

RESEARCH ARTICLE

ASSESSMENT OF CONTAMINATION OF POTENTIALLY TOXIC ELEMENTS (PTES) FROM SOIL MATRICES OF NIGERIA MARITIME UNIVERSITY PREMISE

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ABSTRACT

This study aimed to assess the contamination levels of potentially toxic elements (PTEs) in the soil matrices of Nigeria Maritime University premises. Soil samples were meticulously sieved using a nylon sieve with a diameter of <math><125\mu\text{m}</math> and prepared in triplicates, with reagent blanks included to monitor contamination. Twenty-five topsoil samples were collected and analyzed for PTEs using Flame Atomic Absorption Spectroscopy (FAAS). Pollution levels in the soils were evaluated using the Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI). The mean concentrations of toxic elements in the soil followed the descending order: $\text{Cd} < \text{As} < \text{Fe} < \text{Pb} < \text{Co} < \text{Ni} < \text{Cu} < \text{Zn} < \text{Cr} < \text{Mn}$. Concentration ranges were Cd (0.13-0.95 ppm), As (0.49-4.50 ppm), Fe (6.42-24.80 ppm), Pb (5.96-31.45 ppm), Co (2.93-51.80 ppm), Ni (4.27-82.48 ppm), Cu (7.42-84.90 ppm), Zn (9.10-184.36 ppm), Cr (29.80-234.00 ppm), and Mn (84.30-486.00 ppm). All toxic elements exceeded crustal average values used as background values, except for Cr and Fe in some samples. Ni, As, Co, and Cr exceeded FAO/WHO guidelines, while only Cr surpassed EU standards in certain soil samples. Pollution Indices (PIs) indicated low to high contamination levels for Cu, Zn, Cd, and Mn, low to moderate contamination levels for Pb, Ni, Co, As, and Cr, and low contamination for Fe. The Pollution Load Index revealed that the soil ranged from unpolluted to moderately polluted, with values from 0.28 to 2.76. The toxic elements exhibited Ecological Index Ratios (Eir) of <math><40</math>, indicating low potential ecological risk, except for Cd, Co, Fe, As, and Ni, which showed low to moderate ecological risk. Cd posed the highest contribution to the Ecological Risk Index (PERI), ranging between 18.24 and 109.67, indicating a moderate risk level.

KEYWORDS

Potentially toxic elements; pollution investigation; potential ecological risk; pollution index

1. INTRODUCTION

This research delves into the human health risk assessment concerning potentially toxic elements (PTEs) found in soil matrices within the premises of the Nigeria Maritime University. Such assessments aim to understand the possible adverse health effects resulting from human exposure to environmental contaminants. By quantitatively estimating the consequences, these assessments provide insights into the significance of contamination levels and inform decisions regarding cleanup efforts for site usability. Children are particularly vulnerable to these health effects due to differences in metabolism, behavior, diet, and physiological functions compared to adults. Their exposure to PTEs often begins at conception and continues through breastfeeding, making them more sensitive to environmental contaminants. Recognizing children's unique vulnerabilities is essential for developing adequate risk assessment guidelines to protect human health effectively (Irvine et al., 2019; Allout et al., 2018; Zhao et al., 2016).

The study area, located within the riverine area of Delta State, is surrounded by crude oil mining sites, leading to the dispersion of carbon soot across the communities. This contamination poses risks to residents, particularly children, who may ingest soil during recreational activities in community playgrounds. Intentional ingestion, often due to pica

tendencies, and unintentional ingestion from soil disturbance increase the risk of exposure. Furthermore, urban dust, containing environmental contaminants, presents health risks, especially for young children who may practice pica. The study investigates the bioaccessible fraction of PTEs (As, Cd, Cr, Cu, Pb, Mn, Ni, and Zn) through oral ingestion of soil/dust, inhalation of urban street dust, and airborne dust (PM₁₀) within the university premises (Duong et al., 2019; Abrahams et al., 2016).

Despite increased awareness of environmental and health consequences, workers at Nigeria Maritime University and residents of Escravos communities remain exposed to elevated concentrations of PTEs. This ongoing exposure underscores the need for comprehensive risk assessment strategies endorsed by international organizations like the WHO, OECD, EPA, and others. Implementing risk assessment methodologies is crucial for addressing environmental pollution and safeguarding public health on both local and global scales.

