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Original Research Article

Evaluating Heavy Metal Pollution in Nigerian Coal: Enrichment Factors, Pollution Indices and Environmental Implications

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ABSTRACT
Heavy metal pollution is a significant environmental concern in Nigeria, particularly in coal deposits. This study evaluates the level of heavy metal pollution in Nigerian coal deposits using enrichment factors and pollution indices. Coal samples were collected from Maganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal fields, and the concentrations of lead, arsenic, chromium, manganese, nickel, cobalt, strontium, antimony and barium were determined. The results showed significant levels of heavy metal pollution, with enrichment factors indicating anthropogenic sources. Pollution indices reveal moderate to high levels of pollution. The study highlights the need for effective environmental management and pollution control measures to mitigate the environmental and health risks associated with the heavy metal pollution in Nigerian coal deposits.

INTRODUCTION

Nigeria's coal deposits have been a vital part of the country's energy landscape for decades (Nigerian Geological Survey Agency, 2019). However, the extraction and utilization of coal pose significant environmental and health concerns due to the potential release of heavy metals, such as lead, arsenic, cadmium, mercury and chromium, into the environment (World Health Organization, 2018). These toxic elements can have devastating impacts on ecosystems and human health, underscoring the need for comprehensive assessments of heavy metal pollution in Nigerian coal deposits (Uloko, *et al.,* 2024). Heavy metal is a major environmental concern globally, and Nigeria is not immune to this problem (United Nations Environment Programme, 2013). The mining and utilization of coal can lead to the release of heavy metals into the environment, contaminating soil, water, and air (Environmental Protection Agency, 2020). Prolonged exposure to these heavy metals can cause harm to humans and the ecosystem, including damage to the nervous system, kidney damage, and increased risk of cancer (World Health Organization, 2018). Furthermore, heavy metals can accumulate in the food chain, leading to bioaccumulation and biomagnification (Food and Agriculture Organization, 2017).

The evaluation of heavy metal pollution in Nigerian coal deposits is crucial for understanding the potential environmental and health implications. Enrichment factors and pollution indices are essential tools for assessing the level of heavy metal pollution in coal deposits (International Atomic Energy Agency, 2011). Enrichment factors help to identify the sources of heavy metals, while pollution indices provide a quantitative measure of the level of pollution (World Health Organization, 2018). However, there is paucity of information on the enrichment factors and pollution indices of heavy metals in Nigerian coal deposits. This study aim to evaluate the level of heavy metal pollution in

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Nigerian coal deposits using enrichment factor and pollution indices. This research seeks to provide valuable insights into the environmental implications of heavy metal pollution in Nigerian coal deposits, informing policymakers, regulators, and stakeholders on the need for effective environmental management and pollution control measures. By examining the enrichment factors and the pollution indices of heavy metals in Nigerian coal deposits, the study contributes to the global effort to promote sustainable and responsible practices, mitigate environmental and health risks, and ensure a safer future for generation to come.

MATERIALS AND METHODS

Study Area

In Figure 1, we present the locations of the coal deposits in Nigeria. The study areas of interest include; Maiganga coal field in Gombe State, Gboko coal field in Benue State, Onyeama coal field in Enugu State, Okobo coal field in Kogi State, Opoko-Obido coal field in Kogi State, Odagbo coal field in Kogi State, and Ofugo coal field in Kogi State.

Maiganga is a community located between latitudes 10° 02' and 10° 05' and longitudes 11° 06' and 11° 08' in Akko Local Government Area of Gombe State, northeast Nigeria (Pandey *et al.,* 2014). The Maiganga coal is situated within the late Cretaceous Gombe Formation in the Gongola sub-basin of the Northern Benue Trough, Nigeria (Kolo *et al.,* 2016). The Maiganga coal deposit is a low-rank, sub-bituminous coal resource identified by the Nigerian government as a key target for future power generation initiatives.

The Gboko coal mine is situated in Benue State, Nigeria, within the Gboko Local Government Area. Geographically, it lies at 7.31620°N latitude and 8.90170°E longitude (Uloko *et al.,* 2024). The region is notable for its rich mineral deposits, including limestone, granite, barite, and alluvial clay (Uloko *et al.,* 2024).

The Onyeama coal mine is geographically situated within the latitudes 60°29' - 60°34' N and longitudes 70°30' E, located within the Enugu coal field, specifically within the catchment area of the Ekulu River (Ozoko, 2015). The Onyeama coal is situated approximately 6.5 kilometres northwest of Enugu City, in Enugu State, southeastern Nigeria (Ozoko, 2015). The Onyeama coal mine is an underground mining operation that extracts sub-bituminous coal from the seams 2, 3, and 4 of the Mamu Formation, located at the base of the Enugu Escarpment (Ozoko, 2015).

