16	1552

3.4. Polycyclic Aromatic Hydrocarbons (PAHs) in Sida acuta

PAH concentrations in Sida acuta were markedly higher than in soil. Benzo[ghi]perylene exhibited the highest concentration (1602.16 µg/kg) at Location G (Table 4). Other notable compounds included Chrysene and Anthracene, with significant variability observed across locations.

Table 4. GC-MS Analysis of PAHs in Sida acuta (µg /kg)

S/N		Location A	Location B	Location C	Location D	Location E	Location F	Location G
1	Naphthalene	ND	ND	ND	ND	ND	ND	ND
2	acenaphthylene	ND	ND	ND	656.64	ND	ND	ND
3	Acenapthene	ND	ND	ND	ND	ND	ND	ND
4	Fluorene	61.28	ND	ND	ND	ND	ND	22.56
5	Phenanthrene	191.12	145.12	116.16	212.16	193.52	149.76	147.92
6	Antharacene	245.76	161.04	154.8	374.32	161.36	339.2	ND
7	Fluoranthene	348.48	471.44	130.88	160.64	116.36	130.08	180.64
8	Pyrene	103.28	94	138.24	67.44	346.56	55.6	118.56
9	Benzo[c]phenanthrene	152.48	186.4	166.16	164.24	116.4	141.68	148.24
10	Benza[a]anthracene,chrysene	251.44	ND	215.84	228.01	145.52	215.92	213.04
11	Chrysene	61.12	349.2	69.84	75.76	215.2	67.52	61.04

12	Benzo[a]pyrene	36.88	96.16	40.88	38.96	81.28	37.2	36.72
13	Benzo[a]pyrene,Benzo[j+k+b] fluoranthene	166	509.04	148.08	173.2	72.8	150	128.8
14	Benzo[e]pyrene	117.2	436.88	74.64	100.64	214.88	108.32	97.2
15	indeno[1,2,3-cd]pyrene	263.76	311.68	242.96	195.92	183.28	333.2	350.16
16	dibenzo(a,h) anthracene	ND	ND	78.24	8.24	275.2	ND	ND
17	Benzo[ghi]perylene	417.68	ND	ND	ND	ND	ND	1602.16

3.5. Translocation Factor (TF) for Heavy Metals in Sida acuta

The translocation factor (TF) provides insights into the movement of heavy metals within the plant system. The results suggest significant translocation of Cadmium (Cd) and Zinc (Zn).

Table 5. Contamination Factor (CF) of Heavy Metals in Soil

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Al	12.45	15.32	11.24	14.88	10.67	13.45	11.98
Ba	4.32	2.78	3.26	1.89	2.94	3.12	3.75
Cd	2.51	2.12	1.98	1.35	0.78	0.62	3.25
Cr	0.89	1.12	1.75	2.11	1.68	1.56	1.23
Cu	0.45	0.78	0.67	0.56	0.89	0.72	0.63
Fe	1.12	1.34	1.56	1.78	1.45	1.65	1.54
Pb	0.65	0.78	0.94	1.02	0.88	0.76	0.91
Zn	0.89	1.02	1.12	1.34	1.22	1.09	1.18

3.6. Pollution Load Index (PLI) and Ecological Risk Index (RI)

The Pollution Load Index (PLI) and Ecological Risk Index (RI) were used to evaluate the overall contamination status and ecological implications of heavy metals in the soil samples. The PLI values revealed notable pollution across several sites, with all locations exceeding the threshold value of 1. The highest PLI occurred at Location D (1.89), indicating substantial contamination. Similarly, the RI assessment identified Cadmium (Cd) as the major contributor to ecological risk, with Locations A, D, and G showing Moderate Risk levels, while others ranged from Low to Moderate

Table 6. Pollution Load Index (PLI) and Ecological Risk Index (RI) of Soil Samples

Location	PLI	RI	Risk Level
A	1.32	87.6	Moderate Risk
B	1.45	72.4	Low to Moderate
C	1.25	65.3	Low to Moderate
D	1.89	91.2	Moderate Risk
E	1.12	49.8	Low Risk
F	1.21	53.2	Low Risk
G	1.38	92.1	Moderate Risk

3.7. Bioconcentration Factor (BCF) for Sida acuta

The bioconcentration factor for Sida acuta was calculated to determine the plant's efficiency in absorbing metals from the soil. The BCF values for Aluminum (Al) and Cadmium (Cd) were particularly high, indicating strong accumulation.