2. METHODOLOGY

2.1 Study Area

Situated along the Escravos River in Delta, Nigeria, the Nigeria Maritime University holds historical significance. The term "Escravos" originates from Portuguese, translating to "slaves," and denotes its role as a pivotal

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route for the slave trade between Nigeria and the United States during the 18th century. Spanning a length of 57 kilometers, the river originates from the Niger River, connecting to the Atlantic Ocean and the Gulf of Guinea. Its precise location is defined by the coordinates Latitude: 5° 34' 59.99" N and Longitude: 5° 09' 60.00" E (Ibitola, 2009).

3. SAMPLING AND ANALYSIS

3.1 Sample preparation for FAAS analysis

Samples that were used for the determination of elemental content via flame atomic absorption spectrometer (FAAS) was further sieved using a nylon sieve (<125µm diameter).

3.2 Sample Digestion

All experiments utilized reagent-grade chemicals. Sample digestions followed the protocol outlined in method 3050B by the US EPA. Initially, 10 ml of nitric acid (HNO₃) was added to beakers containing 1g of soil sample, which were then covered with a watch glass and heated for 15 minutes without reaching boiling point. After cooling, 5 ml of HNO₃ was added and the mixture was heated for an additional 30 minutes until brown fumes were emitted. Subsequently, another 5 ml of HNO₃ was added, and heating continued until no further brown fumes were observed. The solution was then allowed to evaporate to a volume of less than 5 ml and left to cool. Next, 2 ml of water and 3 ml of 30% hydrogen peroxide (H₂O₂) were added, and the mixture was heated for 2 hours until effervescence ceased. The solution was then evaporated to a volume of 5 ml. Following this, 10 ml of hydrochloric acid (HCl) was added and heated for 15 minutes without boiling. After cooling, the digested samples were filtered using Whatman filter paper (grade 41, pore size 20 µm) into 100 ml volumetric flasks. The filtrate was diluted to the mark with ultrapure water of resistivity 18.2 MΩ-cm at 25°C and prepared for analysis using Flame Atomic Absorption Spectrophotometer (FAAS). Each sample was digested in triplicate to ensure reproducibility.

3.3 Flame atomic Absorption Spectrophotometer (FAAS) protocol

The samples were prepared in triplicate, and reagent blanks were incorporated to monitor contamination. Six calibration standards spanning the range of 0-10 µg/mL (mg/L) were created from a 1000 µg/mL Pb stock solution. These standards were utilized to calibrate the instrument and generate a calibration curve, yielding a regression coefficient (R²) of 0.999, indicating a linear relationship. Given the high-quality R² value, the samples were subsequently analyzed.

3.4 Data Evaluation and Contamination Assessments

Statistical analysis was performed using Excel software to calculate the range, mean, and standard deviation (Microsoft, 2015). Additionally, multivariate statistical analysis, including inter-elemental correlations and factor analysis, was carried out using SPSS software (version 16). The contamination level of soil samples with potentially toxic elements was assessed using pollution index (PI) and potential ecological risk (PER) parameters, as described in previous studies (Wu et al., 2021; Li et al., 2020; Xiao et al., 2019). Furthermore, both non-carcinogenic and carcinogenic risks associated with these toxic elements were determined using hazard quotient and hazard index parameters.

3.5 Pollution Index (PI)

Pollution Index is the ratio of element in the soil to the background concentration which is the concentration of the same element in the earth's crust.

$$PI = \frac{C_n}{B_n} \quad (1)$$

Classification of PI is presented in Table 1 (Wu et al., 2016).

Table 1: Classification of Pollution Index	
PI ≤ 1	PI ≤ 1
1 < PI ≤ 3	Middle Contamination
PI > 3	High Contamination

Moreover, for a comprehensive evaluation of the pollution status in a sample, the integrated pollution load index (PLI) or the Nemerow integrated pollution index (NIPI) (Nemerow, 1985) can be utilized (Tomlinson et al., 1980; Luo et al., 2012; Lu et al., 2014; Chen et al., 2015; Odukoya et al., 2015; Li et al., 2020). These indices, PLI and NIPI, are computed as follows;

$$NIPI = (PI_1 \times PI_2 \times PI_3 \times \dots \times PI_n)^{1/n} \quad (2)$$

The PLI and NIPI can be calculated using

As per, the classification corresponding to PLI and Nemerow integrated pollution index (NIPI) is provided in Table 2 (Zhang et al., 2020).