Similarly, the geographical location of the Okobo coal mine lies between latitude 7˚22'14" N and longitude 7˚37'31"E in the Enjema district area of Ankpa local government which is about 200 km North of Enugu having coal reserves amounting to 380 million tonnes (Itodo, *et al.,* 2020). While in Igalamela-Odolu local government area of Kogi State, precisely in Egabada community which is surrounded to the East by Enugu State and to the west by the Niger River is the Opoko-Obido coal mine with a longitude of 7^0 1’ 15” E and latitude of 7^0 2’ 36” N having an abundance of coal deposits covering approximately 26 km^2 (Uloko, *et al.,* 2024).

Consequently, in Ankpa local government, specifically Okaba district, the Odagbo coal mine is situated in the North-eastern part of the Anambra Basin with an altitude of about 275 m, longitudes 7^0 43’ 30” E to 7^0 44’ 00” E and latitudes 7^0 28’ 30” N to 7^0 29’ 00” N. The mine in this district is approximately 0.8m thick of bituminous coal, with an overburden of between 3m and 6m. The coal is characterized by a dark colour, with a light grey silty shale that overlies it (Uloko, *et al.,* 2024). Additionally, in Ankpa Local Government, there is the Ofugu coalmine. It has a longitude of 7^0 ° 37’ 24.7” E, a latitude of 70 ° 33’ 36.9” N, and an altitude of 390m (Uloko *et al.,* 2024).

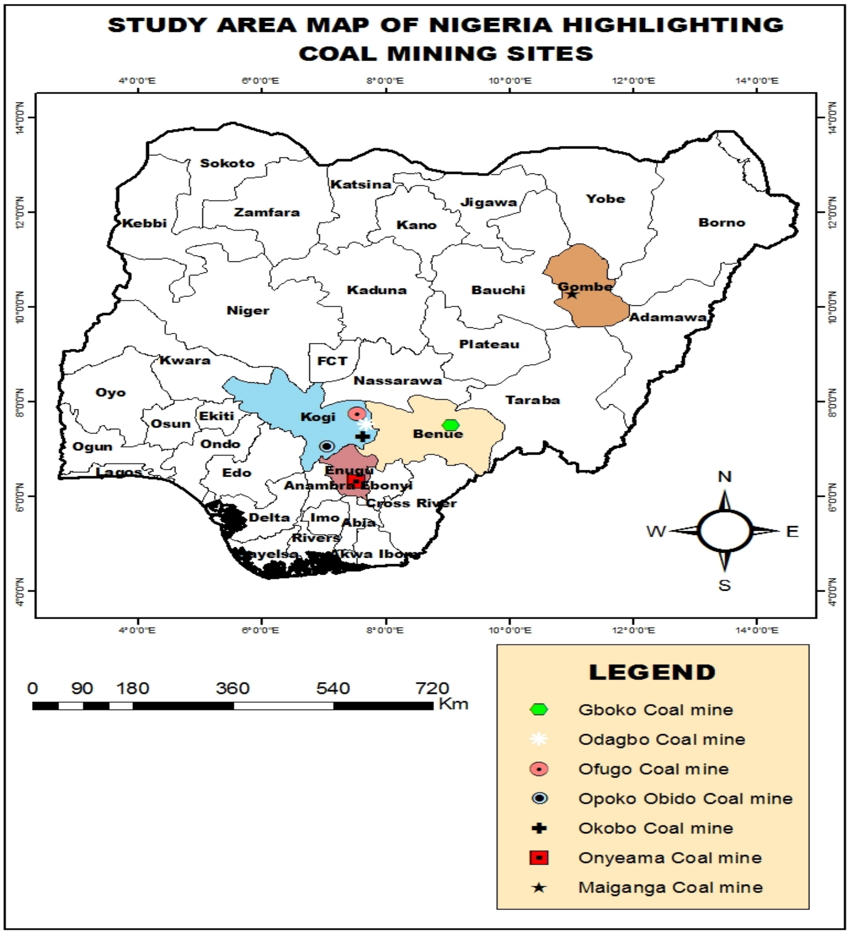

Figure 1: Study Area Map of Nigeria, Showing Coal Mining Sites

Sampling and Preparation

Seven samples were collected from the active seven (7) coal mines in Nigeria, specifically from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo, and Ofugo in Nigeria. These sites were selected due to the reported cases of indiscriminate mining activities, contaminated water supply and continuous acid mine drainage contamination from underground coal mines, which require further investigations, hence the reason for this current study. These regions in Nigeria are known for coal mining activities in the last decades and the coals are constantly transported from these mines to other parts of the country for the purpose of heat and electricity generation, cement production and other industrial processes.