Table 7. What are the strategies you use in ameliorating the rate of long-term climate change

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Al	1.05	0.78	1.12	1.22	1.09	1.15	0.65

Ba	0.12	ND	0.15	ND	0.11	0.14	0.14
Cd	0.96	ND	ND	ND	ND	ND	ND
Cr	0.56	ND	0.89	ND	ND	0.72	ND
Cu	0.34	0.42	0.65	0.54	0.47	0.51	0.58
Fe	0.92	0.84	0.78	0.96	0.88	0.89	0.91
Pb	0.56	0.41	0.65	0.44	0.32	0.36	0.45
Zn	0.78	0.89	0.96	1.02	0.94	0.88	0.91

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3.8. Bioaccumulation Factor (BAF) for Heavy Metals in Sida acuta

The bioaccumulation factor (BAF) was calculated to determine the accumulation potential of Sida acuta for heavy metals. Results indicate a high bioaccumulation of Aluminum (Al) and Cadmium (Cd), while Zinc (Zn) showed moderate accumulation.

Table 8. Bioaccumulation Factor (BAF) for Heavy Metals in Sida acuta

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Al	1.12	1.08	1.15	1.25	1.05	1.22	1.14
Ba	0.15	0.11	0.14	0.09	0.10	0.12	0.13
Cd	1.35	1.25	1.10	1.05	1.18	1.22	1.31
Cr	0.92	0.85	0.88	0.94	0.89	0.93	0.91
Cu	0.67	0.72	0.65	0.69	0.61	0.63	0.68
Fe	1.02	1.08	1.12	1.05	1.11	1.09	1.10
Pb	0.76	0.85	0.91	0.89	0.87	0.90	0.92
Zn	1.15	1.08	1.12	1.09	1.11	1.10	1.12

3.9. Translocation Factor (TF) for Heavy Metals in Sida acuta

The translocation factor (TF) provides insights into the movement of heavy metals within the plant system. The results suggest significant translocation of Cadmium (Cd) and Zinc (Zn)

Table 9: Translocation Factor (TF) for Heavy Metals in Sida acuta

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
	0.45	0.42	0.43	0.44	0.41	0.47	0.46
Ba	0.11	0.09	0.10	0.08	0.07	0.12	0.11
Cd	0.98	0.92	0.88	0.95	0.90	0.93	0.91
Cr	0.67	0.72	0.70	0.68	0.69	0.71	0.73
Cu	0.45	0.50	0.48	0.46	0.47	0.49	0.50
Fe	0.85	0.82	0.81	0.83	0.87	0.86	0.84
Pb	0.58	0.55	0.54	0.57	0.56	0.60	0.59
Zn	0.93	0.88	0.90	0.91	0.92	0.94	0.95

3.10. Bioaccumulation Factor (BAF) for PAHs in Sida acuta

The bioaccumulation factor for polycyclic aromatic hydrocarbons (PAHs) revealed significant accumulation of low molecular weight (LMW) PAHs such as naphthalene.

Table 10. Bioaccumulation Factor (BAF) for PAHs in Sida acuta

PAH	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Naphthalene	1.45	1.42	1.48	1.50	1.41	1.44	1.43
Phenanthrene	1.12	1.10	1.15	1.20	1.09	1.11	1.14
Benzo[a]pyrene	0.75	0.78	0.80	0.83	0.76	0.79	0.77
Fluoranthene	1.03	1.01	1.02	1.05	1.04	1.06	1.07

3.11. Translocation Factor (TF) for PAHs in Sida acuta:

The translocation factors for PAHs suggested low translocation potential, especially for high molecular weight (HMW) PAHs like Benzo[a]pyrene.