Table 2: Classification Based on Pollution Index (PI) and Pollution Load Index (PLI) (Odukoya et al., 2015; Zhang et al., 2020).			
PLI = 0 0 < PLI = 1	Background Concentration Unpolluted	NIPL = 0.7 0.7 < NIPL = 1	Safe Precaution
1 < PLI = 2	unpolluted to moderately polluted	1 < NIPL = 2	Slight Pollution
2 < PLI = 3	Moderately polluted	2 < NIPL = 3	Moderate Pollution
3 < PLI = 4	Moderately to highly polluted	NIPL > 3	Heavy Pollution
4 < PLI = 5	Highly polluted	NIPL = 0.7	Safe
PLI > 5	Very highly polluted		

3.6 Potential Ecological Risk Factor

An ecological risk factor (E^r) quantitatively expresses the potential ecological risk of a given contaminant as suggested is expressed as by (Håkanson, 1980)

$$E^r = Tr * Cf \quad (3)$$

where Tr is the toxic-response factor for a given substance and Cf is the contamination factor. The Tr values of heavy metals given is given in Table 3 by (Håkanson, 1980). The terminologies used to describe the risk factor are listed in Table 4.

Table 3: Pre-industrial reference level (kg/g) and toxic- response factor by (Håkanson, 1980)							
Elements	Cd	As	Ni	Cu	Pb	Cr	Zn
Pre-industrial reference level	1	15		50	7	90	175
Toxic-response factor	30	10	5	5	5	2	1

Table 4: The terminologies used to describe the risk factor			
ER	Ecological Potential Risk for Single Element	PERI	Ecological Risk
E ^r <40	Low potential ecological risk	PERI < 150	Low
40≤E ^r <80	moderate potential ecological risk	150 ≤ PERI <300	Moderate
80≤E ^r <160	considerable potential ecological risk	300 ≤ PERI <600	Considerable
160≤E ^r <320	high potential ecological risk	600 ≤ PERI	Very High
E ^r ≥320	very high ecological risk		

Table 5: Summary of Potential Toxic Elements in Soil within and around NMU premises FAO/WHO Guidelines-Chiroma et al., 2014: EU Guidelines – European Commission on environment, 2002.

Potential Toxic Metals (ppm)	Min.	Max.	Mean	Std. Dev.	FAO/WHO std	EU Std	Crustal Average
Cu	7.42	84.90	36.94	20.82	100	140	23
Pb	5.96	31.45	14.61	6.40	100	300	19
Zn	9.10	184.36	72.81	42.70	300	300	84
Ni	4.27	82.48	28.64	19.21	50	75	39
Co	2.93	51.80	14.62	7.15	50	Na	19
Fe	6.42	24.80	5.10	3.67	Na	Na	17
As	0.49	4.50	1.84	1.21	1.5	Na	1.5
Cd	0.13	0.95	0.16	0.03	3	3	0.2
Mn	84.30	486.00	349.14	314.19	Na	Na	586
Cr	29.80	234.00	89.76	56.40	100	100	86

