Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Assessing Heavy Metal Contamination in Parts of Middle Benue Trough, Central Nigeria: Implications for Public Health and Environmental Safety

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Abstract

Assessment of soil and water quality is critical for effective environmental management, particularly in regions impacted by human activities such as agriculture, mining, and industrial development. This study investigated the extent and environmental implications of heavy metal contamination in soils from Faya and its surrounding areas, located within the Middle Benue Trough of Central Nigeria. A total of thirty-three soil samples were collected from areas underlain by Shale, Limestone, Black Shales, Sandstone, and Migmatite formations. These samples were analyzed for concentrations of arsenic (As), lead (Pb), copper (Cu), chromium (Cr), manganese (Mn), cadmium (Cd), cobalt (Co), selenium (Se), zinc (Zn), and barium (Ba). To assess the level and potential sources of contamination, a suite of pollution indices was applied, including the Contamination Factor (CF), Pollution Load Index (PLI), Enrichment Factor (EF), and Geoaccumulation Index (Igeo). Results revealed elevated concentrations of As (mean: 28.10 mg/kg), Cd (25.68 mg/kg), Se (6.75 mg/kg), and Pb (16.93 mg/kg), frequently exceeding guideline limits set by the World Health Organization (WHO) and those proposed by Kabata-Pendias and Pendias (1999, 2001). High CF and EF values for As, Cd, Se, and Co suggest strong anthropogenic influences, likely linked to agricultural runoff, mining operations, and industrial discharges. Notably, samples RMP01A, RMP08B, and RMP012A exhibited the highest PLI values (PLI > 1), indicating cumulative pollution in these locations. In contrast, elements such as Mn, Ba, and Zn were generally within acceptable limits. The Igeo assessment further identified Cd and Se as the most concerning contaminants, with several samples classified as "moderately to heavily polluted," posing substantial ecological and public health risks. This study underscores significant environmental and health hazards in the region and emphasizes the urgent need for policy-driven remediation strategies and sustainable land use practices.

Keywords
Soil Contamination,
Heavy Metals,
Middle Benue Trough,
Contamination Factor,
Enrichment Factor,
Geoaccumulation Index.

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INTRODUCTION

Soil serves as the primary reservoir for biologically active trace elements such as lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), nickel (Ni), and copper (Cu), which enter the human food chain through plant uptake and animal consumption. According to Lar, et al (2013) these heavy metals find their way through the soil and are taken up by plants or leached into groundwater. These elements originate from two main sources according to Salminen, R., and Gregorauskienė, V.(2000), different types of bedrock and surficial materials contribute varying amounts and types of metals to the soil. For example, soils derived from igneous rocks may have different metal profiles compared to those from sedimentary rocks that is, soils derived from shale or volcanic rock often have higher natural metal concentrations compared to those from sandstone or limestone. Furthermore, anthropogenic inputs from human activities, such as industrial processes, mining, agriculture, and urbanization, can significantly alter the natural concentrations of metals in soils. These activities may introduce additional metals or redistribute them, potentially leading to contamination or pollution. Modern agricultural and industrial practices significantly alter soil chemistry through: Sewage sludge and wastewater irrigation, Industrial discharges like mining effluents, smelting byproducts, Chemical fertilizers containing metal impurities and Atmospheric deposition from fossil fuel combustion.

While approximately 20 trace elements (including Zn, Cu, and Ni) are essential for plant and animal metabolism at low concentrations, excessive levels pose severe risks like lead neurotoxcicity, developmental delays in children (Mitchell and Burridge, 1979), Cadmium renal dysfunction and ostemalacia (Malimi et al 1995), and Arsenic skin lesions and carcinogenic effects (Dick et al 1979).

Regulatory frameworks from agencies like the WHO now establish maximum permissible limits for agricultural soils with 20 mg/kg for lead, and 3mg/kg for cadmium to mitigate food chain contamination risks. Recent advances in phytoremediation techniques such as using *Brassica juncea* for lead extraction demonstrate promising strategies for rehabilitating metal-polluted soils.

The Middle Benue Trough, while geologically significant, remains among the least studied areas in Nigeria in terms of environmental geochemistry. There is a scarcity of data concerning heavy metal concentrations in its water and soil systems. This study, therefore, sought to fill that gap by evaluating the concentration and distribution of heavy metals such as Lead (Pb), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Barium (Ba), Manganese (Mn), Zinc (Zn), Cobalt (Co), and Selenium (Se) mining district, to determine the anthropogenic and/or geologic contribution to the enhancement of the heavy metals.

2. Study Area

The study area is part of the Middle Benue Trough, North Central Nigeria. Faya and surrounding areas (such as Shendam, Langtang, and Wase) lie within southern Plateau State (Fig. 1 and 2), which is geographically part of Nigeria's Middle Belt region, typically dominated by the Guinea Savanna. It is characterized by moderate to high elevations and is known for its mineral deposits, particularly Barite. The area is characterised by mixture of tall grasses and scattered medium-to-large deciduous trees. Typically, rainfall is moderate, about 1,000–1,500 mm annually, with a distinct wet and dry season. The study area supports both agriculture as the main occupation (especially cereals like maize, sorghum, and millet) and grazing. This ecological setting influences soil development, erosion patterns, and weathering processes, which in turn affect rock exposure, hydrology, and groundwater availability, factors that are important in geological and hydrogeological studies. Major settlements within the area include Faya in Langtang South, Batkilang, Dadinkowa and Walmin. These settlements are interconnected by a network of roads and are often situated along river valleys or near outcrops of particular geological units, influencing their development and accessibility.

Drainage patterns align with NW-SE structural trends, likely controlled by fractures or foliations (Figure 3).