Three samples taken at 0–5 cm, 5–10 cm, and 10–15 cm below the surface were collected from each site of Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo, and Ofugo to form the composite sample. The coal samples were collected using aluminium foil, wrapped and packed in polythene bags and transported safely to the laboratory at the Nigerian Geological Survey Agency (NGSA), Kaduna, Kaduna State for preparation.

The coal samples were pulverized into fine powder, sieved with a mesh of diameter 2mm, and homogenized at the Nigerian Geological Survey Agency (NGSA) laboratory in Kaduna State, Nigeria. Each time a sample was pulverized; the plate inside the machine was washed and dry-cleaned with acetone and tissue paper to avoid cross-contamination of the samples. Then the powdered samples were packed in well-labelled plastic containers and properly sealed to avoid cross-contamination and for ease of identification. These coal samples were transported to the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU) Zaria for the Instrumental Neutron Activation Analysis (INAA). Similarly, another set of the coal samples were taken to the Centre for Energy Research and Development (CERD) of the Obafemi Awolowo University Ile-Ife, Osun State for the Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis. In the laboratory at the Centre for Energy Research and Training (CERT) of Ahmadu Bello University (ABU) Zaria, the homogenized samples of coal were weighed (0.15 g), transferred to a 0.5 mL polyethylene vial (irradiation capsule) then sealed. The same process was done for 0.10 g for the standard reference material (SRM) NIST 1633c Coal Fly Ash. Subsequently, the coal samples and the primary standard (NIST 1633c) were encapsulated in a cladding and subjected to neutron irradiation using the Instrumental neutron Activation analysis (INAA) technique which details has been described elsewhere (Joseph et al., 2011 & 2017).

Similarly, in the laboratory at the Centre for Energy Research and Development (CERD) of the Obafemi Awolowo University Ile-Ife, the homogenized coal samples were weighed of approximately 5.0 g and put into the polythene bottle lining of mylar plastic, then the pellet samples were then analysed using the Energy Dispersive X-ray Fluorescence (EDXRF) method.

Analytical Techniques

The digested samples were analyzed using Instrumental Neutron Activation Analysis (INAA) and Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometry to determine the concentration of heavy metals in the coal.

Data Analysis

The analytical data were processed using specialized software to calculate the enrichment factors (EFs) and pollution indices (PIs) for each heavy metal.

Enrichment factor (EF)

The enrichment factor provides a quantitative measure of abundance of the elements in the sample compared to the background level. The EFs were calculated using the formula:

$$EF = \frac{(C_x/C_f)sample}{(C_x/C_f)crust} \quad (1)$$

where: C_x and C_f represent concentrations of the element x and reference element f in the coal and reference samples (Asubiojo *et al.,* 2012).

Five contamination categories were generally recognized based on the enrichment factor: EF<2, depletion to minimal enrichment; 2≤EF<5, moderate enrichment; 5 ≤EF<20, significant enrichment; 20≤EF<40, very high enrichment; and EF>40, extremely high enrichment (Asubiojo *et al.,* 2012).

Pollution Index (PI)

The pollution index is a quantitative measure used to assess the degree or level of pollution in a particular environment, such as air, water, or soil (Fagbenro *et al*., 2021). It provided a numerical representation of the concentration of harmful impurities (contaminants) in the coal found in the environment. The heavy metals pollution index in the coal serves as a valuable tool for assessing and monitoring the environmental impact of coal-related activities, as well as for safeguarding human health and the environment from the adverse effects of toxic metals contamination (Fagbenro *et al*., 2021). Equation (2) was used to evaluate the pollution index of toxic metals in the coal deposits.

$$PI = \frac{C_i}{S_i} \quad (2)$$

where: PI = pollution index corresponding to each sample, C_i = concentration of each metal (mg/kg), and S_i = maximum permissible level or background value (mg/kg) of the element (Fagbenro *et al*., 2021).

In principle, if the value of pollution index of an element is > 1, it means high contamination and may be toxic at that level in the sample (Asubiojo *et al*., 2012).

The purpose of the pollution index evaluation was to provide policymakers, scientists, environmentalists, and the public with information about the environmental quality and health risks associated with coal pollution. By quantifying pollution levels, indices can help prioritize pollution control efforts, inform regulatory decisions, evaluate the effectiveness of pollution mitigation measures, and raise awareness about environmental issues.