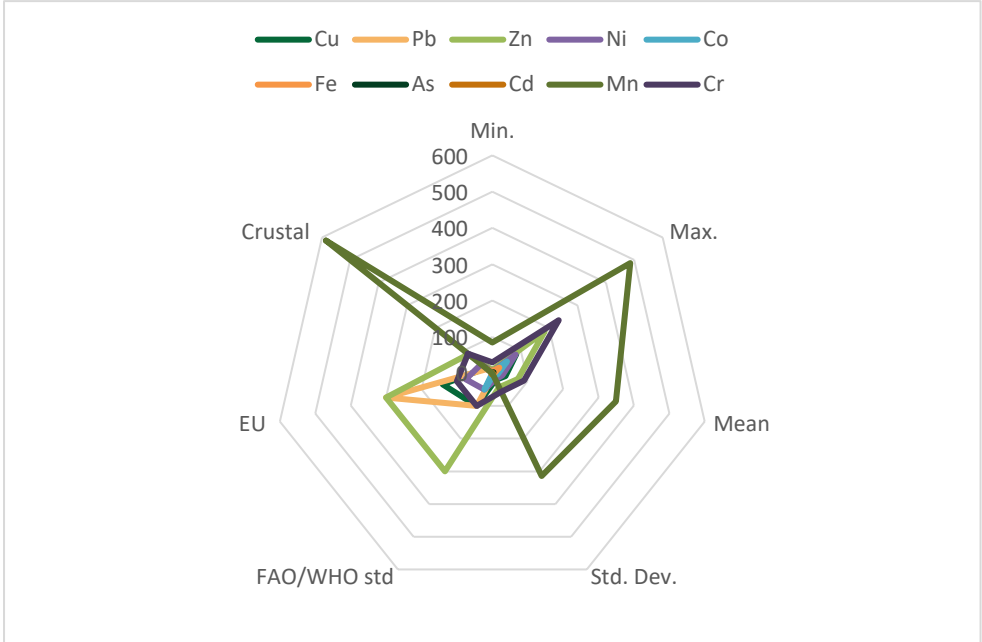


Figure 1: Summary of Potential Toxic Elements in Soil within and around NMU premises

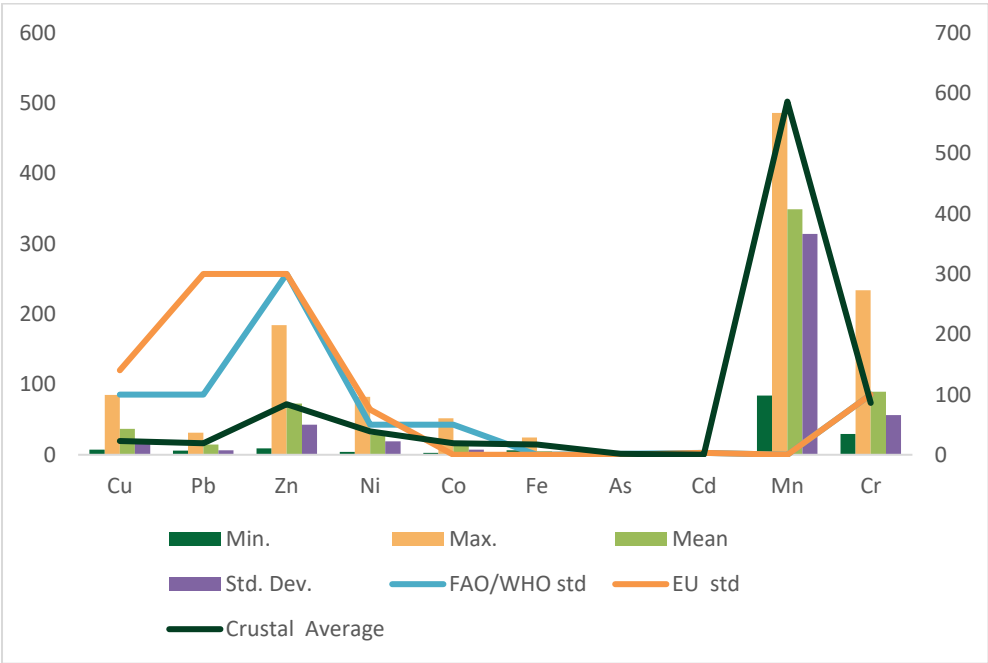


Figure 2: Summary chart of Potential Toxic Elements in Soil within and around NMU premises

4. RESULTS AND DISCUSSION

Table 6 presents the statistics of potentially toxic elements (PTEs) content in the vicinity of Nigeria Maritime University (NMU). The concentrations of ten PTEs, namely Cd, As, Pb, Cr, Cu, Ni, Mn, Co, Fe, and Zn, were analyzed across the area. The mean values of these elements in the soil followed a decreasing order of Cd < As < Fe < Pb < Co < Ni < Cu < Zn < Cr < Mn. The concentration ranges were as follows: Cd (0.13-0.95 ppm), As (0.49-4.50 ppm), Fe (6.42-24.80 ppm), Pb (5.96-31.45 ppm), Co (2.93-51.80 ppm), Ni (4.27-82.48 ppm), Cu (7.42-84.90 ppm), Zn (9.10-184.36 ppm), Cr (29.80-234.00 ppm), and Mn (84.30-486.00 ppm). Notably, all toxic elements exceeded the crustal average values considered as background levels, except for Cr and Fe in certain samples as indicated in Table 5. Specifically, Ni, As, Co, and Cr surpassed the FAO/WHO guidelines, while Cr alone exceeded the EU standard in some soil samples as detailed in Table 5.

