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Analysis of the Impact of Abandoned Coal Mines on Water Quality in Enugu Environs

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ABSTRACT: Enugu state also known coal city played a major role in the pre-independence Nigeria due to the abundance of coal deposits in the state. The mines were developed by the colonial administrators and was a major source of revenue for the government until the discovery of crude oil in Niger Delta, Nigeria when it was eventually abandoned. However, the manner in which the mines were abandoned negate international best practices leading to contamination of the environment. Given this, this study presents an assessment of environmental impact of the abandoned coal mines in Enugu state Nigeria. The study examined the Onyeama mine, Asata mines, and a well dug in Independence layout in Enugu Metropolis. The study adopted an experimental research design. Thus, coal samples and water sample around the mines, and the well at Independent Layout were collected and analyzed at the Projects Development Institute (PRODA), Enugu. The analysis was done using multi water checker, flame photometry and other techniques. The results indicated that all the water samples have low pH values indicating that they are acidic. The total suspended solid on the sample from Onyeama is higher than the WHO standard. Sulphate and other metals are within the WHO acceptable range. However, there were traces of heavy metals such as chromium and mercury in the water samples. The elemental analysis of the coal sample from Independence Layout showed that chromium is a constituent of the coal, thus accounting for the presence of chromium found in the water samples. The biochemical oxygen demand of all the water samples was found to be within the acceptable limit. It can then be concluded therefore, that water bodies around the abandoned coal mines and within Enugu metropolis have been contaminated and thus, unsafe for human and animals alike; unless they are treated properly.

I. INTRODUCTION

Enugu state owes its metropolitan status in Southeast Nigeria largely to the presence of extensive sub-bituminous coal deposits (Ezeigbo and Ezeanyim 1993; Eze, 2021). Historically, the city functioned as the administrative capital of the former Eastern region of Nigeria. The population of the city has steadily increased. This was driven by the establishment of numerous industries, factories, and the Government Secretariat, which have attracted a significant workforce and their families. Coal was a substantial contributor to Nigeria's revenue at the time of independence and played a pivotal role in the development of national infrastructure. Although precise employment figures for the entire duration of the operation of the coal mine are unavailable, what is not in doubt is that the mines provided considerable employment and that the decline of the Nigeria Coal Corporation adversely affected the city's commercial activities. As a mining hub, Enugu drew migrants from local, national, and international locations which enriched the cultural diversity of the city. In 1952, Enugu's population was approximately 62,000, with non-indigenes constituting more than half (Iyida, 2015). However, with the shift to crude oil as the primary revenue source, the impact of the coal industry diminished on a national level.

While the coal mines provided significant economic benefits, they also resulted in long-term environmental damage. The adverse effects of mining activities include land degradation, improper disposal of overburden, deforestation, washing rejects, subsidence, and various forms of pollution, such as water, air, and noise pollution, as well as mine fires. Water pollution related to coal mining encompasses harmful impacts on both health and the environment, stemming from the mining, processing, burning, and waste disposal of coal. These include acid mine drainage, thermal pollution from coal plants, acid rain, and contamination of groundwater, streams, rivers, and seas by heavy metals, mercury, and other pollutants present in coal ash, sludge, and waste. The situation is exacerbated by the failure of the government to reclaim many of these mines, particularly those abandoned during the civil war. Enugu State is known for having the most severe erosion in Nigeria, a condition linked to the un-reclaimed mines and unregulated artisanal mining at abandoned sites across the state (Nganje, et al., 2011).

Extensive coal mining activities have been conducted in the Enugu area of Nigeria, with notable mines including Udi Mines, Onyeama Mines, Okpara Mines, Iva Valley Mines, Asata Mines, and Ribadu Mines (Ani and Odife, 2020). These mining operations have generated significant amounts of mine waste, which have been disposed of in landfills and surface dumps. The locations of these dumps were selected primarily for convenience and proximity to the waste sources rather than based on environmental, geological, or engineering considerations. This has led to environmental degradation and the potential for groundwater contamination (Ezeigbo and Ezeanyim 1993). Local communities rely on surface water resources, such as rivers, streams, and springs, as well as groundwater resources accessed through boreholes and shallow wells scattered throughout the area. These water sources are essential for domestic, agricultural, and industrial purposes. However, Obiadi et al. (2016) observed that the inhabitants depend more on surface water than groundwater, likely due to the limited number of boreholes and shallow wells, which may be attributed to economic and geological constraints arising from the area's unique geological characteristics.