RESULTS AND DISCUSSION

The results of the heavy metals concentration (mg/kg) obtained from the Instrumental Neutron Activation Analysis of the samples collected from Maiganga coal, Gboko coal, Onyeama coal, Okobo coal, Opoko-obido coal, Odabgo coal, and the Ofugo coal deposits (Table 1) showed the presence of ten (10) notable heavy metals (V, Mn, As, U, Cr, Co, Sr, Sb, Ba and Th). The concentrations (mg/kg) of these heavy metals ranged from 4.69 ± 0.92 to 18.40 ± 1.10 for V, 4.82 ± 0.29 to 185 ± 2 for Mn, 0.11 ± 0.01 to 0.33 ± 0.04 for As, 0.19 ± 0.04 to 0.74 ± 0.05 for U, 7.14 ± 1.62 to 16.60 ± 1.80 for Cr, 1.49 ± 0.16 to 9.10 ± 0.33 for Co, 312 ± 71 to 383 ± 107 for Sr, 0.12 ± 0.03 to 296 ± 23 for Sb, 92 ± 25 to 296 ± 22 for Ba, and 0.26 ± 0.04 to 2.39 ± 0.11 for Th. The results showed that the heavy metal concentrations varied within the coal samples and between locations.

The concentration of Manganese (Mn) in samples S1, S2, S4 and S7 were slightly higher than the permissible limits of 150 mg/kg given by the Nigerian National Environmental Standards and Regulations Enforcement Agency (NESREA) and the United States Environmental Protection Authority (USEPA). Similarly, the concentration of Strontium (Sr) in S1, S4 and S6 were slightly higher than the NESREA limit of 300 mg/kg. Furthermore, Antimony (Sb) concentration in sample S1 was greater than the NESREA, USEPA and European Union permissible limits of 3.0 mg/kg, 6.0 mg/kg and 2.5 mg/kg respectively.

Table 1: Heavy Metals Concentration (mg/kg) in the Coal Samples using INNA Technique

Elements	Locations						
	S1	S2	S3	S4	S5	S6	S7
V	BDL	10.16±1.68	4.69±0.92	13.8±0.9	14.59±1.24	6.03±0.66	18.4±1.1
Mn	164±2	162±25	4.82±0.29	237±2	34.1±0.7	6.06±1.17	185±2
As	0.33±0.02	0.15±0.02	0.11±0.01	0.18±0.02	0.33±0.04	0.28±0.04	0.30±0.03
U	0.29±0.04	0.48±0.06	0.19±0.04	0.57±0.05	0.66±0.07	0.61±0.09	0.74±0.05
Cr	7.14±1.62	12.2±1.4	BDL	16.2±1.5	16.6±1.8	10.5±1.6	15.9±1.6
Co	BDL	3.58±0.27	4.17±0.22	2.42±0.19	9.10±0.33	3.86±0.28	1.49±0.16
Sr	326±86	BDL	BDL	312±71	BDL	383±107	BDL
Sb	296±23	0.12±0.03	BDL	BDL	0.17±0.05	BDL	BDL
Ba	296±22	92±25	BDL	BDL	BDL	131±19	174±19
Th	1.10±0.10	1.9±0.10	0.26±0.04	1.87±0.09	2.16±0.12	1.30±0.09	2.39±0.11

The analysis results of the toxic heavy metal concentrations (mg/kg) obtained from the Energy Dispersive X-ray Fluorescence (EDXRF) nuclear analytical technique of the measured coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal mines are presented in Table 2. The results showed the presence of six (6) prominent toxic heavy metals (Cr, Mn, Ni, Cu, Sr and Pb). The concentrations of the heavy metals content ranged from 25.738 ± 7.189 to 36.568 ± 5.484 for Cr, 141.155 ± 6.980 to 783.933 ± 24.431 for Mn, 39.691 ± 3.540 to 85.383 ± 5.879 for Ni, 67.212 ± 3.231 to 94.929 ± 4.302 for Cu, 24.081 ± 5.981 to 176.704 ± 7.126 for Sr and 7.491± 1.487 to 35.473 ± 6.326 for Pb respectively.

The concentration of Manganese (Mn) in samples S1, S2, S4 and S7 were much higher than the National Environmental Standards and Regulations Enforcement Agency (NESREA) and the European Union limits of 150 mg/kg. Prolonged exposure to Manganese could cause memory loss, mood changes, cognitive impairment, respiratory problems, reproductive issues, cardiovascular disease and increase risk of osteoporosis and fractures in bone. In addition, the concentrations of Nickel (Ni) in the coal samples S2, S3, S5, S6, and S7 were NESREA and European Union permissible limits of 50 mg/kg and 20 mg/kg respectively. Protracted exposure to this Nickel (Ni) content in the coal could lead to several health effects such as respiratory problems (inhaling nickel particles, causing lung inflammation, bronchitis and asthma), it can also increase cancer risk because nickel is classified as a carcinogen. Nickel has the tendency to cause neurological damage, kidney damage, skin irritation, cardiovascular disease and reproductive issues. All these are dependent on the concentration and duration of exposure as well as the route of exposure (inhalation, ingestion, or skin contact).