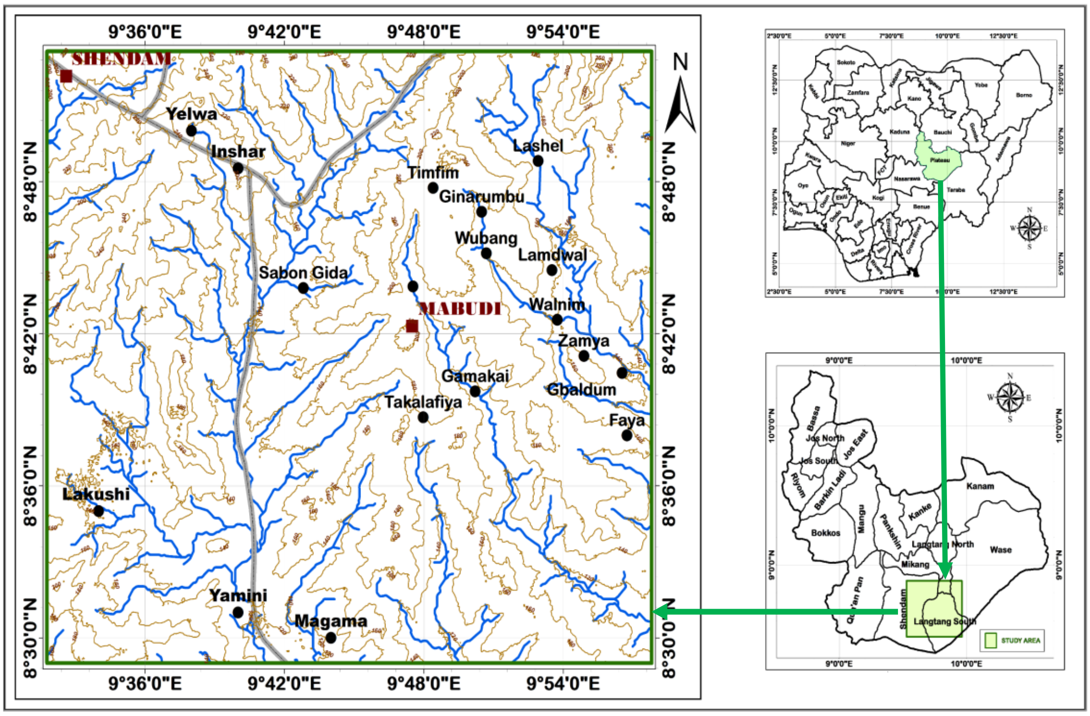

Figure 1: Location map of the study Area

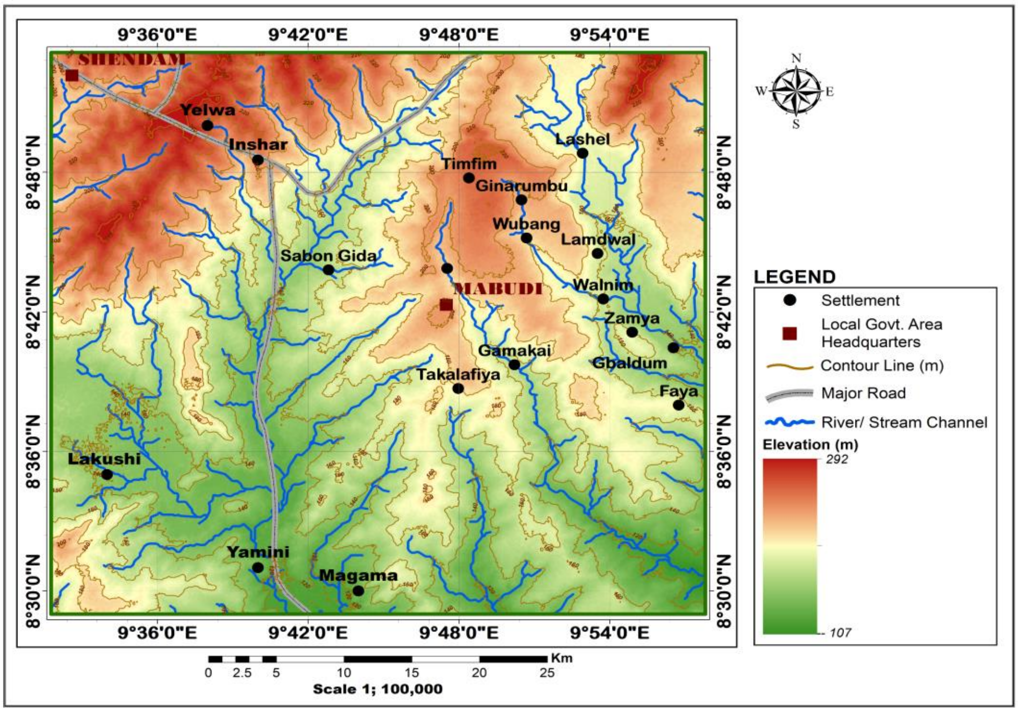

Figure 2: Elevation map of the study Area

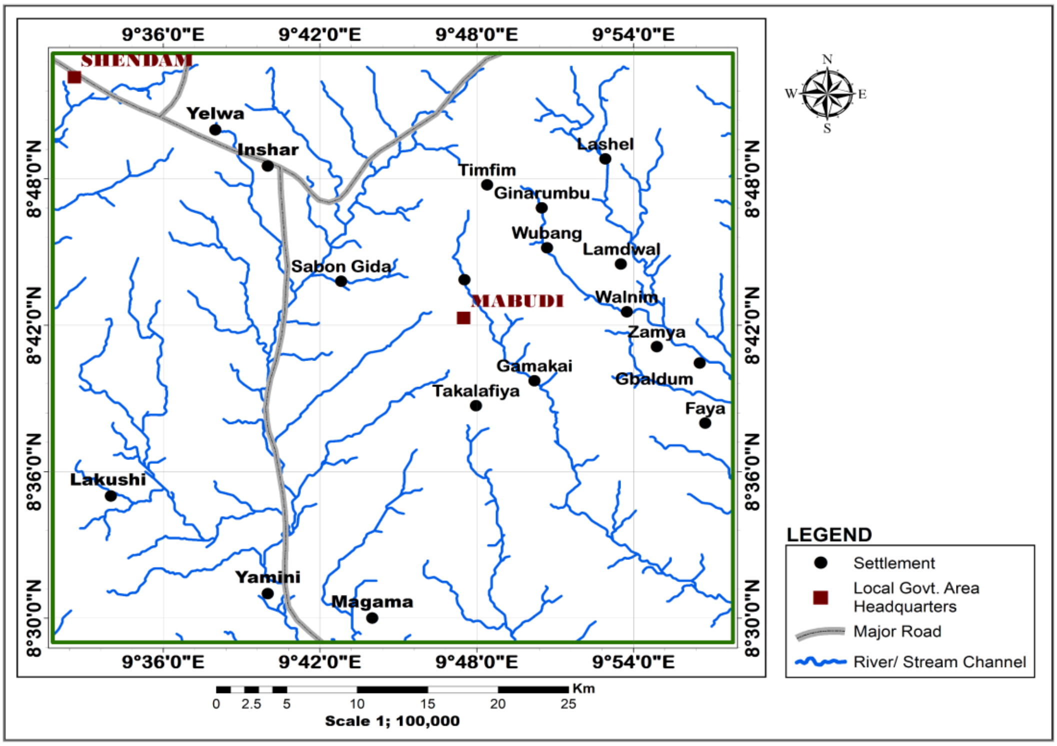

Figure 3: Drainage map of the study Area

2.1 Geology of the Study Area

The area is generally underlain by the Precambrian Basement Complex (Migmatite) shows evidence of Pan-African orogeny (550–600 Ma), with foliations and lineations oriented NW-SE, The Migmatite (M) is of Precambrian (Early–Mid Proterozoic, >1000 Ma) age and are high-grade metamorphic rocks formed during ancient orogenic events, representing the oldest crustal components in the region. The western portion of the study area has the Feldspathic-Calcareous-Shelly Sandstone (Bss), likely Upper Cretaceous in age part of the Cretaceous sedimentary rocks of the Middle BenueTrough according to Macleod et al and possibly part of the Gombe or Yolde Formations, representing high-energy shallow marine environments (Figure 3).

The Sedimentary units relate to Cretaceous rifting in the Benue Trough, accompanied by basaltic volcanism. Pindiga Formation – Shale and Limestone (Psh), Upper Cretaceous (Turonian–Santonian) and represents a transgressive-regressive sequence in the Middle Benue Trough; The Eze Aku Formation which is characterized by black shale and limestone, suggesting anoxic deep-water conditions with organic-rich sedimentation. Other formations in the study area are the Agwu Formation composed of shale and limestone, indicative of a marine depositional environment during the Cretaceous period and the Recent Alluvium (Al) Quaternary (Holocene–Recent), which are unconsolidated sediments, such as sand, silt, and clay, deposited by rivers and streams.

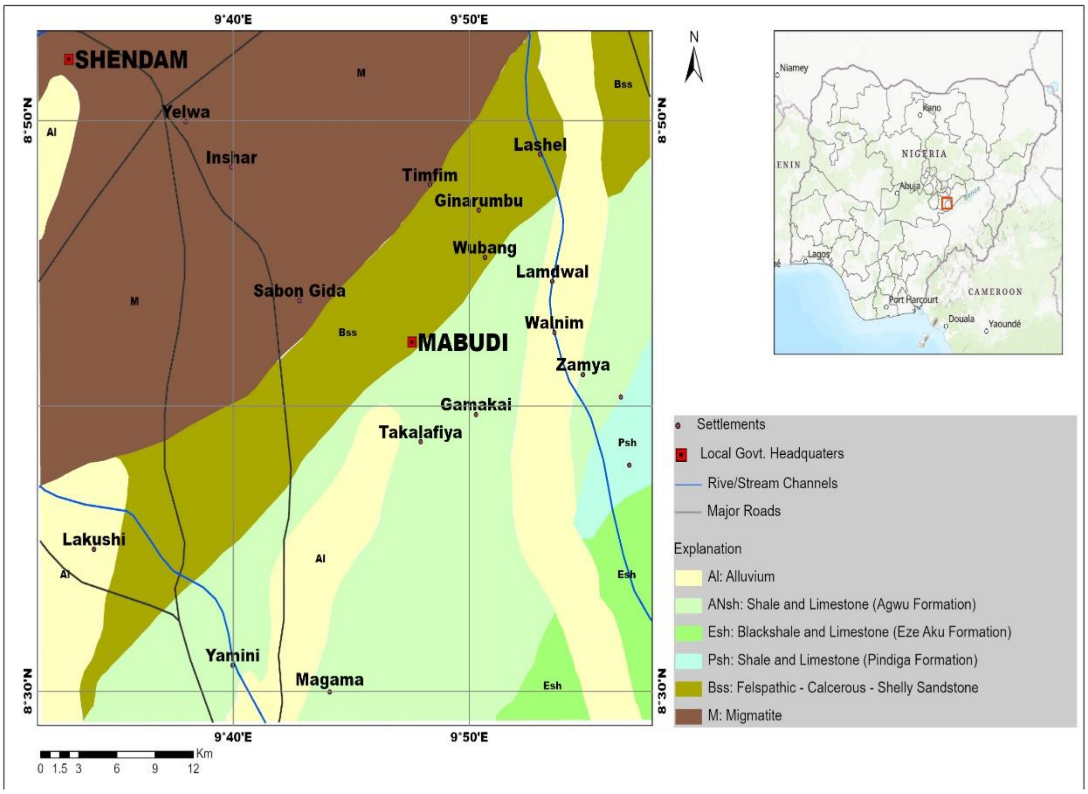

Figure 4: Geological Map of the Study Area (Modified after NGSA)

3. Materials and Methodology

3.1 Parameters Measured: The research involved the measurement of a range of chemical, and contamination parameters.

Chemical: Heavy metals

Heavy Metal Contamination Indices: Geo-accumulation Index (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and Pollution Load Index (PLI) for selected metals.