4.1 Assessment of Contamination of Potentially Toxic Elements

To assess the degree of contamination in the study area, Pollution Index (PI), Pollution Load Index (PLI) and Potential Ecological Risk Index were used

4.2 Pollution Index (PI) and Pollution Load Index (PLI)

Table 6 and Figure 3 illustrate the Pollution Indices (PIs) of the toxic elements, revealing a descending order of Fe < As < Co < Cr < Pb < Ni < Mn < Zn < Cd < Cu. The PIs for Cu, Zn, Cd, and Mn ranged from low to high contamination levels, while Pb, Ni, Co, As, and Cr fell within the low to moderate contamination range. Fe was classified as low contamination. Moreover, the Pollution Load Index indicated that the soil in the study area ranged from unpolluted to moderately polluted, with values ranging from 0.28 to 2.76, as depicted in Table 6 and Figure 3.

Potential Toxic Elements	Pollution Index (Range)	Pollution Index (Mean)	Interpretations
Cu	0.4-4.2	2.20	Low to High Contamination
Pb	0.5-1.9	1.20	Low to Middle Contamination
Zn	0.2-3.4	1.82	Low to High Contamination
Ni	0.2-2.4	1.34	Low to Middle Contamination
Co	0.3-1.9	0.94	Low to Middle Contamination
Fe	0.04-0.7	0.18	Low Contamination
As	0.2-1.9	0.84	Low to Middle Contamination
Cd	0.4-3.6	1.84	Low to High Contamination
Mn	0.2-2.8	1.70	Low to High Contamination
Cr	0.4-2.8	1.09	Low to Middle Contamination
PLI	0.28-2.76	1.52	Unpolluted to moderately polluted