High concentrations of Copper (Cu) were recorded in all the coal samples in comparison with the National Environmental Standards and Regulations Enforcement Agency (NESREA), United States Environmental Protection Agency (USEPA) and European Union limits of 35 mg/kg, 41.9 mg/kg and 20 mg/kg respectively for coal mining and coal combustion residue. This high concentration of copper (Cu) could lead to immune system suppression, increase cancer risk, and causes damage to both the liver and kidney. Similarly, the concentrations of Lead (Pb) in virtually all the coal samples were higher than the NESREA limit of 10 mg/kg, the USEPA permissible limit of 5 mg/kg and the European Union limit of 10 mg/kg for coal mining and coal combustion residues. The implication of constant exposure to high concentration of Pb in the coal is the risk of neurological damage, kidney damage, cardiovascular disease, developmental delays, reproductive issues, anaemia and blood disorders, gastrointestinal problems and cancer risk.

Table 2: Heavy Metals Concentration (mg/kg) of the Coal Samples using EDXRF Technique

Elements	Locations							NESREA Limits (mg/kg)
	S1	S2	S3	S4	S5	S6	S7	
Cr	<13.608	25.738 ±7.189	36.568 ±5.484	35.935 ±5.650	35.162 ±8.361	<66.236	35.162 ±6.794	50
Mn	347.032 ±13.469	516.056 ±15.182	<15.564	783.933 ±24.431	141.155 ±6.980	BDL	557.022 ±18.946	150
Ni	48.184 ±5.363	63.281 ±5.622	80.650 ±8.704	39.691 ±3.540	85.383 ±5.879	63.311 ±5.550	50.778 ±7.440	50
Cu	71.214 ±4.316	68.206 ±3.314	88.631 ±5.457	67.212 ±3.231	68.904 ±3.486	70.180 ±3.446	94.929 ±4.302	35

Sr	128.701 ±9.819	<23.567	BDL	27.047 ±5.139	BDL	176.704 ±7.126	24.081 ±5.981	300
Pb	12.782 ±3.819	18.782 ±4.130	7.491 ±1.487	25.419 ±4.852	8.982 ±3.169	14.109 ±4.251	35.473 ±6.326	10

Table 3 and Figure 2 presents the Enrichment Factor of the Instrumental Neutron Activation Analysis (INAA) results with variations in the values of enrichment factors. The value of Ba showed moderate enrichment. Similarly, Sr value indicated deficiency to minimal enrichment. V, Mn, As, U, Cr, Co, and Th with mean values less than 1 indicated no enrichment. The Sb value in the Maiganga coal (S1) indicated extremely high enrichment factor greater than 40 (EF>40). These variations could be from natural and anthropogenic sources, such as natural weathering of the earth's crust, mining and agricultural practices (use of fertilizers). Chilikwazi *et al.*, (2023) also reported high enrichment factor for Antimony (Sb) and Barium (Ba).

Table 3: Enrichment Factor of INAA Results

Elements	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
V	0.0000	0.0774	0.1804	0.0738	0.1688	0.1979	0.1062
Mn	1.0254	1.4699	0.2209	1.5097	0.4701	0.2369	1.2721
As	0.0027	0.0018	0.0065	0.0015	0.0059	0.0141	0.0027
U	0.0471	0.1131	0.2261	0.0943	0.2363	0.6193	0.1321
Cr	0.0416	0.1031	0.0000	0.0961	0.2130	0.3822	0.1018
Co	0.0000	0.1819	1.0699	0.0863	0.7024	0.8450	0.0574
Sr	0.5434	0.0000	0.0000	0.5298	0.0000	3.9921	0.0000
Sb	51.9310	0.0306	0.0000	0.0000	0.0658	0.0000	0.0000
Ba	3.9479	1.7808	0.0000	0.0000	0.0000	10.9258	2.5524
Th	0.0718	0.1800	0.1244	0.1244	0.3110	0.5308	0.1716