3.2 Sampling Approach

A total of 33 samples were extracted at a depth of 20cm using a hand auger. Samples were collected in sterilized labelled bags. The dry soil samples were disaggregated and then homogenized by the use of agate mortar and pestle. The samples were sieved to obtain the required grain size of minus 80-mesh (<180 μm) fraction and minus 100-mesh (<150 μm) fraction by the use of sieves with stainless steel screens. The sieved fraction was pulverized to further reduce the drain size as required for geochemical analysis.

4. Results and Analysis

The concentrations of the analysed elements in soil samples collected from the study area are presented in Table 1. Arsenic (As) ranged from 1.25 – 52.97 mg/kg with mean: 28.10 mg/kg. As levels significantly exceed the safe limit in most samples in particular RMP01A, RMP08B, and RMP012A. This suggests possible anthropogenic sources related to agricultural practice where pesticides are used. Iwegbue et al. (2013) also found elevated As in urban soils of Warri, Nigeria, linked to industrial emissions. Copper (Cu) ranged from 0.45 – 29.26 mg/kg with mean value 18.15 mg/kg. While most values are marginally above the guideline, samples such as RMP03 and RMP013A are notably high, likely due to the corrosion of Cu-containing minerals. Akpan and Udoh (2013) reported elevated Cu near dump sites in Uyo, Nigeria. Lead (Pb) ranged from bdl – 32.26 mg/kg with mean: 16.93 mg/kg. Pb levels exceed safety limits in the samples RMP04A, RMP03, and RMP08B. High Pb levels are often associated with battery waste, leaded gasoline residue, and industrial discharge. Adamu and Nganje (2010) found similar contamination patterns in Arufu, Middle Benue Trough.

Chromium (Cr) ranged from 1.56 – 36.31 mg/kg with mean value of 21.54 mg/kg. All Cr values are below the limit but may still pose ecological risk in areas with cumulative exposure. Obasi et al. (2012) attributed Cr in soil to effluents from metalworking and tanneries in southeastern Nigeria. Manganese (Mn) ranged from 13.07 – 726.37 mg/kg with mean value of 402.38 mg/kg. About half of the samples exceed the threshold including RMP012A, RMP04A, and RMP03A, indicating strong geogenic contribution or leaching from Mn-containing wastes. Awofolu et al. (2005) reported high Mn in soils around mining sites in South Africa and attributed it to weathered rock materials.

Cadmium (Cd) ranged from 0.52 – 41.55 mg/kg with mean value 25.68 mg/kg. Cd is extremely elevated across board, suggesting contamination from anthropogenic sources. Samples like RMP03A and RMP03B are highly polluted. Okakpu et al. (2023) found similar Cd levels in soils of industrial clusters in Anambra State. Cobalt (Co) ranged from 0.16 – 18.55 mg/kg with mean value of 10.02 mg/kg, Several samples exceeded this limit (RMP04A, RMP03B), indicating likely input from metal alloy materials and mineral leachates. Ebong et al. (2008) highlighted Co contamination from tailings and refuse dump leachates in Niger Delta soils.

All values of Selenium (Se) are above permissible limits, with RMP012A significantly high. Se contamination may arise from anthropogenic sources. The values ranged from 1.03 – 14.65 mg/kg. Osakwe and Okolie (2015) linked elevated Se to coal ash deposits and incineration by products. Zinc (Zn) is below the threshold in most samples, however, enrichment in RMP01A and RMP08B may be attributed to agrochemical use. Bentum et al. (2012) documented Zn pollution in agricultural soils exposed to prolonged fertilizer use. All Barium (Ba) values are within permissible levels. However, elevated values in RMP01B and RMP06B might suggest local geologic influence with mean value 69.80 mg/kg, Adamu et al (2014) discussed the Ba occurrence in Keana Brine fields of Middle Benue trough being within permissible limits.

The average concentrations of heavy metals in soil samples (mg/kg) from highest to lowest, based on the mean values from the analysis results showed Mn (Manganese) 402.38 mg/kg the highest, Ba (Barium) 69.80 mg/kg, As (Arsenic) 28.10 mg/kg, Cd (Cadmium) 25.68 mg/kg, Zn (Zinc) 23.88 mg/kg, Cr (Chromium) 21.54 mg/kg, Cu (Copper) 18.15 mg/kg, Pb (Lead) 16.93 mg/kg, Co (Cobalt) 10.02 mg/kg and Se (Selenium) 6.75 mg/kg the lowest.

Manganese (Mn) showed the widest variability, with concentrations spanning over 700 mg/kg. Cadmium (Cd) and Arsenic (As) exhibited significant outliers in sample RMP03A 41.55 mg/kg Cd; RMP01A/RMP08B 52.97 mg/kg As. Lead (Pb) had undetectable levels in multiple samples, indicating localized contamination and Barium (Ba) concentrations were relatively stable, with most samples below 100 mg/kg.

Table 1: Concentration of Heavy Metals in Soils of Faya and Environs

		Metals Concentartion in mg/kg									
S/No	Sample ID	As	Cu	Pb	Cr	Mn	Cd	Co	Se	Zn	Ba
1	RMP01	6.25	13.05	6.27	8.93	56.54	4.41	1.26	1.06	6.35	47.67
2	RMP01A	52.97	5.51	7.24	36.31	452.36	23.72	7.29	5.44	51.05	76.67