Evidently, numerous mines were abandoned without proper waste management, resulting in the accumulation of hazardous materials. Consequently, environmental assessments and remediation efforts are critically needed. In this context, the Onyeama and Asata coal mines have been selected for a geochemical investigation to assess heavy metal contamination in local water sources. These mines, along with their associated waste rock piles, have been abandoned for over twenty years without remediation, and the nearby land is used for crop cultivation. The primary sources of drinking water in these areas are hand-dug wells, boreholes within the community, and stream channels that traverse the mine sites. Water draining from coal dump sites along stream banks is a concern, as coal contains heavy metals that dissolve in acidic water with low pH, often resulting from pyrite oxidation (Adaikpo et al., 2005; Todd and Fall, 1997). The impact of untreated mine drainage on streams depends on factors such as the frequency, volume, and chemical composition of the drainage, as well as the buffering capacity of the receiving streams (Todd and Fall, 1997).

II. LITERATURE REVIEW

2.1 Coal Boom and the Challenges that Led to Its Abandonment in Enugu

Coal was first discovered in Nigeria in 1909 at Udi Ridge, Enugu, by Albert Kitson, a British mining engineer originally searching for silver. By 1914, the first shipment of coal was exported to the United Kingdom from newly established ports in Port Harcourt, coinciding with Nigeria's amalgamation (Adebesin and Amosun, 2022). By 1916, the Ogbete Mine was fully operational, producing 24,511 metric tons of coal that year. Subsequently, other mines emerged in the area, which is now part of modern-day Enugu State. Coal production reached a peak of 790,030 metric tons before experiencing a steady decline, leading to the abandonment of many mines (Ohimain, 2014). Currently, Nigeria's coal reserves are estimated at approximately 2.8 billion metric tons (Ogunsola, 1991). The Nigeria Coal Corporation was established in 1950 to manage these resources. Initially, the domestic market for coal was primarily driven by the emerging rail system, which relied heavily on coal for powering locomotives. However, Fatoye and Gideon (2014) observed that the discovery of hydrocarbons in the late 1950s led the Nigerian Railway Corporation to switch to diesel-powered engines, and the Electric Company of Nigeria also transitioned to diesel for power generation. The loss of these significant customers contributed to the decline in coal production, as the government deemed further investment in the sector unfeasible. Additionally, the discovery of crude oil in Oloibiri, which promised greater revenue through exports, further diminished the importance of coal. Nevertheless, the Nigeria Coal Corporation persisted, maintaining a national monopoly on coal production.

The Nigerian Civil War significantly contributed to the decline of the Nigeria Coal Corporation. During the conflict, several coal mines became inaccessible and were subsequently abandoned, with many never being revived or

reclaimed. Notably, two mines were commissioned during the war: the Odagbor mine, later known as the Okaba coal mine in present-day Kogi State, and the Biafra Coal Corporation in Enugu. These were eventually merged into the Nigeria Coal Corporation after the war (Nwaobi and Territory, 1987). As noted by Adebesein and Amosun (2022), efforts to mechanize the mines in the late 1970s and 1980s were unsuccessful, leading to further reductions in production. Poor management also plagued the Corporation during the 1980s and 1990s, as the military government frequently appointed individuals lacking managerial or technical expertise to oversee public enterprises, including the Nigeria Coal Corporation. The appointment of a university professor without management experience to lead the Corporation exacerbated its decline. In 1999, the Nigerian government's attempt to attract foreign investment by privatizing the Corporation and opening the solid mineral market to large private investors failed, resulting in the withdrawal of government support and the eventual cessation of the Corporation's operations in 2002. Following the unsuccessful privatization attempt, the Federal Government sold some of the Corporation's assets to the Enugu State government in 2013 to settle outstanding debts (Adebesein and Amosun, 2022).

The discovery of coal in Enugu had profound effects on both the town and the nation. It significantly accelerated the development of Enugu, transforming it into a commercial hub for the region. The economic importance of coal was so substantial that Enugu was designated the capital of the Eastern Region in 1938. The influence of coal mining extended to the establishment of a thriving port in what is now Port Harcourt, which emerged as a prominent city, facilitating the export of coal to Europe. The mining industry also spurred population growth in Enugu, with the number of miners in the region increasing from 6,000 in 1948 to 8,000 by 1958 (Baiyewu-Teru, 2015).