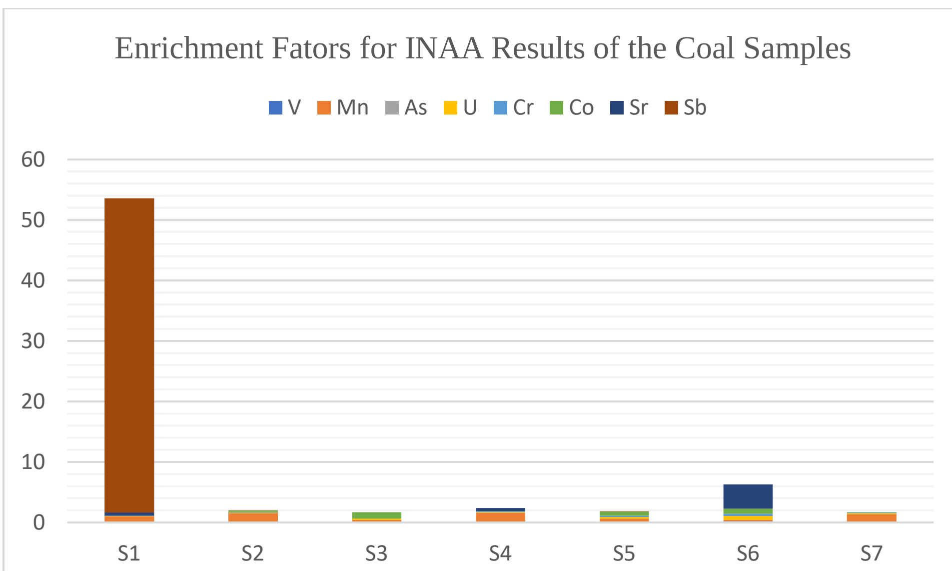

Figure 2: Enrichment Factor of INAA Results of Coal

Similarly, the enrichment factors of the Energy Dispersive X-Ray Fluorescence (EDXRF) analysis results, showed variations in values as presented in Table 4 and Figure 3. The mean values for Ti and Mn showed significant enrichment, while Ni, Cu and Pb values indicated depletion to minimal enrichment. For Cr, Zn, and Sr with mean values less than 1, therefore, there is no enrichment.

Table 4: Enrichment Factor of EDXRF Results

Elements	S1	S2	S3	S4	S5	S6	S7
Ti	1.4793	20.7348	10.0729	21.5328	4.9488	23.0961	43.3991
Cr	0.0567	0.9910	0.9548	1.0603	0.2141	1.5312	1.1718
Mn	1.5523	21.3420	0.4365	24.8446	0.9232	0.0000	19.9395
Ni	0.3922	4.7622	4.1159	2.2890	1.0162	2.8605	3.3076
Cu	0.4405	3.9006	3.4373	2.9456	0.6232	2.4097	4.6991
Zn	0.1198	1.1496	0.8023	0.9249	0.4133	1.9271	0.9458
Sr	0.1535	0.2598	0.0000	0.2285	0.0000	1.1697	0.2298
Pb	0.1443	1.9598	0.5301	2.0326	0.1482	0.8839	3.2039

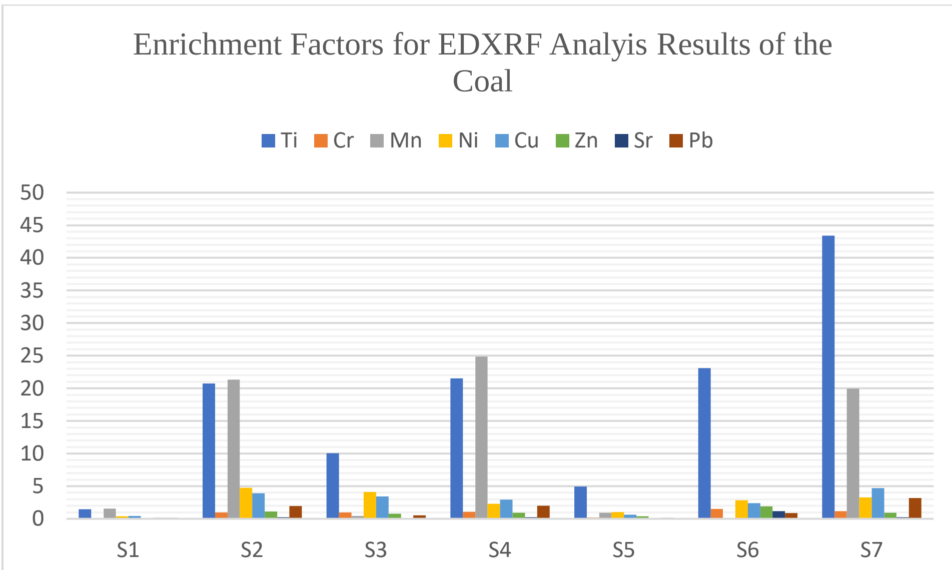

Figure 3: Enrichment Factor of EDXRF Analysis Results of Coal

Table 5 and Figure 4 represents the evaluated pollution index in the coal deposits from the different coal mines in Nigeria using the Instrumental Neutron Activation Analysis (INAA) results. At the Maiganga coal mine (S1), the soil was moderately polluted (2<PI≤3) by Ba and Sr. According to Meng *et al.,* (2014), the pollution index (PI > 3) showed highly contaminated soil. Therefore, Antimony (Sb) with pollution index (PI) of 34.58 indicated high pollution. Similarly, at the Okobo coal mine (S4), the soil was moderately polluted (2<PI≤3) by Sr. Likewise, at the Odagbo coal mine (S6), the soil was slightly polluted (1<PI≤2) by Ba, and highly polluted (PI>3) by Sr. Also, at the Ofugo coal mine (S7), the soil was slightly polluted (1<PI≤2) by Ba. Marrero *et al*. (2007) and Chilikwazi *et al*. (2023), also reported moderate and high pollution due to Manganese (Mn) and Barium (Ba).