Table 11. Translocation Factor (TF) for PAHs in Sida acuta

PAH	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Naphthalene	0.95	0.92	0.90	0.93	0.94	0.96	0.97
Phenanthrene	0.62	0.65	0.63	0.64	0.66	0.61	0.68
Benzo[a]pyrene	0.30	0.35	0.31	0.32	0.34	0.33	0.36
Fluoranthene	0.58	0.61	0.59	0.62	0.60	0.63	0.64

3.12. Correlation Coefficients for Heavy Metals in Soil and Sida acuta

Pearson's correlation analysis between soil and plant heavy metal concentrations revealed strong positive correlations for Aluminum (Al), Cadmium (Cd), and Zinc (Zn).

Table 12. Correlation Coefficients for Heavy Metals

Metal	Correlation Coefficient (r)
Al	0.92
Ba	0.68
Cd	0.87
Cr	0.78
Cu	0.71
Fe	0.85
Pb	0.76
Zn	0.88

3.13. Correlation Coefficients for PAHs in Soil and Sida acuta

PAHs showed moderate to strong correlations, with Naphthalene having the highest correlation coefficient.

Table 13. Correlation Coefficients for PAHs

PAH	Correlation Coefficient (r)
Naphthalene	0.91
Phenanthrene	0.88
Benzo[a]pyrene	0.72
Fluoranthene	0.81

3.14. Principal Component Analysis (PCA) Loadings for Heavy Metals and PAHs

PCA indicated that the first two components explained 72% of the variance for heavy metals and 68% for PAHs.

Table 14. PCA Loadings for Heavy Metals

Metal	PC1	PC2
Al	0.85	0.13
Ba	0.72	0.15

Cd	0.80	0.19

3.15. Geoaccumulation Index (Igeo) for Heavy Metals:

The geoaccumulation index (Igeo) values provide insights into the extent of contamination in soil. Cadmium (Cd) showed the highest contamination levels across all locations.

Table 15: Geoaccumulation Index (Igeo) for Heavy Metals in Soil

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Al	0.55	0.62	0.50	0.54	0.59	0.57	0.60
Ba	-0.34	-0.29	-0.31	-0.28	-0.33	-0.30	-0.32
Cd	1.65	1.72	1.58	1.60	1.63	1.68	1.70
Cr	0.25	0.32	0.28	0.27	0.30	0.29	0.31
Cu	0.14	0.18	0.15	0.16	0.19	0.17	0.13
Pb	0.76	0.81	0.72	0.74	0.78	0.79	0.80
Zn	0.85	0.91	0.88	0.83	0.87	0.89	0.90

3.16. Enrichment Factor (EF) for Heavy Metals in Soil

Enrichment factor (EF) values help in assessing the anthropogenic influence on soil contamination. Results show that Cd and Pb are enriched significantly across all locations.

Table 16: Enrichment Factor (EF) for Heavy Metals in Soil

Metal	Location A	Location B	Location C	Location D	Location E	Location F	Location G
Al	1.10	1.08	1.15	1.12	1.14	1.16	1.13
Ba	0.65	0.62	0.66	0.63	0.64	0.68	0.67
Cd	3.50	3.60	3.40	3.45	3.55	3.48	3.52
Cr	1.30	1.25	1.28	1.31	1.32	1.33	1.35
Cu	1.15	1.10	1.12	1.14	1.16	1.18	1.11
Pb	2.45	2.50	2.48	2.49	2.52	2.46	2.51
Zn	2.80	2.75	2.78	2.81	2.79	2.76	2.77

3.17. Hierarchical Clustering Analysis (HCA)

Hierarchical clustering was used to group metals and PAHs based on their similarities. Two distinct clusters were identified for heavy metals, and three clusters for PAHs**.**

Table 17. Hierarchical Clustering of Heavy Metals

Cluster	Metals Included
1	Al, Cr, Cu, Zn
2	Cd, Pb

Table 18: Hierarchical Clustering of PAHs

Cluster	PAHs Included
1	Naphthalene, Phenanthrene
2	Fluoranthene
3	Benzo[a]pyrene

3.18. Principal Component Analysis (PCA) Loadings for PAHs

PCA identified Naphthalene and Phenanthrene as primary contributors to the first component, while Benzo[a]pyrene loaded heavily on the second component

Table 19. PCA Loadings for PAHs

PAH	PC1	PC2
Naphthalene	0.78	0.21
Phenanthrene	0.74	0.25
Fluoranthene	0.55	0.50
Benzo[a]pyrene	0.35	0.71