The Iva Valley Massacre of 1949 significantly influenced the national movement for independence in Nigeria. The incident centered around a miners' strike in which workers demanded better wages and working conditions, which the colonial government interpreted as both a challenge to authority and a covert push for independence. Historical records indicate that coal miners, frustrated by rising inflation and the management's refusal to recognize the Colliery Workers Union, began advocating for wage increases and union recognition as early as 1944. Tensions escalated in November 1949 when the miners initiated a work-to-rule strike, working only the minimum required hours and thus severely disrupting coal mine operations. In response, the management attempted to dismiss 200 hewers, leading the dismissed workers to occupy the mines to prevent their replacement. The miners' wives supported the strike by protesting at the colliery's office, where they damaged equipment and broke windows. When the management called in the police, several women were injured in the ensuing clash. Despite these actions, the miners remained resolute (Jaja, 1982). The widespread support for the strike led the colonial authorities to suspect an insurrection, possibly with communist influences, and believed that members of the Zikist Movement, who were advocating for national independence, were involved. Fearing that the protesters might seize explosives from the mines for terrorist activities, the colonial government dispatched 900 soldiers and policemen from northern Nigeria to suppress the miners and secure the explosives. The confrontation resulted in the Colonial Police killing 21 unarmed miners and severely injuring 51 others (Alimi, 2024). The Iva Valley Massacre became a pivotal event in the history of Nigeria's labor movement and marked a crucial turning point in the country's struggle for independence; an aspect often overlooked in formal historical education. Post-independence, coal continued to play a significant role in Nigerian politics, particularly in Enugu, which had risen to prominence as the capital of the Eastern Region. During the Nigerian Civil War, Enugu briefly served as the strategic capital of Biafra, with the Biafra Coal Corporation providing essential power to support the Biafran cause.

III. MATERIALS AND METHOD

3.1 Materials

The research utilized several materials, including water samples from Onyeama Mine, Asata Mine, and a well in the Independence Layout, as well as coal samples from both Onyeama and Asata Mines. The equipment used in the study comprised sample bottles, a multi-water checker with 99.9% accuracy and a 0.01% margin of error, flame atomic absorption spectrometry with an accuracy range of 1-5%, flame photometry, along with associated apparatus such as burners, lamps, pressure-reducing valves, and vents.

3.2 Area of Study

The study is carried out in Enugu state, Nigeria. Enugu state is the capital of the old Easter Region and is popularly known as "Coal City" because of the large deposit of coal in the state. Enugu state has a landmass of 7,161km² with a

population of 4,396,098 (Enete, 2014). Enugu state is made up of seventeen (17) local government areas with three senatorial zones. Two out of the three senatorial zones have large deposits of coal.

3.3 Sample Collection

The areas for sampling were deliberately selected to capture the effects of the abandoned mining operations in those locations. The water bodies from which samples were taken were not isolated but were situated within the mining areas, being directly or indirectly linked to the mining activities. The collected samples were meticulously handled to prevent any significant alterations between the time of collection and the measurement of various parameters. To ensure this, the samples were promptly stored in a laboratory equipped with proper preservation facilities. For accurate and representative results, the collection of water samples was pre-planned and conducted systematically, rather than through random selection.

3.4 Analytical Procedures

The analytical procedures involved in this study included both physical and chemical analyses, conducted using various methods and instruments. A Multi Water Quality Checker was employed for measurements of pH, conductivity, dissolved oxygen (DO), and total dissolved solids (TDS), with the device being calibrated with standard solutions prior to use. To determine the concentration of heavy metals such as arsenic, lead, nickel, cobalt, and chromium, Flame Atomic Absorption Spectrophotometry (FAAS) was utilized. This method involved aspirating the samples into a flame and measuring their absorbance to calculate metal concentrations. Additionally, Flame Photometry was used to quantify elements like sodium and potassium by analyzing the wavelengths emitted as atoms transitioned from an excited to a ground state. The Biochemical Oxygen Demand (BOD) test was conducted to assess the oxygen required by organic matter in the water for decomposition, with samples incubated at 27°C for three days, after which oxygen consumption was measured using the Multi Water Quality Checker. Finally, spectrophotometric analysis was employed to determine sulphate concentrations, where sulphate ions were precipitated with barium chloride, and the absorbance of the resulting solution was measured.