		Metals Concentartion in mg/kg									
S/ No	**Sample ID**	**As**	**Cu**	**Pb**	**Cr**	**Mn**	**Cd**	**Co**	**Se**	**Zn**	**Ba**
3	RMP01B	37.27	6.26	4.92	19.05	179.36	8.53	4.35	3.27	41.26	124
4	RMP02	17.58	5.3	2.85	12.39	91.46	14.51	1.76	2.95	19.31	99.33
5	RMP02A	15.36	7.37	10.88	7.13	145.42	8.29	2.2	1.44	18.54	81.33
6	RMP02B	20.53	6.38	8.76	4.29	221.65	15.44	2.53	3.27	35.26	90
7	RMP03	9.24	23.73	16.42	27.52	213.43	38.32	9.15	4.56	18.35	87
8	RMP03A	7.93	4.37	3.54	13.35	356.29	41.55	10.23	3.54	12.54	77.67
9	RMP03B	5.15	0.45	1.47	9.43	193.51	32.66	13.62	3.16	5.36	81
10	RMP04	1.83	3.21	6.83	9.16	152.61	4.54	4.22	3.49	27.35	Bdl
11	RMP04A	2.84	8.23	32.26	2.76	554.26	1.7	18.55	6.36	35.29	3
12	RMP04B	16.22	6.75	bdl	4.39	136.46	2.73	0.68	1.75	1.33	124
13	RMP05	6.54	3.95	7.44	24.61	267.23	5.86	3.41	1.27	15.05	72
14	RMP05A	33.56	14.42	26.52	5.14	396.49	8.28	12.15	4.29	41.65	8.67
15	RMP05B	13.22	4.22	bdl	7.55	75.35	1.55	0.43	1.25	3.79	77
16	RMP06	2.03	1.84	4.42	17.4	68.45	2.33	5.85	1.66	34.18	72
17	RMP06A	19.84	5.31	7.5	4.4	231.28	2.71	8.94	7.3	35.54	82
18	RMP06B	8.54	2.75	bdl	5.39	21.42	0.65	0.16	1.44	2.52	150
19	RMP07	7.43	7.39	3.27	8.27	75.25	5.37	2.14	1.56	3.19	61
20	RMP07A	5.03	3.55	5.29	1.56	111.51	0.85	5.04	2.18	15.94	75
21	RMP08	10.14	26.38	7.3	10.44	251.46	19.38	3.74	4.28	42.23	82
22	RMP08A	26.41	7.43	5.47	8.56	111.28	13.46	1.09	3.27	22.43	58.67
23	RMP08B	52.97	13.35	26.49	12.58	172.35	32.62	2.54	6.64	45.15	3
24	RMP09	3.33	5.65	2.82	12.56	205.18	8.31	1.47	2.54	32.35	84.67
25	RMP09B	10.25	25.68	3.07	3.75	207.64	14.65	5.65	3.55	21.68	81
26	RMP010	1.25	8.21	2.94	8.71	71.55	26.33	3.34	1.03	25.77	53.67
27	RMP010A	2.83	5.17	1.45	5.84	83.36	27.34	6.42	1.33	7.28	56
28	RMP010B	6.42	1.8	bdl	3.59	13.07	0.52	0.64	1.15	1.45	1
29	RMP011	2.16	9.42	2.34	31.55	213.41	9.29	6.44	2.15	28.76	60
30	RMP012	8.26	16.65	12.06	10.59	148.5	12.58	7.66	2.55	42.27	74.67
31	RMP012A	34.95	15.84	9.35	13.3	726.37	19.36	6.39	14.65	39.61	61

		Metals Concentartion in mg/kg									
S/ No	Sample ID	As	Cu	Pb	Cr	Mn	Cd	Co	Se	Zn	Ba
32	RMP013	6.54	9.73	18.31	7.24	395.23	18.51	5.29	1.46	29.71	72.33
33	RMP013A	22.83	29.26	6.56	8.47	240.74	10.36	5.86	8.94	25.56	56.33
	TOTAL	477.7	308.61	254.04	366.21	6840.47	436.71	170.49	114.78	788.1	2233.68
	MEAN	28.10	18.15	16.93	21.54	402.38	25.68	10.02	6.75	23.88	69.80
	Std. Deviation	13.77	7.41	7.80	8.18	154.02	11.34	4.11	2.77	14.52	32.55
	Kabata-Pendias and Pendias (1999, 2001)	4.7	14	25	42	418	1.1	6.9	0.7	62	362

The heavy metal contamination across multiple samples was determined using Contamination Factor (CF) and Pollution Load Index (PLI). The analysis compares site-specific contamination with global baseline values from Kabata-Pendias and Pendias (1999, 2001), providing insights into environmental quality and potential risks. The contamination levels of the ten heavy metals (As, Cu, Pb, Cr, Mn, Cd, Co, Se, Zn, and Ba) were evaluated across the 33 samples. The CF and PLI values were calculated using the following formulas:

Contamination Factor (CF): CF = C_sample / C_background

Pollution Load Index (PLI): PLI = (CF1 × CF2 × ... × CFn)^(1/n)

Global background concentrations were adopted from Kabata-Pendias and Pendias (1999, 2001).

Contamination Factor (CF)

CF provides an indication of contamination levels per metal. The classification used is:

CF < 1: Low contamination

1 ≤ CF < 3: Moderate contamination

3 ≤ CF < 6: Considerable contamination

CF ≥ 6: Very high contamination

High CF values were especially notable for Arsenic (As), Cadmium (Cd), and Selenium (Se), indicating serious contamination concerns.

Table 2: Summary Average Contamination Factor Results and Comparison with Background Values

Element	Global Avg (Kabata-Pendias)	Mean CF	Contamination Level
As	4.7	28.10	Very High
Cu	14	18.15	Moderate to High
Pb	25	16.94	Moderate
Cr	42	21.54	Low to Moderate
Mn	418	402.38	Low
Cd	1.1	25.69	Very High
Co	6.9	10.03	Moderate
Se	0.7	6.75	Very High
Zn	62	23.88	Low to Moderate
Ba	362	69.80	Low

Pollution Load Index (PLI)

PLI provides a cumulative assessment of contamination across all metals:

PLI < 1: Baseline level (no pollution)

PLI = 1: Threshold of pollution

PLI > 1: Pollution present

These samples demonstrate cumulative metal contamination above acceptable levels. Samples RMP01A and RMP08B exhibited extremely high CF values for As and Cd, RMP012A showed the highest overall PLI and elevated levels in Mn, Cd, and Se, RMP05A and RMP03 also demonstrated high CFs for multiple toxic metals and several sites (e.g., RMP010B, RMP04, RMP06B) showed low PLI values, suggesting minimal contamination. Elevated levels of arsenic, cadmium, and selenium pose significant ecological and health risks. Areas with PLI > 1 require further monitoring and possible remediation. Metals such as Mn, Ba, and Zn largely remained within acceptable contamination levels. Undertake risk assessment studies for affected communities and encourage sustainable practices to prevent future contamination.

The PLI summary statistics with mean PLI: 0.69 and maximum PLI: 1.51 (Sample RMP012A) with minimum PLI: 0.11 (Sample RMP010B). Notable Samples Exceeding PLI = 1 are RMP01A: 1.44, RMP03: 1.32, RMP012A: 1.51, RMP05A: 1.02, RMP08: 1.05, RMP013A: 1.07.

Table 3: Contamination Factor (CF) and Pollution Load Index (PLI) values of Heavy Metals in soil of Faya and Environs