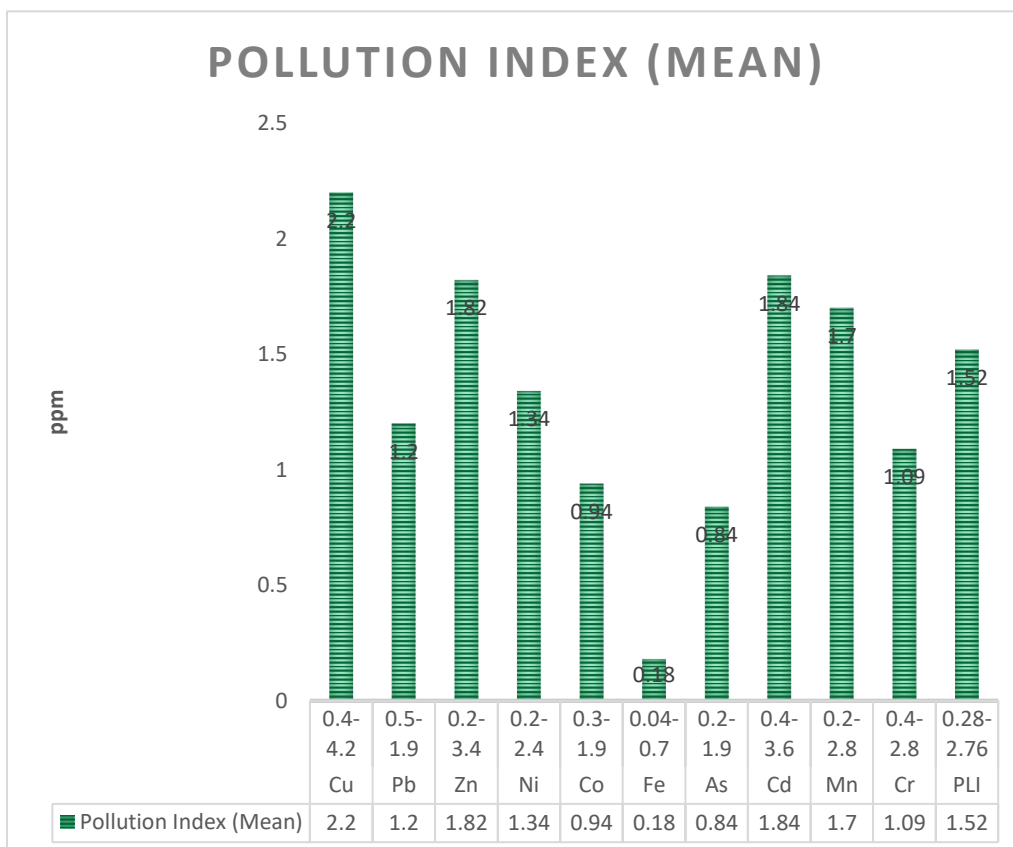


Figure 3: Results of Pollution Load Index in NMU premise

4.3 Ecological Risk Index (E_r) and Potential Ecological Risk Index (PERI)

The Ecological Risk Index (E_r) analysis for the toxic elements revealed the following order of pollution: Cd > Co > Fe > As > Ni > Cu > Mn > Pb > Zn >

Cr. With E_r values consistently below 40, the majority of the toxic elements indicated a low ecological potential risk, except for Cd, Co, Fe, As, and Ni, which demonstrated a low to moderate ecological potential risk, as shown in Table 7. Notably, Cd contributed the highest to the Ecological Risk (PERI), with values ranging between 18.24 and 109.67, indicating a moderate risk level.

Table 7: Result of Potential Ecological Risk Index				
Potential Toxic Elements	E _r (min)	E _r (max)	E _r (mean)	Interpretations
Cu	1.64	19.40	10.50	Low potential ecological risk
Pb	2.90	14.35	8.60	Low potential ecological risk
Zn	1.48	8.60	6.43	Low potential ecological risk
Ni	2.80	21.38	11.84	Low to moderate potential ecological risk
Co	4.32	52.00	28.20	Low to moderate potential ecological risk
Fe	2.14	34.82	16.48	Low to moderate potential ecological risk
As	3.42	22.41	12.60	Low to moderate potential ecological risk
Cd	5.40	58.70	32.12	Low to moderate potential ecological risk
Mn	1.34	28.66	9.39	Low potential ecological risk
Cr	0.24	3.69	1.87	Low potential ecological risk
PERI	18.24	109.67	67.80	Moderate risk