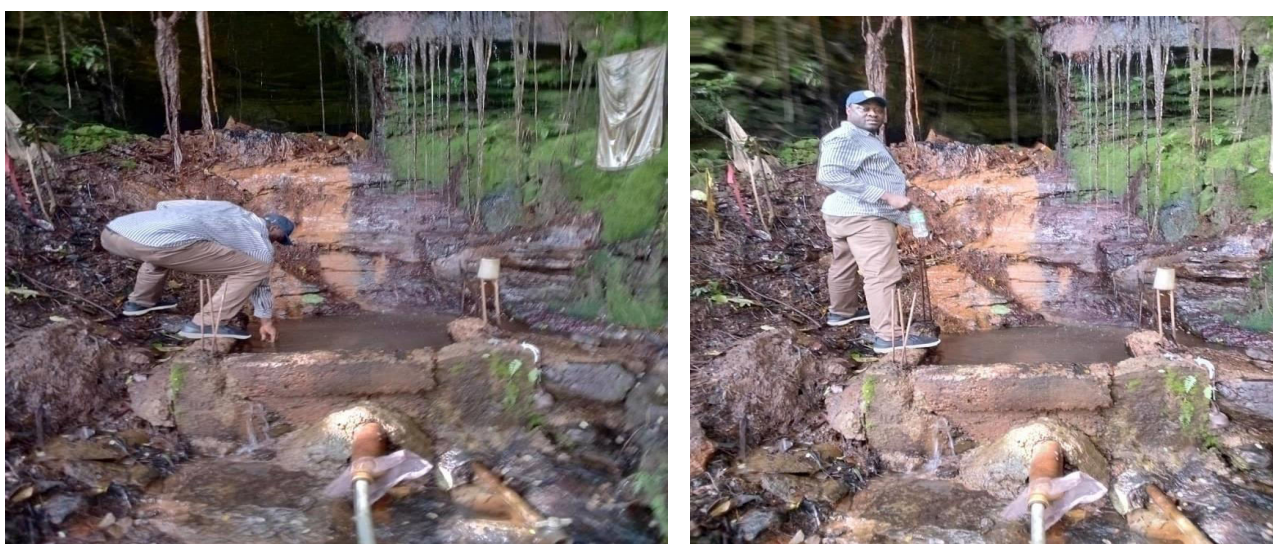


Figure 3.1: First author collecting sample at Asata Mine

IV. RESULTS AND DISCUSSIONS

Table 4.1: Physicochemical and elemental analysis result of the water samples against WHO Standard

PARAMETERS	UNIT	WHO Std	INDEPENDENCE LAYOUT WELL	ONYEAMA MINE	ASATA MINE
Odour		Odourless	Odourless	Odourless	Odourless

pH		6.5 – 8.5	4.91	4.39	5.01
Conductivity	(µs/cm)	500	83.8	4.22	26.6
Total Suspended Solid	mg/L	30	18.00	50.00	22.00
Total Dissolved Solids	mg/L	500	60.00	64.00	52.00
Total Solids	mg/L	500	78.00	114.00	74.00
Chloride	mg/L	250	21.84	9.93	8.94
Total Hardness	mg/L	200	42.00	20.00	18.00
Lead	mg/L		Nil	Nil	Nil
Sulphate	mg/L	500	17.59	23.15	25.4
Nitrate	mg/L	10	0.34	0.56	0.29
Dissolved Oxygen	mg/L	5-14	4.8	12	9
Biochemical Oxygen Demand	mg/L	<5	0.2	0.7	0.5
Cadmium	mg/L	0.01	Nil	0.007	0.001
Chromium	mg/L	0.05	0.106	0.201	0.114
Nickel	mg/L		0.013	0.166	0.082
Arsenic	mg/L	0.001	Nil	Nil	Nil
Cobalt	mg/L		Nil	0.010	Nil
Mercury	mg/L	0.001	Nil	0.010	0.002

The analysis of water samples from Independence Layout Well, Onyeama Mine, and Asata Mine reveals significant deviations in several parameters when compared to the World Health Organization (WHO) standards. The pH levels of all three sites fall below the recommended range of 6.5 to 8.5, with Onyeama Mine showing the lowest pH at 4.39, indicating acidic conditions that could harm aquatic life and corrode infrastructure. Conductivity values also vary, with Independence Layout Well and Asata Mine within acceptable limits, but Onyeama Mine registering a notably low value of 4.22 µs/cm, which may suggest minimal ionized substance presence. Furthermore, Total Suspended Solids (TSS) exceed the WHO standard of 30 mg/L at Onyeama Mine, reaching 50 mg/L, which could reduce light penetration and hinder aquatic ecosystems.

Heavy metal analysis also reveals concerning results, particularly at Onyeama Mine, where cadmium, chromium, nickel, and mercury concentrations exceed WHO limits. Chromium levels are especially high across all sites, with Onyeama Mine at 0.201 mg/L, significantly surpassing the 0.05 mg/L standard, indicating potential contamination from industrial activities. Nickel and mercury concentrations are also elevated, particularly at Onyeama Mine, where nickel is 0.166 mg/L, highlighting the mine's considerable contribution to heavy metal pollution. Conversely, lead and arsenic levels are within safe limits across all sites. These findings suggest that abandoned coal mines, especially Onyeama Mine, contribute significantly to water pollution, necessitating immediate remediation to protect water quality and public health.