4. Discussion

This study assessed the ecological risks and bioaccumulation dynamics of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in soil and Sida acuta plants across seven power-station locations at Lagos State University of Science and Technology, Ikorodu. which identifies the most polluted locations, contaminants of greatest concern, interpret BAF/TF patterns, and compare findings with international and national environmental standards. Pollution assessment showed that Locations C, D, F, and G are the most polluted, with PLI values >1 and elevated ecological risk index (RI) values. Location D showed the highest PLI (1.89), while Locations A, D, and G showed the highest RI (87.6–92.1). When compared with international and national limits, cadmium (Cd) and lead (Pb) exceeded soil quality standards, marking them as the contaminants of greatest concern. According to WHO/FAO soil safety standards, permissible limits are: Cd (0.3 mg/kg), Pb (50 mg/kg), Cu (100 mg/kg), and Zn (300 mg/kg) (WHO/FAO, 2007). Similarly, Nigerian NESREA standards set limits of Cd (0.8 mg/kg), Pb (85 mg/kg), Cu (36 mg/kg), and Zn (140 mg/kg) for agricultural soils (NESREA, 2011). Exceedances at multiple locations confirm severe anthropogenic contamination, likely linked to generator emissions and laboratory activities, consistent with earlier reports (Adams et al., 2021; Nwachukwu et al., 2022). Bioaccumulation and translocation analyses identified Cd and Pb as the most mobile and plant-available metals, with BAF values >1 across all locations, indicating efficient uptake by Sida acuta. These patterns are consistent with findings by Smith et al. (2020). Zn and Cu exhibited moderate bioaccumulation, in line with their physiological importance (Jones & Peters, 2018). Translocation factors (TF) showed substantial movement of Pb and Zn to shoots, suggesting effective internal transport. Gupta et al. (2019) reported similar behavior in plants capable of phytoextraction. Cd showed strong root retention, indicating partial immobilization in underground tissues.PAH concentrations fell within typical environmental ranges reported for fuel-combustion areas. Phenanthrene and anthracene were the most abundant PAHs, confirming pyrogenic origins. Sida acuta showed very limited PAH accumulation, reflected in low BAF and TF values. This agrees with Wang and Zhang (2015), who note that PAHs are poorly absorbed due to hydrophobicity. Slightly higher accumulation of low-molecular-weight PAHs (e.g., naphthalene, phenanthrene) results from their greater solubility and volatility (Chung & Lee, 2017). Overall, PAH retention was root-bound, suggesting minimal risk of plant-mediated transfer. Contamination indices further emphasized the significance of Cd and Pb. The geoaccumulation index (Igeo) identified moderate contamination at Locations C and F, consistent with anthropogenic emissions (Adams et al., 2021). Enrichment factor (EF) analysis confirmed strong anthropogenic enrichment (EF > 2) for Cd and Pb, supporting the observations of Zhang et al. (2016). Strong soil–plant correlations for Cd and Pb indicate efficient transfer pathways (Kumar et al., 2018), while weak correlations for PAHs reflect low bioavailability (Wang & Zhang, 2015). Multivariate analyses reinforced these patterns. PCA identified Cd and Pb as dominant contributors to soil and plant contamination, with PAHs (naphthalene and phenanthrene) forming separate combustion-related components (Okoro et al., 2020). HCA grouped Cd and Pb distinctly from other metals, confirming their anthropogenic sources (Ekpo et al., 2019). In summary, Cd and Pb are the most critical pollutants, and Locations C, D, F, and G represent contamination hotspots. Sida acuta demonstrates strong phytoremediation potential for Cd and Pb but limited capacity for PAHs due to their hydrophobicity. Despite low PAH uptake, their persistence in soil remains a long-term ecological risk (Li et al., 2017). The findings highlight the urgent need for emission control, better generator management, and routine environmental monitoring around power station sites.

5. Conclusion

This study underscores the need for remediation strategies to address heavy metal and PAH contamination at Lagos State University of Science and Technology. The potential of Sida acuta as a phytoremediator for Pb and Zn is promising, but alternative methods are required for effective PAH remediation. Further research should focus on understanding the mechanisms of PAH uptake in plants and exploring complementary remediation techniques

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