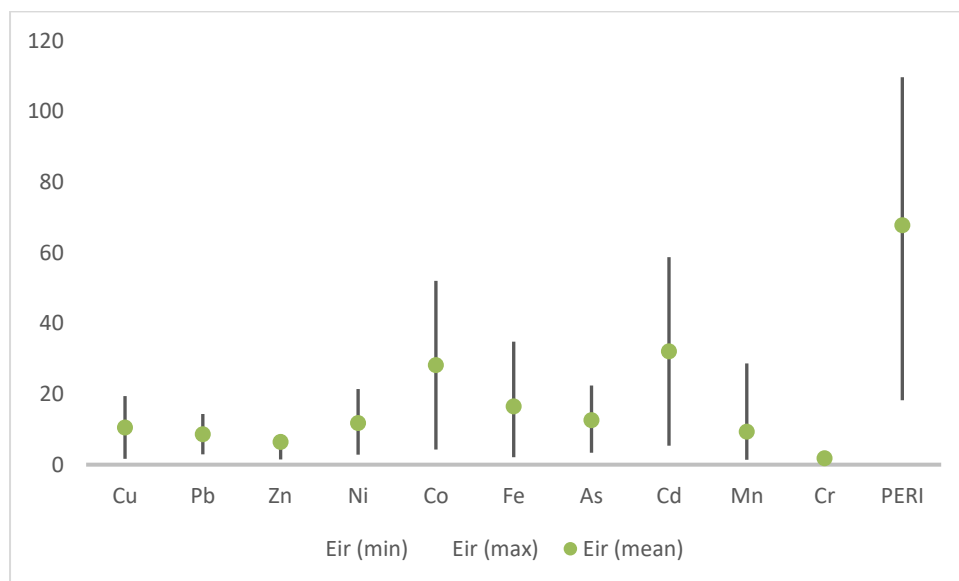


Figure 4: Result of Potential Ecological Risk Index

5. CONCLUSION

The analysis of potentially toxic elements (PTEs) around the premises of Nigeria Maritime University (NMU) revealed a distinct trend in the mean values of these elements in the soil. The descending order of concentration was observed as $Cd < As < Fe < Pb < Co < Ni < Cu < Zn < Cr < Mn$. Notably, all measured toxic elements exceeded the crustal average values commonly used as background references, except for Cr and Fe in select samples. Among the studied elements, Ni, As, Co, and Cr surpassed the recommended guidelines set by the FAO/WHO, with Cr exceeding the EU standard in certain soil samples. Furthermore, the Pollution Indices (PIs) for the toxic elements demonstrated a descending order of $Fe < As < Co < Cr < Pb < Ni < Mn < Zn < Cd < Cu$. PIs for Cu, Zn, Cd, and Mn ranged from low to high contamination levels, while Pb, Ni, Co, As, and Cr indicated low to moderate contamination. Fe was categorized as having low contamination levels. Additionally, the Ecological Risk Index (E_r) calculation for the toxic elements revealed the following pollution order: $Cd > Co > Fe > As > Ni > Cu > Mn > Pb > Zn > Cr$. Most elements exhibited E_r values below 40, indicating a low ecological potential risk. However, Cd, Co, Fe, As, and Ni showed E_r values suggesting a low to moderate ecological potential risk.

In conclusion, the assessment of contamination of potentially toxic elements (PTEs) from soil matrices around the premises of Nigeria Maritime University (NMU) provides valuable insights into the environmental quality and potential risks posed to human health and ecosystems. The study revealed varying concentrations of PTEs in the soil, with notable elements exceeding recommended guidelines and standards set by regulatory bodies. The results indicated that Cd, As, Co, and Cr were present at levels higher than those deemed safe by FAO/WHO guidelines, with Cr surpassing EU standards in select samples. This underscores the significance of monitoring and managing soil contamination to mitigate potential health hazards. Furthermore, the Pollution Indices (PIs) highlighted the extent of contamination, with certain elements categorized

as having low to moderate contamination levels. These findings emphasize the importance of adopting appropriate remediation measures to address soil pollution and safeguard public health. Moreover, the Ecological Risk Index (E_r) assessment identified Cd, Co, Fe, As, and Ni as posing low to moderate ecological potential risks, warranting further attention to mitigate adverse impacts on the surrounding environment and ecosystems. Overall, the findings of this study underscore the need for continued monitoring and remediation efforts to mitigate soil contamination and minimize associated health and environmental risks around the premises of Nigeria Maritime University. Such measures are crucial for promoting a safe and sustainable environment for present and future generations.

RECOMMENDATIONS

Based on the assessment of contamination of potentially toxic elements (PTEs) from the soil matrices of Nigeria Maritime University premises, the following recommendations are proposed:

Implement a systematic and periodic monitoring program to continuously assess the levels of PTEs in the soil matrices of the university premises. This will help in early detection of any changes in contamination levels and facilitate timely intervention measures. Develop and implement effective soil remediation strategies to mitigate the contamination of PTEs in areas where concentrations exceed acceptable limits. Techniques such as phytoremediation, soil washing, and chemical immobilization can be explored depending on the specific contaminants and site conditions. Conduct educational programs and awareness campaigns to educate students, faculty, and staff about the risks associated with PTE contamination in soil and the importance of adopting proper soil management practices to minimize exposure. Establish and enforce guidelines for the proper handling, storage, and disposal of hazardous materials within the university premises to prevent further contamination of soil matrices. Foster collaboration with relevant environmental

agencies and research institutions to exchange knowledge, share resources, and leverage expertise in addressing soil contamination issues effectively. Encourage the adoption of sustainable practices such as organic farming, green landscaping, and waste recycling to minimize the introduction of harmful substances into the soil matrices. Emphasize the importance of long-term monitoring to track trends in PTE contamination levels and evaluate the effectiveness of remediation efforts over time. Engage with local communities residing near the university premises to raise awareness about soil contamination issues and involve them in collaborative efforts to address environmental concerns collectively. By implementing these recommendations, the Nigeria Maritime University can effectively manage and mitigate the contamination of potentially toxic elements in its soil matrices, ensuring a safer and healthier environment for all stakeholders.

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