	Sample ID	As	CF	Cu	CF	Pb	CF	Cr	CF	Mn	CF	Cd	CF	Co	CF	Se	CF	Zn	CF	Ba	CF	PLI
1	RMP01	6.25	1.33	13.05	0.93	6.27	0.25	8.93	0.21	56.54	0.14	4.41	4.01	1.26	0.18	1.06	1.51	6.35	0.10	47.67	0.13	0.41
2	RMP01A	52.97	11.27	5.51	0.39	7.24	0.29	36.31	0.86	452.36	1.08	23.72	21.56	7.29	1.06	5.44	7.77	51.05	0.82	76.67	0.21	1.44
3	RMP01B	37.27	7.93	6.26	0.45	4.92	0.20	19.05	0.45	179.36	0.43	8.53	7.75	4.35	0.63	3.27	4.67	41.26	0.67	124	0.34	0.97
4	RMP02	17.58	3.74	5.3	0.38	2.85	0.11	12.39	0.30	91.46	0.22	14.51	13.19	1.76	0.26	2.95	4.21	19.31	0.31	99.33	0.27	0.65
5	RMP02A	15.36	3.27	7.37	0.53	10.88	0.44	7.13	0.17	145.42	0.35	8.29	7.54	2.2	0.32	1.44	2.06	18.54	0.30	81.33	0.22	0.66
6	RMP02B	20.53	4.37	6.38	0.46	8.76	0.35	4.29	0.10	221.65	0.53	15.44	14.04	2.53	0.37	3.27	4.67	35.26	0.57	90	0.25	0.81
7	RMP03	9.24	1.97	23.73	1.70	16.42	0.66	27.52	0.66	213.43	0.51	38.32	34.84	9.15	1.33	4.56	6.51	18.35	0.30	87	0.24	1.32
8	RMP03A	7.93	1.69	4.37	0.31	3.54	0.14	13.35	0.32	356.29	0.85	41.55	37.77	10.23	1.48	3.54	5.06	12.54	0.20	77.67	0.21	0.87
9	RMP03B	5.15	1.10	0.45	0.03	1.47	0.06	9.43	0.22	193.51	0.46	32.66	29.69	13.62	1.97	3.16	4.51	5.36	0.09	81	0.22	0.51
10	RMP04	1.83	0.39	3.21	0.23	6.83	0.27	9.16	0.22	152.61	0.37	4.54	4.13	4.22	0.61	3.49	4.99	27.35	0.44	bdl	0.00	0.60
11	RMP04A	2.84	0.60	8.23	0.59	32.26	1.29	2.76	0.07	554.26	1.33	1.7	1.55	18.55	2.69	6.36	9.09	35.29	0.57	3	0.01	0.61
12	RMP04B	16.22	3.45	6.75	0.48	bdl	bdl	4.39	0.10	136.46	0.33	2.73	2.48	0.68	0.10	1.75	2.50	1.33	0.02	124	0.34	0.40
13	RMP05	6.54	1.39	3.95	0.28	7.44	0.30	24.61	0.59	267.23	0.64	5.86	5.33	3.41	0.49	1.27	1.81	15.05	0.24	72	0.20	0.63
14	RMP05A	33.56	7.14	14.42	1.03	26.52	1.06	5.14	0.12	396.49	0.95	8.28	7.53	12.15	1.76	4.29	6.13	41.65	0.67	8.67	0.02	1.02
15	RMP05B	13.22	2.81	4.22	0.30	bdl	bdl	7.55	0.18	75.35	0.18	1.55	1.41	0.43	0.06	1.25	1.79	3.79	0.06	77	0.21	0.34
16	RMP06	2.03	0.43	1.84	0.13	4.42	0.18	17.4	0.41	68.45	0.16	2.33	2.12	5.85	0.85	1.66	2.37	34.18	0.55	72	0.20	0.45
17	RMP06A	19.84	4.22	5.31	0.38	7.5	0.30	4.4	0.10	231.28	0.55	2.71	2.46	8.94	1.30	7.3	10.43	35.54	0.57	82	0.23	0.81
18	RMP06B	8.54	1.82	2.75	0.20	bdl	bdl	5.39	0.13	21.42	0.05	0.65	0.59	0.16	0.02	1.44	2.06	2.52	0.04	150	0.41	0.22
19	RMP07	7.43	1.58	7.39	0.53	3.27	0.13	8.27	0.20	75.25	0.18	5.37	4.88	2.14	0.31	1.56	2.23	3.19	0.05	61	0.17	0.40
20	RMP07A	5.03	1.07	3.55	0.25	5.29	0.21	1.56	0.04	111.51	0.27	0.85	0.77	5.04	0.73	2.18	3.11	15.94	0.26	75	0.21	0.37
21	RMP08	10.14	2.16	26.38	1.88	7.3	0.29	10.44	0.25	251.46	0.60	19.38	17.62	3.74	0.54	4.28	6.11	42.23	0.68	82	0.23	1.05
22	RMP08A	26.41	5.62	7.43	0.53	5.47	0.22	8.56	0.20	111.28	0.27	13.46	12.24	1.09	0.16	3.27	4.67	22.43	0.36	58.67	0.16	0.67
23	RMP08B	52.97	11.27	13.35	0.95	26.49	1.06	12.58	0.30	172.35	0.41	32.62	29.65	2.54	0.37	6.64	9.49	45.15	0.73	3	0.01	0.99
24	RMP09	3.33	0.71	5.65	0.40	2.82	0.11	12.56	0.30	205.18	0.49	8.31	7.55	1.47	0.21	2.54	3.63	32.35	0.52	84.67	0.23	0.57
25	RMP09B	10.25	2.18	25.68	1.83	3.07	0.12	3.75	0.09	207.64	0.50	14.65	13.32	5.65	0.82	3.55	5.07	21.68	0.35	81	0.22	0.79
26	RMP010	1.25	0.27	8.21	0.59	2.94	0.12	8.71	0.21	71.55	0.17	26.33	23.94	3.34	0.48	1.03	1.47	25.77	0.42	53.67	0.15	0.48
27	RMP010A	2.83	0.60	5.17	0.37	1.45	0.06	5.84	0.14	83.36	0.20	27.34	24.85	6.42	0.93	1.33	1.90	7.28	0.12	56	0.15	0.44
28	RMP010B	6.42	1.37	1.8	0.13	bdl	bdl	3.59	0.09	13.07	0.03	0.52	0.47	0.64	0.09	1.15	1.64	1.45	0.02	1	0.00	0.11
29	RMP011	2.16	0.46	9.42	0.67	2.34	0.09	31.55	0.75	213.41	0.51	9.29	8.45	6.44	0.93	2.15	3.07	28.76	0.46	60	0.17	0.68
30	RMP012	8.26	1.76	16.65	1.19	12.06	0.48	10.59	0.25	148.5	0.36	12.58	11.44	7.66	1.11	2.55	3.64	42.27	0.68	74.67	0.21	0.95
31	RMP012A	34.95	7.44	15.84	1.13	9.35	0.37	13.3	0.32	726.37	1.74	19.36	17.60	6.39	0.93	14.65	20.93	39.61	0.64	61	0.17	1.51
32	RMP013	6.54	1.39	9.73	0.70	18.31	0.73	7.24	0.17	395.23	0.95	18.51	16.83	5.29	0.77	1.46	2.09	29.71	0.48	72.33	0.20	0.89
33	RMP013A	22.83	4.86	29.26	2.09	6.56	0.26	8.47	0.20	240.74	0.58	10.36	9.42	5.86	0.85	8.94	12.77	25.56	0.41	56.33	0.16	1.07
	TOTAL	477.70		308.61		254.04		366.21		6840.47		436.71		170.49		114.78		788.10		2233.68		

	Sample ID	As	CF	Cu	CF	Pb	CF	Cr	CF	Mn	CF	Cd	CF	Co	CF	Se	CF	Zn	CF	Ba	CF	PLI
	MEAN	28.10		18.15		16.94		21.54		402.38		25.69		10.03		6.75		23.88		69.80		
	Std. Dev.	13.77		7.42		7.81		8.18		154.03		11.35		4.12		2.77		14.53		32.55		
	Worldwide data after Kabata-Pendias and Pendias, 1999,2001	4.7		14		25		42		418		1.1		6.9		0.7		62		362		

Enrichment Factor (EF)

The heavy metal EF values across 33 soil samples is as shown in Tables 4 and 5. The analysis compares results with worldwide background levels and published literature to assess anthropogenic influence and environmental risk.

EF is a standard geochemical tool used to assess the level of anthropogenic impact on soils. It is calculated using the formula:

EF = (C_x / C_ref)_sample / (C_x / C_ref)_background

where C_x is the concentration of the metal of interest, and C_ref is the concentration of a reference element, typically Fe or Al. For this study, background values were obtained from Kabata-Pendias and Pendias (1999, 2001).

EF values are interpreted as follows:

EF < 2: Deficiency to minimal enrichment

2 ≤ EF < 5: Moderate enrichment

5 ≤ EF < 20: Significant enrichment

20 ≤ EF < 40: Very high enrichment

EF ≥ 40: Extremely high enrichment

Table 4 Summary of Mean Enrichment Factor (EF) values compared to Background Values

Element	Background (mg/kg)	Mean EF	Interpretation
As	4.7	18.15	Significant enrichment
Cu	14	21.54	Very high enrichment
Pb	25	25.69	Very high enrichment
Cr	42	10.03	Significant enrichment
Cd	1.1	6.75	Significant enrichment
Co	6.9	23.88	Very high enrichment
Se	0.7	69.80	Extremely high enrichment
Zn	62	18.15	Significant enrichment
Ba	362	0.97	Minimal enrichment

Arsenic (As)

The mean EF of 18.15 indicates significant enrichment. Comparable EF values have been reported in mining zones (Zhang et al., 2012), suggesting anthropogenic input likely from agrochemical or industrial sources.

Copper (Cu)

The mean EF of 21.54, Cu shows very high enrichment. Studies in industrial areas (Al-Khashman and Shawabkeh, 2006) reported similar values, pointing to vehicular emissions and waste disposal as probable contributors.

Lead (Pb)

The EF of 25.69 denotes very high enrichment, aligning with findings from urban soils in Nigeria where EF values >20 were linked to traffic and industrial activities (Osakwe and Okolie, 2015),

Chromium (Cr)

A mean EF of 10.03 signifies significant enrichment. This is consistent with moderate to high EF values found in areas influenced by tannery and electroplating industries (Chabukdhara and Nema, 2013).

Cadmium (Cd)

An EF of 6.75 indicates significant enrichment, similar to studies by Nnabo,P (2015) in Shale rich soils of South Eastern Nigeria, and Luo et al. (2012) where Cd EF >5 was attributed to fertilizers and sewage sludge.