Table 4.2: Sample of coal found in Independence Layout Enugu

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Layer Table=====
#      Thick Type   Error  Units  Density  Norm Total
1      0.00  Bulk   0.00  mg/cm²  0.00F on  100.00
Sample Table=====
=====

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Layer	Component	Type	Concn.	Error	Units	Mole%	Error
1	SiO2	Calc	39.532	1.802	wt. %	57.296	2.612

1	V2O5	Calc	0.111	0.021	wt. %	0.053	0.010
1	Cr2O3	Calc	0.027	0.011	wt. %	0.016	0.007
1	MnO	Calc	0.036	0.012	wt. %	0.045	0.015
1	Fe2O3	Calc	35.801	0.179	wt. %	19.523	0.098
1	Co3O4	Calc	0.160	0.054	wt. %	0.058	0.019
1	NiO	Calc	0.001	0.033	wt. %	0.001	0.038
1	CuO	Calc	0.044	0.013	wt. %	0.048	0.015
1	Nb2O3	Calc	0.217	0.527	wt. %	0.081	0.196
1	WO3	Calc	0.012	0.059	wt. %	0.005	0.022
1	P2O5	Calc	0.158	0.358	wt. %	0.097	0.220
1	SO3	Calc	3.907	0.286	wt. %	4.250	0.311
1	CaO	Calc	0.424	0.044	wt. %	0.658	0.068
1	MgO	Calc	0.000	0.000	wt. %	0.000	0.000
1	K2O	Calc	1.001	0.076	wt. %	0.925	0.070
1	BaO	Calc	0.092	0.148	wt. %	0.052	0.084
1	Al2O3	Calc	15.535	3.849	wt. %	13.268	3.288
1	Ta2O5	Calc	0.007	0.053	wt. %	0.001	0.010
1	TiO2	Calc	1.928	0.058	wt. %	2.102	0.063
1	ZnO	Calc	0.055	0.013	wt. %	0.059	0.014
1	Ag2O	Calc	0.000	0.000	wt. %	0.000	0.000
1	Cl	Calc	0.494	0.064	wt. %	1.213	0.156
1	ZrO2	Calc	0.047	0.135	wt. %	0.034	0.096
1	SnO2	Calc	0.000	0.000	wt. %	0.000	0.000
1	Rb2O	Calc	0.165	0.026	wt. %	0.077	0.012
1	PbO	Calc	0.148	0.051	wt. %	0.058	0.020
1	SrO	Calc	0.096	0.037	wt. %	0.081	0.031

The coal sample from Independence Layout in Enugu indicates a complex mineral composition, with significant concentrations of various oxides. The most abundant component is silicon dioxide (SiO₂), constituting 39.532 wt.% of the sample, followed closely by iron(III) oxide (Fe₂O₃) at 35.801 wt.%. These oxides, along with aluminum oxide (Al₂O₃) at 15.535 wt.%, indicate the presence of silicate minerals and iron-bearing compounds, which are common in coal deposits. Sulfur trioxide (SO₃) also shows a considerable presence at 3.907 wt.%, suggesting potential environmental concerns related to sulfur emissions during coal combustion. Additionally, minor constituents such as potassium oxide (K₂O) and titanium dioxide (TiO₂) are present in smaller amounts, highlighting the diverse elemental makeup of the coal. Trace elements like chromium oxide (Cr₂O₃), vanadium pentoxide (V₂O₅), and nickel oxide (NiO) are also detected, albeit in minimal concentrations, which could have implications for both the industrial use and environmental impact of this coal.

Table 4.3: Elements of coal found in independence Layout Enugu

Elemt	Line Code	Cond. Code	Ratio Method	Intensity (c/s)	Error (c/s)	Intensity Method	Conc.	Conc. Method	Calibration Coefficient
O	Ka	0	None	0.000	0.0000	Gaussian	42.859	None	0.000
Mg	Ka	1	None	0.000	1.7944	Gaussian	0.000	FP	0.000
Al	Ka	1	None	23.985	5.9428	Gaussian	8.222	FP	0.000
Si	Ka	1	None	273.127	12.4525	Gaussian	18.479	FP	0.000
P	Ka	1	None	2.691	6.1170	Gaussian	0.069	FP	0.000
S	Ka	1	None	118.090	8.6405	Gaussian	1.565	FP	0.000
Cl	Ka	1	None	50.272	6.4695	Gaussian	0.494	FP	0.000
K	Ka	1	None	134.156	10.1917	Gaussian	0.831	FP	0.000
Ca	Ka	1	None	71.588	7.4025	Gaussian	0.303	FP	0.000
Ti	Ka	1	None	549.512	16.4433	Gaussian	1.156	FP	0.000
V	Ka	1	None	39.262	7.4948	Gaussian	0.062	FP	0.000