Table 5: Pollution Index / Contamination Factor of INAA Results

Elements	S1	S2	S3	S4	S5	S6	S7
V	0.0000	0.0355	0.0164	0.0482	0.0510	0.0211	0.0643
Mn	0.6828	0.6744	0.0201	0.9867	0.1420	0.0252	0.7702
As	0.0018	0.0008	0.0006	0.0010	0.0018	0.0015	0.0016
U	0.0314	0.0519	0.0205	0.0616	0.0714	0.0659	0.0800
Cr	0.0277	0.0473	0.0000	0.0628	0.0643	0.0407	0.0616
Co	0.0002	0.0834	0.0972	0.0564	0.2121	0.0900	0.0347
Sr	3.6182	0.0001	0.0001	3.4628	0.0001	4.2508	0.0001
Sb	34.5794	0.0140	0.0012	0.0012	0.0199	0.0012	0.0012
Ba	2.6288	0.8171	0.0001	0.0001	0.0001	1.1634	1.5453
Th	0.0478	0.0826	0.0113	0.0813	0.0939	0.0565	0.1039

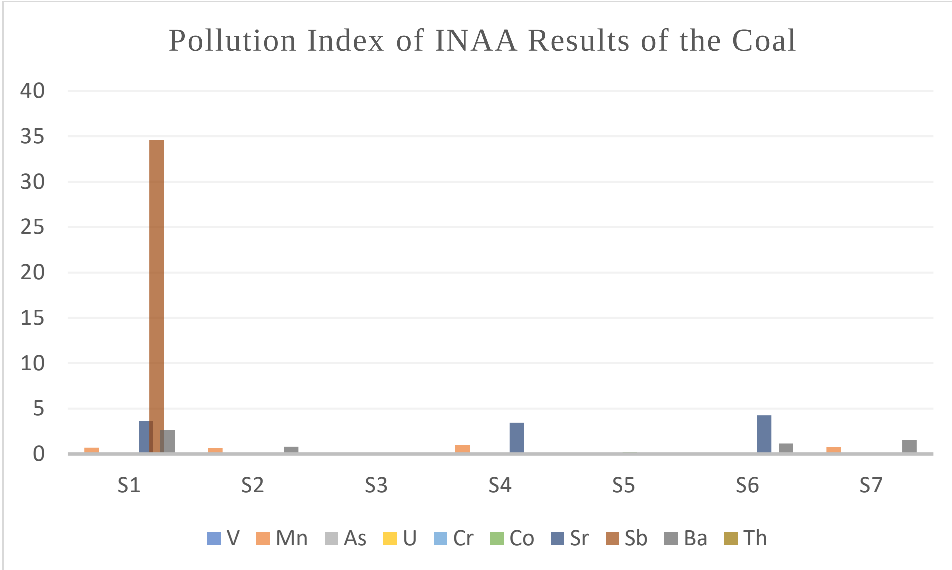

Figure 4: Pollution Index of the INAA Results of Coal

Similarly, Table 6 and Figure 5 presents the pollution index of the coal deposits in Nigeria using the Energy Dispersive X-Ray Fluorescence (EDXRF) analysis results. For the Maiganga coal mine (Figure 5), the mean pollution index indicates that the soil was not polluted (PI < 1) by Cr, Fe, Ni, Cu, Zn, Sr and Pb, but slightly polluted (1<PI≤2) by Ti and Mn. At the Gboko coal mine (Figure 5), the mean pollution index indicated that the soil was not polluted (PI < 1) by Cr, Fe, Ni, Cu, Zn, Sr and Pb, but slightly polluted (1<PI≤2) by Ti and Mn. At the Onyeama coal mine (Figure 5), the mean pollution index indicated that the soil was not polluted (PI < 1) by Cr, Mn, Fe, Ni, Cu, Zn, Sr and Pb, but slightly polluted (1<PI≤2) by Ti. At the Okobo coal mine (Figure 5), the mean pollution index indicated that the soil was not polluted (PI < 1) by Cr, Fe, Ni, Cu, Zn, Sr and Pb, but slightly polluted (1<PI≤2) by Ti, and moderately polluted (2<PI≤3) by Mn. At the Opoko-Obido coal mine (Figure 5), the mean pollution index indicated that the soil was not polluted (PI < 1) by Cr, Mn, Fe, Ni, Cu, Zn, Sr and Pb, but moderately polluted (2<PI≤3) by Ti.