Cobalt (Co)

A very high EF (23.88), Co shows anthropogenic input likely from metallurgical and mechanical waste sources, similar to findings by Wei and Yang (2010).

Selenium (Se)

The mean EF of 69.80 is alarmingly high, suggesting extreme enrichment confirming anthropogenic source. Such elevated EF values are rare but may arise from industrial discharges or combustion of coal (Wang et al., 2017).

Zinc (Zn)

The EF value of 18.15 suggests significant enrichment. Zn enrichment is commonly linked to tire wear, galvanized structures, and wastewater (Imperato et al., 2003), samples such as RMP06B, RMP010B, and RMP08B display extremely high EF values (>40) for Se and As, flagging them as contamination hotspots. RMP01A, RMP012A, and RMP013A also showed multiple metals with significant to very high EF, suggesting cumulative pollution.

Table 5: Enrichmnet Factor (EF) values of Heavy Metals in soil of Faya and Environs

S/No	Sample ID	As	EF	Cu	EF	Pb	EF	Cr	EF	Cd	EF	Co	EF	Se	EF	Zn	EF	Ba	EF
1	RMP01	6.25	9.83	13.05	6.89	6.27	1.85	8.93	1.57	4.41	29.64	1.26	1.35	1.06	11.20	6.35	0.76	47.67	0.97
2	RMP01A	52.97	10.41	5.51	0.36	7.24	0.27	36.31	0.80	23.72	19.93	7.29	0.98	5.44	7.18	51.05	0.76	76.67	0.20
3	RMP01B	37.27	18.48	6.26	1.04	4.92	0.46	19.05	1.06	8.53	18.07	4.35	1.47	3.27	10.89	41.26	1.55	124	0.80
4	RMP02	17.58	17.09	5.3	1.73	2.85	0.52	12.39	1.35	14.51	60.29	1.76	1.17	2.95	19.26	19.31	1.42	99.33	1.25
5	RMP02A	15.36	9.39	7.37	1.51	10.88	1.25	7.13	0.49	8.29	21.66	2.2	0.92	1.44	5.91	18.54	0.86	81.33	0.65
6	RMP02B	20.53	8.24	6.38	0.86	8.76	0.66	4.29	0.19	15.44	26.47	2.53	0.69	3.27	8.81	35.26	1.07	90	0.47
7	RMP03	9.24	3.85	23.73	3.32	16.42	1.29	27.52	1.28	38.32	68.23	9.15	2.60	4.56	12.76	18.35	0.58	87	0.47
8	RMP03A	7.93	1.98	4.37	0.37	3.54	0.17	13.35	0.37	41.55	44.32	10.23	1.74	3.54	5.93	12.54	0.24	77.67	0.25
9	RMP03B	5.15	2.37	0.45	0.07	1.47	0.13	9.43	0.48	32.66	64.14	13.62	4.26	3.16	9.75	5.36	0.19	81	0.48
10	RMP04	1.83	1.07	3.21	0.63	6.83	0.75	9.16	0.60	4.54	11.30	4.22	1.68	3.49	13.66	27.35	1.21	bdl	bdl
11	RMP04A	2.84	0.46	8.23	0.44	32.26	0.97	2.76	0.05	1.7	1.17	18.55	2.03	6.36	6.85	35.29	0.43	3	0.01
12	RMP04B	16.22	10.57	6.75	1.48	bdl	bdl	4.39	0.32	2.73	7.60	0.68	0.30	1.75	7.66	1.33	0.07	124	1.05
13	RMP05	6.54	2.18	3.95	0.44	7.44	0.47	24.61	0.92	5.86	8.33	3.41	0.77	1.27	2.84	15.05	0.38	72	0.31
14	RMP05A	33.56	7.53	14.42	1.09	26.52	1.12	5.14	0.13	8.28	7.94	12.15	1.86	4.29	6.46	41.65	0.71	8.67	0.03
15	RMP05B	13.22	15.60	4.22	1.67	bdl	bdl	7.55	1.00	1.55	7.82	0.43	0.35	1.25	9.91	3.79	0.34	77	1.18
16	RMP06	2.03	2.64	1.84	0.80	4.42	1.08	17.4	2.53	2.33	12.93	5.85	5.18	1.66	14.48	34.18	3.37	72	1.21
17	RMP06A	19.84	7.63	5.31	0.69	7.5	0.54	4.4	0.19	2.71	4.45	8.94	2.34	7.3	18.85	35.54	1.04	82	0.41
18	RMP06B	8.54	35.46	2.75	3.83	bdl	bdl	5.39	2.50	0.65	11.53	0.16	0.45	1.44	40.14	2.52	0.79	150	8.09
19	RMP07	7.43	8.78	7.39	2.93	3.27	0.73	8.27	1.09	5.37	27.12	2.14	1.72	1.56	12.38	3.19	0.29	61	0.94
20	RMP07A	5.03	4.01	3.55	0.95	5.29	0.79	1.56	0.14	0.85	2.90	5.04	2.74	2.18	11.67	15.94	0.96	75	0.78
21	RMP08	10.14	3.59	26.38	3.13	7.3	0.49	10.44	0.41	19.38	29.29	3.74	0.90	4.28	10.16	42.23	1.13	82	0.38
22	RMP08A	26.41	21.11	7.43	1.99	5.47	0.82	8.56	0.77	13.46	45.96	1.09	0.59	3.27	17.55	22.43	1.36	58.67	0.61
23	RMP08B	52.97	27.33	13.35	2.31	26.49	2.57	12.58	0.73	32.62	71.92	2.54	0.89	6.64	23.01	45.15	1.77	3	0.02
24	RMP09	3.33	1.44	5.65	0.82	2.82	0.23	12.56	0.61	8.31	15.39	1.47	0.43	2.54	7.39	32.35	1.06	84.67	0.48
25	RMP09B	10.25	4.39	25.68	3.69	3.07	0.25	3.75	0.18	14.65	26.81	5.65	1.65	3.55	10.21	21.68	0.70	81	0.45
26	RMP010	1.25	1.55	8.21	3.43	2.94	0.69	8.71	1.21	26.33	139.84	3.34	2.83	1.03	8.60	25.77	2.43	53.67	0.87
27	RMP010A	2.83	3.02	5.17	1.85	1.45	0.29	5.84	0.70	27.34	124.63	6.42	4.67	1.33	9.53	7.28	0.59	56	0.78
28	RMP010B	6.42	43.69	1.8	4.11	bdl	bdl	3.59	2.73	0.52	15.12	0.64	2.97	1.15	52.54	1.45	0.75	1	0.09
29	RMP011	2.16	0.90	9.42	1.32	2.34	0.18	31.55	1.47	9.29	16.54	6.44	1.83	2.15	6.02	28.76	0.91	60	0.32

S/No	**Sample ID**	**As**	**EF**	**Cu**	**EF**	**Pb**	**EF**	**Cr**	**EF**	**Cd**	**EF**	**Co**	**EF**	**Se**	**EF**	**Zn**	**EF**	**Ba**	**EF**
30	RMP012	8.26	4.95	16.65	3.35	12.06	1.36	10.59	0.71	12.58	32.19	7.66	3.12	2.55	10.25	42.27	1.92	74.67	0.58
31	RMP012A	34.95	4.28	15.84	0.65	9.35	0.22	13.3	0.18	19.36	10.13	6.39	0.53	14.65	12.04	39.61	0.37	61	0.10
32	RMP013	6.54	1.47	9.73	0.74	18.31	0.77	7.24	0.18	18.51	17.80	5.29	0.81	1.46	2.21	29.71	0.51	72.33	0.21
33	RMP013A	22.83	8.43	29.26	3.63	6.56	0.46	8.47	0.35	10.36	16.35	5.86	1.47	8.94	22.18	25.56	0.72	56.33	0.27
	TOTAL	477.70		308.61		254.04		366.21		436.7		170.49		114.78		788.10		2233.68	
	MEAN	28.10		18.15		16.94		21.54		25.69		10.03		6.75		23.88		69.80	
	Std. Deviation	13.77		7.42		7.81		8.18		11.35		4.12		2.77		14.53		32.55	
	Worldwide data after Kabata-Pendias and Pendias, 1999,2001	4.7		14		25		42		1.1		6.9		0.7		62		362	

Geoaccumulation Index (Igeo)

The Geoaccumulation Index (Igeo), originally developed by Müller (1969), is widely used to evaluate the degree of heavy metal pollution in sediments and soils by comparing current concentrations with pre-industrial levels. Igeo values are categorized into seven classes, ranging from class 0 (unpolluted) to class 6 (extremely polluted).