Cr	Ka	1	None	14.082	5.8495	Gaussian	0.019	FP	0.000
Mn	Ka	1	None	20.178	6.9077	Gaussian	0.028	FP	0.000
Fe	Ka	1	None	18641.910	93.2634	Gaussian	25.041	FP	0.000
Co	Ka	1	None	98.470	33.0562	Gaussian	0.118	FP	0.000
Ni	Ka	1	None	0.310	11.7721	Gaussian	0.001	FP	0.000
Cu	Ka	1	None	16.585	5.0948	Gaussian	0.035	FP	0.000
Zn	Ka	1	None	22.841	5.3356	Gaussian	0.044	FP	0.000
Rb	Ka	1	None	28.429	4.4052	Gaussian	0.151	FP	0.000
Sr	Ka	1	None	11.002	4.1905	Gaussian	0.081	FP	0.000
Zr	Ka	1	None	1.322	3.7662	Gaussian	0.035	FP	0.000
Nb	Ka	1	None	1.333	3.2352	Gaussian	0.173	FP	0.000
Ag	Ka	1	None	0.000	0.0000	Gaussian	0.000	FP	0.000
Sn	La	1	None	0.000	10.2206	Gaussian	0.000	FP	0.000
Ba	La	1	None	9.508	15.2978	Gaussian	0.082	FP	0.000
Ta	La	1	None	0.730	5.1987	Gaussian	0.006	FP	0.000
W	La	1	None	1.191	5.7112	Gaussian	0.010	FP	0.000
Pb	La	1	None	16.632	5.7971	Gaussian	0.137	FP	0.000

Analysis conditions Thick kV uA ---Detector--- Thick. Atm present Actual
 # Target Filter
 mg/cm² Type Filter mg/cm² Time(s) Times(s)
 1 Rh None 0.00 20.0 30.0 SDD None 0.00 Air 60.0 20.0

Processing Conditions===== # No. Escape Sum Back C/R Blank ----Blank----
 Smths peaks peaks Type Ratio Rem. ---- File-----
 1 Yes Yes Auto No No

The elemental analysis of the coal sample from Independence Layout, Enugu, reveals that iron (Fe) is the most abundant element, with an intensity reading of 18,641.910 c/s and a concentration of 25.041 wt.%. This high iron content is characteristic of many coal types and can influence both the combustion properties of the coal and its environmental impact when burned. Silicon (Si) also shows a significant presence with an intensity of 273.127 c/s, corresponding to a concentration of 18.479 wt.%, indicating the likely presence of silicate minerals within the coal matrix. Additionally, titanium (Ti) is notable with an intensity of 549.512 c/s and a concentration of 1.156 wt.%, suggesting the presence of titanium-bearing minerals, which may impact the coal's utility in industrial applications. Other elements detected in smaller quantities include sulfur (S), which has an intensity of 118.090 c/s and a concentration of 1.565 wt.%, and potassium (K), with an intensity of 134.156 c/s and a concentration of 0.831 wt.%. The presence of sulfur is particularly important from an environmental perspective, as it can lead to the formation of sulfur dioxide (SO₂) during coal combustion, contributing to acid rain. Trace elements such as chromium (Cr), cobalt (Co), and nickel (Ni) are also present, though in much smaller amounts, with concentrations of 0.019 wt.%, 0.118 wt.%, and 0.001 wt.% respectively. These trace metals, although present in low concentrations, could pose environmental and health risks if released into the atmosphere or waterways during coal use or disposal.

Table 4.4: Sample Analysis of coal sample found at Onyeama Mine

Layer Table =====
 # Thick Type Error Units Density Norm Total
 1 0.00 Bulk 0.00 mg/cm² 0.00F on 100.00
 Sample Table =====

Layer	Component	Type	Concn.	Error	Units	Mole%	Error
1	SiO ₂	Calc	30.821	2.309	wt. %	37.437	2.804
1	V ₂ O ₅	Calc	0.127	0.057	wt. %	0.051	0.023
1	Cr ₂ O ₃	Calc	0.040	0.037	wt. %	0.019	0.018
1	MnO	Calc	0.256	0.035	wt. %	0.263	0.036