At the Odagbo coal mine (Figure 5), the mean pollution index indicated that the soil was not polluted (PI < 1) by Cr, Mn, Fe, Ni, Cu, Zn, Sr and Pb, but moderately polluted (2<PI≤3) by Ti. Similarly, at the Ofugo coal mine (Figure 5), the mean pollution index showed that the soil was not polluted (PI < 1) by Cr, Fe, Ni, Cu, Zn, Sr and Pb, but slightly polluted (1<PI≤2) by Mn and highly polluted (PI>3) by Ti.

Table 6: Pollution Index / Contamination Factor of EDXRF Results

Elements	S1	S2	S3	S4	S5	S6	S7
Ti	1.3768	2.0873	1.4953	2.8286	3.1501	3.8725	5.0474
Cr	0.0527	0.0998	0.1417	0.1393	0.1363	0.2567	0.1363
Mn	1.4448	2.1484	0.0648	3.2637	0.5877	0.0000	2.3190
Fe	0.9307	0.1007	0.1484	0.1314	0.6365	0.1677	0.1163
Ni	0.3650	0.4794	0.6110	0.3007	0.6468	0.4796	0.3847
Cu	0.4100	0.3927	0.5103	0.3869	0.3967	0.4040	0.5465
Zn	0.1115	0.1157	0.1191	0.1215	0.2631	0.3231	0.1100
Sr	0.1428	0.0262	0.0000	0.0300	0.0000	0.1961	0.0267
Pb	0.1343	0.1973	0.0787	0.2670	0.0943	0.1482	0.3726

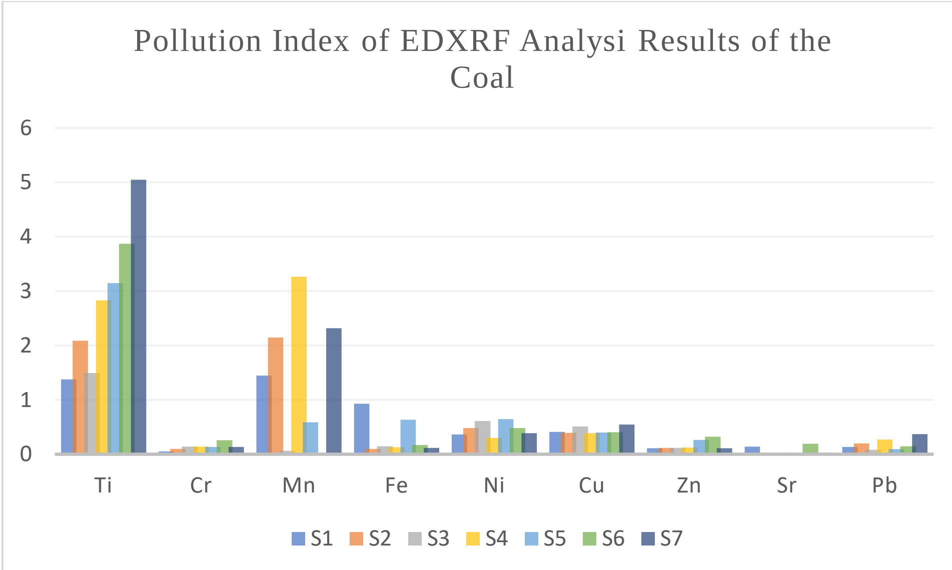

Figure 5: Pollution Index of the EDXRF Analysis Results of Coal

CONCLUSION

The Enrichment Factor of the Instrumental Neutron Activation Analysis (INAA) results with variations in the values of enrichment factors. The value of Ba showed moderate enrichment. Similarly, Sr value indicated deficiency to minimal enrichment. V, Mn, As, U, Cr, Co, and Th with mean values less than 1 indicated no enrichment. The Sb value in the Maiganga coal (S1) indicated extremely high enrichment factor greater than 40 (EF>40). These variations could be from natural and anthropogenic sources, such as natural weathering of the earth's crust, mining and agricultural practices (use of fertilizers). Similarly, the enrichment factors of the Energy Dispersive X-Ray Fluorescence (EDXRF) analysis results, showed variations in values as presented in Table 2. The mean values for Ti and Mn showed significant enrichment, while Ni, Cu and Pb values indicated depletion to minimal enrichment.

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