The Igeo is expressed using the following Muller equation:

$$Igeo = \log_2(Cn/ 1.5Bn)$$

Where Cn is the measured concentration of the given heavy metal examined in the soil or sediment, Bn is the geochemical background value of the element, 1.5 is incorporated in the relationship to account for possible variation in background data (the background matrix correction factor) owing to lithogenic effects, according to Loska et al 1997.

The geo-accumulation index, consist of seven grades (0 to 6) based on the increasing numerical value of the index and ranges from unpolluted to extremely polluted. The standard Igeo values are presented below (Table 6)

Table 6: Summary of Geo-accumulation Index (Igeo) values of Trace Elements in soil of Faya and Environs

Igeo Class	Value Range	Pollution Level
0	Igeo ≤ 0	Unpolluted
1	0 < Igeo ≤ 1	Unpolluted to moderately polluted
2	1 < Igeo ≤ 2	Moderately polluted
3	2 < Igeo ≤ 3	Moderately to heavily polluted
4	3 < Igeo ≤ 4	Heavily polluted
5	4 < Igeo ≤ 5	Heavily to extremely polluted
6	Igeo > 5	Extremely polluted

The calculated results show Arsenic (As) has a mean of 0.3955 (unpolluted to moderately polluted),most locations are unpolluted, but some (e.g., RMP01A, RMP08B) show moderate to heavy pollution indicating anthropogenic enrichment. Copper (Cu) with mean -1.6229 (unpolluted),range from -5.5443 to 0.47854. Only RMP013A shows any pollution, categorized as unpolluted to moderately polluted. All other samples are within or below this range. Lead (Pb) is unpolluted with mean -2.5708, value of RMP04A (32.3 mg/kg) show slight anthropogenic influence. Chromium (Cr) is unpolluted, Manganese (Mn) with mean -2.018 (unpolluted) with maximum value of 554.26 mg/kg (RMP04A) despite high concentrations, the Igeo remains low due to normalization factor and natural variability. Cadmium (Cd) several samples such as RMP03A, RMP08B, and RMP010A exceed Igeo of 4 with range values of -1.6659 to 4.65431 therefore moderately to heavily polluted this was also findings by Zhang et al. (2016), who reported high Cd Igeo though in an industrial region. Cobalt (Co) generally unpolluted with mean value -1.5906, Selenium (Se) mean Igeo: 1.3855 moderately polluted with range -6.0154 to 3.80244, very high Igeo in RMP012A (14.7 mg/kg, Igeo = 3.80) indicates potential anthropogenic impact even moderate concentrations show high Igeo due to low background. Zinc (Zn) mean -2.4653 (unpolluted) all values are below the limit except few marginally elevated ones. Barium (Ba) with mean value of -3.413 is unpolluted.

The results broadly reflect low pollution levels in most metals, except Cd and Se, which present notable contamination risks. Studies by Ali et al. (2017) and Zhang et al. (2016) emphasize the persistent and mobile nature of cadmium, often linked to agricultural runoff, industrial discharge, and mining activities. The elevated Igeo values here (especially up to 4.65 in RMP03A) align with zones experiencing such pressures. Despite relatively low concentrations, Se shows high Igeo due to its low geochemical background. High Igeo values (e.g., 3.80 in RMP012A) suggest possible inputs from agrochemicals or fossil fuel combustion, as noted in Lu et al. (2012). The occasional elevated As and Pb values suggest localized contamination. Comparisons with Ugochukwu et al. (2018), studying sediments in the Niger Delta, show similar sporadic elevations due to oil-related activities.

Table 7: Geo-accumulation Index (Igeo) values of Heavy Metals in soil of Faya and Environs

S/No	Sample ID	As	Igeo	Cu	Igeo	Pb	Igeo	Cr	Igeo	Mn	Igeo	Cd	Igeo	Co	Igeo	Se	Igeo	Zn	Igeo	Ba	Igeo
1	RMP01	6.25	-0.17	13.05	-0.69	6.27	-2.58	8.93	-2.82	56.54	-3.47	4.41	1.42	1.26	-3.04	1.06	0.01	6.35	-3.87	47.67	-3.51
2	RMP01A	52.97	2.91	5.51	-1.93	7.24	-2.37	36.31	-0.79	452.36	-0.47	23.72	3.85	7.29	-0.51	5.44	2.37	51.05	-0.87	76.67	-2.82
3	RMP01B	37.27	2.40	6.26	-1.75	4.92	-2.93	19.05	-1.73	179.36	-1.81	8.53	2.37	4.35	-1.25	3.27	1.64	41.26	-1.17	124	-2.13
4	RMP02	17.58	1.32	5.3	-1.99	2.85	-3.72	12.39	-2.35	91.46	-2.78	14.51	3.14	1.76	-2.56	2.95	1.49	19.31	-2.27	99.33	-2.45
5	RMP02A	15.36	1.12	7.37	-1.51	10.9	-1.79	7.13	-3.14	145.42	-2.11	8.29	2.33	2.2	-2.23	1.44	0.46	18.54	-2.33	81.33	-2.74
6	RMP02B	20.53	1.54	6.38	-1.72	8.76	-2.10	4.29	-3.88	221.65	-1.50	15.44	3.23	2.53	-2.03	3.27	1.64	35.26	-1.40	90	-2.59
7	RMP03	9.24	0.39	23.73	0.18	16.4	-1.19	27.52	-1.19	213.43	-1.55	38.32	4.54	9.15	-0.18	4.56	2.12	18.35	-2.34	87	-2.64
8	RMP03A	7.93	0.17	4.37	-2.26	3.54	-3.41	13.35	-2.24	356.29	-0.82	41.55	4.65	10.23	-0.02	3.54	1.75	12.54	-2.89	77.67	-2.81
9	RMP03B	5.15	-0.45	0.45	-5.54	1.47	-4.67	9.43	-2.74	193.51	-1.70	32.66	4.31	13.62	0.40	3.16	1.59	5.36	-4.12	81	-2.74
10	RMP04	1.83	-1.95	3.21	-2.71	6.83	-2.46	9.16	-2.78	152.61	-2.04	4.54	1.46	4.22	-1.29	3.49	1.73	27.35	-1.77	bdl	bdl
11	RMP04A	2.84	-1.31	8.23	-1.35	32.3	-0.22	2.76	-4.51	554.26	-0.18	1.7	0.04	18.55	0.84	6.36	2.60	35.29	-1.40	3	-7.50
12	RMP04B	16.22	1.20	6.75	-1.64	bdl	bdl	4.39	-3.84	136.46	-2.20	2.73	0.73	0.68	-3.93	1.75	0.74	1.33	-6.13	124	-2.13
13	RMP05	6.54	-0.11	3.95	-2.41	7.44	-2.33	24.61	-1.36	267.23	-1.23	5.86	1.83	3.41	-1.60	1.27	0.27	15.05	-2.63	72	-2.91
14	RMP05A	33.56	2.25	14.42	-0.54	26.5	-0.50	5.14	-3.62	396.49	-0.66	8.28	2.33	12.15	0.23	4.29	2.03	41.65	-1.16	8.67	-5.97
15	RMP05B	13.22	0.91	4.22	-2.32	bdl	bdl	7.55	-3.06	75.35	-3.06	1.55	-0.09	0.43	-4.59	1.25	0.25	3.79	-4.62	77	-2.82
16	RMP06	2.03	-1.80	1.84	-3.51	4.42	-3.08	17.4	-1.86	68.45	-3.20	2.33	0.50	5.85	-0.82	1.66	0.66	34.18	-1.44	72	-2.91
17	RMP06A	19.84	1.49	5.31	-1.98	7.5	-2.32	4.4	-3.84	231.28	-1.44	2.71	0.72	8.94	-0.21	7.3	2.80	35.54	-1.39	82	-2.73
18	RMP06B	8.54	0.28	2.75	-2.93	bdl	bdl	5.39	-3.55	21.42	-4.87	0.65	-1.34	0.16	-6.02	1.44	0.46	2.52	-5.21	150	-1.86
19	RMP07	7.43	0.08	7.39	-1.51	3.27	-3.52	8.27	-2.93	75.25	-3.06	5.37	1.70	2.14	-2.27	1.56	0.57	3.19	-4.87	61	-3.15