1	Fe2O3	Calc	5.820	0.098	wt. %	2.660	0.045
1	Co3O4	Calc	0.106	0.038	wt. %	0.032	0.011
1	NiO	Calc	0.053	0.030	wt. %	0.052	0.029
1	CuO	Calc	0.337	0.030	wt. %	0.310	0.028
1	Nb2O3	Calc	0.073	0.032	wt. %	0.023	0.010
1	WO3	Calc	0.000	0.000	wt. %	0.000	0.000
1	P2O5	Calc	0.000	0.000	wt. %	0.000	0.000
1	SO3	Calc	34.038	1.142	wt. %	31.026	1.041
1	CaO	Calc	5.947	0.248	wt. %	7.739	0.323
1	MgO	Calc	0.000	0.000	wt. %	0.000	0.000
1	K2O	Calc	0.608	0.163	wt. %	0.471	0.126
1	BaO	Calc	0.000	0.000	wt. %	0.000	0.000
1	Al2O3	Calc	15.664	5.267	wt. %	11.212	3.770
1	Ta2O5	Calc	0.000	0.000	wt. %	0.000	0.000
1	TiO2	Calc	2.794	0.124	wt. %	2.553	0.114
1	ZnO	Calc	0.172	0.026	wt. %	0.154	0.023
1	Ag2O	Calc	0.070	0.178	wt. %	0.022	0.056
1	Cl	Calc	2.852	0.265	wt. %	5.871	0.546
1	ZrO2	Calc	0.084	0.032	wt. %	0.050	0.019
1	SnO2	Calc	0.000	0.000	wt. %	0.000	0.000
1	Rb2O	Calc	0.018	0.021	wt. %	0.007	0.008
1	PbO	Calc	0.096	0.065	wt. %	0.032	0.021
1	SrO	Calc	0.024	0.024	wt. %	0.017	0.017

The coal sample from Onyeama Mine exhibits a complex chemical composition, with significant amounts of silicon dioxide (SiO₂) and sulfur trioxide (SO₃). SiO₂ is the most prevalent component, constituting 30.821 wt.% of the sample, indicating the presence of silicate minerals, which are common in coal. SO₃ is also highly concentrated, at 34.038 wt.%, which suggests that the coal may have a high sulfur content, potentially leading to the release of sulfur dioxide (SO₂) during combustion—a key contributor to acid rain. This high sulfur content is of particular environmental concern, as it poses significant challenges for air quality management and pollution control in coal utilization.

The sample also contains notable quantities of aluminum oxide (Al₂O₃) and calcium oxide (CaO), at 15.664 wt.% and 5.947 wt.%, respectively. These oxides are important as they influence the ash characteristics of the coal, impacting its behavior during combustion and its suitability for various industrial applications. Iron(III) oxide (Fe₂O₃), although present in smaller amounts at 5.820 wt.%, suggests some level of iron content, which can also affect the coal's properties. Other trace elements such as titanium dioxide (TiO₂), present at 2.794 wt.%, and copper oxide (CuO), at 0.337 wt.%, indicate the presence of metal oxides, which could have implications for both the environmental impact and the industrial use of the coal. The presence of these diverse elements underscores the complex nature of the coal from Onyeama Mine and highlights the need for careful consideration in its exploitation and use.

Table 4.5: Sample Analysis of coal sample found at Onyeama Coal mine

Elemnt	Line Code	Cond. Code	Ratio Method	Intensity (c/s)	Error (c/s)	Intensity Method	Conc.	Conc. Method	Caliberation Coeffient
O	Ka	0	None	0.000	0.0000	Gaussian	49.182	None	0.000
Mg	Ka	1	None	0.000	2.1726	Gaussian	0.000	FP	0.000
Al	Ka	1	None	12.909	4.3407	Gaussian	8.290	FP	0.000
Si	Ka	1	None	109.248	8.1835	Gaussian	14.407	FP	0.000

P	Ka	1	None	0.000	5.7793	Gaussian	0.000	FP	0.000
S	Ka	1	None	514.376	17.2591	Gaussian	13.632	FP	0.000
Cl	Ka	1	None	111.299	10.3508	Gaussian	2.852	FP	0.000
K	Ka	1	None	29.400	7.8588	Gaussian	0.505	FP	0.000
Ca	Ka	1	None	372.756	15.5606	Gaussian	4.250	FP	0.000
Ti	Ka	1	None	296.092	13.1620	Gaussian	1.675	FP	0.000
V	Ka	1	None	17.153	7.7454	Gaussian	0.071	FP	0.000
Cr	Ka	1	None	8.156	7.6519	Gaussian	0.027	FP	0.000
Mn	Ka	1	None	73.827	10.2218	Gaussian	0.198	FP	0.000
Fe	Ka	1	None	1818.137	30.5426	Gaussian	4.070	FP	0.000
Co	Ka	1	None	41.222	14.5967	Gaussian	0.078	FP	0.000
Ni	Ka	1	None	21.747	12.1889	Gaussian	0.042	FP	0.000
Cu	Ka	1	None	162.515	14.5823	Gaussian	0.269	FP	0.000
Zn	Ka	1	None	92.791	14.1046	Gaussian	0.138	FP	0.000
Rb	Ka	1	None	12.699	14.5086	Gaussian	0.016	FP	0.000
Sr	Ka	1	None	13.664	14.0062	Gaussian	0.020	FP	0.000
Zr	Ka	1	None	35.775	13.6900	Gaussian	0.062	FP	0.000
Nb	Ka	1	None	29.704	13.0561	Gaussian	0.058	FP	0.000
Ag	Ka	1	None	3.157	8.0269	Gaussian	0.065	FP	0.000
Sn	La	1	None	0.000	11.7269	Gaussian	0.000	FP	0.000