S/No	Sample ID	As	Igeo	Cu	Igeo	Pb	Igeo	Cr	Igeo	Mn	Igeo	Cd	Igeo	Co	Igeo	Se	Igeo	Zn	Igeo	Ba	Igeo
20	RMP07A	5.03	-0.49	3.55	-2.56	5.29	-2.83	1.56	-5.34	111.51	-2.49	0.85	-0.96	5.04	-1.04	2.18	1.05	15.94	-2.54	75	-2.86
21	RMP08	10.14	0.52	26.38	0.33	7.3	-2.36	10.44	-2.59	251.46	-1.32	19.38	3.55	3.74	-1.47	4.28	2.03	42.23	-1.14	82	-2.73
22	RMP08A	26.41	1.91	7.43	-1.50	5.47	-2.78	8.56	-2.88	111.28	-2.49	13.46	3.03	1.09	-3.25	3.27	1.64	22.43	-2.05	58.67	-3.21
23	RMP08B	52.97	2.91	13.35	-0.65	26.5	-0.50	12.58	-2.32	172.35	-1.86	32.62	4.31	2.54	-2.03	6.64	2.66	45.15	-1.04	3	-7.50
24	RMP09	3.33	-1.08	5.65	-1.89	2.82	-3.73	12.56	-2.33	205.18	-1.61	8.31	2.33	1.47	-2.82	2.54	1.27	32.35	-1.52	84.67	-2.68
25	RMP09B	10.25	0.54	25.68	0.29	3.07	-3.61	3.75	-4.07	207.64	-1.59	14.65	3.15	5.65	-0.87	3.55	1.76	21.68	-2.10	81	-2.74
26	RMP010	1.25	-2.50	8.21	-1.35	2.94	-3.67	8.71	-2.85	71.55	-3.13	26.33	4.00	3.34	-1.63	1.03	-0.03	25.77	-1.85	53.67	-3.34
27	RMP010A	2.83	-1.32	5.17	-2.02	1.45	-4.69	5.84	-3.43	83.36	-2.91	27.34	4.05	6.42	-0.69	1.33	0.34	7.28	-3.68	56	-3.28
28	RMP010B	6.42	-0.14	1.8	-3.54	bdl	bdl	3.59	-4.13	13.07	-5.58	0.52	-1.67	0.64	-4.02	1.15	0.13	1.45	-6.00	1	-9.08
29	RMP011	2.16	-1.71	9.42	-1.16	2.34	-4.00	31.55	-1.00	213.41	-1.55	9.29	2.49	6.44	-0.68	2.15	1.03	28.76	-1.69	60	-3.18
30	RMP012	8.26	0.23	16.65	-0.33	12.1	-1.64	10.59	-2.57	148.5	-2.08	12.58	2.93	7.66	-0.43	2.55	1.28	42.27	-1.14	74.67	-2.86
31	RMP012A	34.95	2.31	15.84	-0.41	9.35	-2.00	13.3	-2.24	726.37	0.21	19.36	3.55	6.39	-0.70	14.7	3.80	39.61	-1.23	61	-3.15
32	RMP013	6.54	-0.11	9.73	-1.11	18.3	-1.03	7.24	-3.12	395.23	-0.67	18.51	3.49	5.29	-0.97	1.46	0.48	29.71	-1.65	72.33	-2.91
33	RMP013A	22.83	1.70	29.26	0.48	6.56	-2.52	8.47	-2.89	240.74	-1.38	10.36	2.65	5.86	-0.82	8.94	3.09	25.56	-1.86	56.33	-3.27
	TOTAL	477.7		308.6		254		366.2		6840.5		436.71		170.5		115		788.1		2233.7	
	MEAN	28.1	0.40	18.15	-1.62	16.9	-2.57	21.54	-2.85	402.38	-2.02	25.689	2.26	10.03	-1.59	6.75	1.39	23.88	-2.47	69.803	-3.41
	Std. Deviation	13.77		7.419		7.81		8.184		154.03		11.347		4.115		2.77		14.53		32.55	
	Worldwide data after Kabata-Pendias and Pendias, 1999,2001	4.7		14		25		42		418		1.1		6.9		0.7		62		362	

Conclusion

The results of the soil analysis reveal significant contamination patterns and variability across heavy metal concentrations, with Manganese (Mn) and Barium (Ba) dominating the soil profile, with mean concentrations of 402.38 mg/kg and 69.80 mg/kg, respectively. Mn shows extreme variability, ranging from 13.07 mg/kg (RMP010B) to 726.37 mg/kg (RMP012A). Cadmium (Cd) and Arsenic (As) exhibit concerning levels, with means of 25.68 mg/kg and 28.10 mg/kg, respectively. Notably, Cd peaks at 41.55 mg/kg (RMP03A), while As reaches its highest concentration at 52.97 mg/kg (RMP01A, RMP08B).

Contamination hotspots are RMP01A As (52.97), Zn (51.05), Cd (23.72), RMP03A Cd (41.55), Mn (356.29), RMP012A, Mn (726.37), Se (14.65) and RMP08B As (52.97), Cd (32.62), Zn (45.15).

These samples exceed typical geochemical baselines for agricultural soils , WHO recommends <3 mg/kg for Cd, and <20 mg/kg for Pb. The metal risk indicators are Lead (Pb) mean 16.93 mg/kg, with 32.26 mg/kg (RMP04A) which is above EPA's 15 mg/kg threshold for residential soils, Zinc (Zn) mean 23.88 mg/kg, but samples like RMP01A (51.05 mg/kg) suggest localized industrial or agricultural inputs and Cobalt (Co) with high variability (0.16–18.55 mg/kg), with RMP04A (18.55 mg/kg) posing potential ecological risks.

The CF and PLI analyses reveal that while most sites exhibit low to moderate pollution, the samples defined as hotspots confirm significant contamination, particularly from As, Ca, and Se. All the values far exceed global standards, which is a signal of serious environmental and health threat. The EF analysis confirmed considerable anthropogenic enrichment of several heavy metals, but particularly Se, Pb, Cu, Co, and As. The Igeo analysis provided essential insight into site-specific contamination risks and should guide further risk assessment, particularly for Cadmium hotspots. The majority of analyzed metals fall within unpolluted to moderately polluted categories, with exceptions in Cd and Se, which show significant anthropogenic enrichment.

The findings of this study indicate that the soil in Faya are impacted by heavy metal contamination. The Contamination Factor (CF), Pollution Load Index (PLI), and Enrichment Factor (EF) collectively identify specific locations such as RMP01A, RMP08B, and RMP012A as contamination hotspots with high anthropogenic influence. While some metals like manganese and barium remained within safe limits, the cumulative presence of multiple metals in other areas points to a complex contamination profile with potential ecological and human health risks. The results point to both natural and human-induced sources of pollution. The elevated Igeo values underscore the role of anthropogenic factors in exacerbating contamination. Without intervention, the health and livelihoods of the local population remain at risk. Immediate action is needed to remediate contaminated sites and ensure the provision of safe water and soil resources for the community.

Recommendations

These findings underline the need for targeted environmental management, continuous monitoring, and further risk assessments to mitigate potential hazards.

1. Remediation activity of phytoremediation and soil washing in hotspots such as RMP03, and RMP04A.

2. Restrict farming or encourage additional measure such as deep plowing to reduce metal concentrations at the soil surface which would be needed to reduce metal intake by crops during cultivation.

3. Conduct regular monitoring of Se and As due to their toxicological importance and monitor Mn levels due to their ecological mobility.

4. Implement pollution control strategies in hotspot area

5. Conduct regular environmental monitoring to track changes in heavy metal concentrations over time.

6. Educate the local communities on the health risks associated with using polluted soil for farming.

7. Collaborate with governmental agencies to regulate activities contributing to environmental degradation in the region.

8. Encourage in-depth studies to explore the sources, pathways, and long-term impacts of heavy metal exposure in the whole of the Middle Benue Trough.

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