Elemt	Line Code	Cond. Code	Ratio Method	Intensity (c/s)	Error (c/s)	Intensity Method	Conc.	Conc. Method	Calibration Coefficient
Ba	La	1	None	0.000	12.2229	Gaussian	0.000	FP	0.000
Ta	La	1	None	0.000	15.0838	Gaussian	0.000	FP	0.000
W	La	1	None	0.000	15.7264	Gaussian	0.000	FP	0.000
Pb	La	1	None	24.291	16.3438	Gaussian	0.090	FP	0.000

Analysis conditions

#	Target	Filter	Thick	kV	uA	---Detector---	Thick.	Atm present	Actual
1	Rh	None	0.00	30.0	30.0	SDD	None	Air 60.0	20.0

Processing Conditions===== # No. Escape Sum Back C/R Blank ----Blank----

Smths	peaks	Type	Ratio	Rem.	----	File----
1	Yes	Yes	Auto	No	No	

The elemental analysis of the Onyema coal sample reveals a diverse range of components, with sulfur (S) being the most dominant element, indicated by a high intensity of 514.376 c/s and a concentration of 13.632 wt.%. This significant sulfur content suggests potential challenges in coal combustion, as sulfur dioxide (SO₂) emissions can contribute to air pollution and acid rain. Silicon (Si) also exhibits a notable presence, with an intensity of 109.248 c/s and a concentration of 14.407 wt.%, highlighting the coal's substantial silicate mineral content, which is typical of many coal deposits. Other major elements include calcium (Ca) and iron (Fe), with calcium showing an intensity of 372.756 c/s and a concentration of 4.250 wt.%, while iron displays an intensity of 1,818.137 c/s and a concentration of 4.070 wt.%. These elements play crucial roles in determining the coal's combustion properties and its suitability for various industrial applications.

In addition to the major elements, trace elements such as titanium (Ti), chlorine (Cl), and copper (Cu) are also present in measurable amounts. Titanium has an intensity of 296.092 c/s and a concentration of 1.675 wt.%, while chlorine and copper show concentrations of 2.852 wt.% and 0.269 wt.%, respectively. The presence of these trace metals, although in smaller quantities, could have implications for both the environmental impact and the utility of the coal. The analysis

also detects minor quantities of other elements, including manganese (Mn), nickel (Ni), and lead (Pb), with manganese showing a concentration of 0.198 wt.% and lead at 0.090 wt.%. These trace elements, particularly lead, though present in low concentrations, could pose environmental and health risks if not managed properly during coal processing and combustion. The comprehensive elemental profile of Onyema coal underscores its complex composition and the need for careful management in its industrial use.

V. CONCLUSION

This study provides a critical insights into the environmental consequences of coal mining activities. The findings indicate significant deviations from WHO standards in several key water quality parameters, particularly in areas surrounding the Onyema and Asata mines. The water samples revealed elevated levels of heavy metals, such as chromium, nickel, and mercury, particularly in proximity to the abandoned mines, which underscores the potential health risks and environmental hazards associated with mining activities. The acidic pH levels and high concentrations of total solids further highlight the ongoing degradation of water quality, which could have severe implications for both human health and the surrounding ecosystem.

In addition, the elemental analysis of coal samples from Onyema Mine and other sites revealed a complex composition, with high concentrations of sulfur, iron, and silicon, among other elements. These findings suggest that the coal from these sites has significant potential to contribute to environmental pollution, particularly through the release of sulfur dioxide and other harmful emissions during combustion. The presence of trace metals such as lead and arsenic in both water and coal samples further emphasizes the need for stringent environmental monitoring and remediation efforts. Conclusively, this study underscores the urgent need for effective management strategies to mitigate the environmental impact of abandoned coal mines and protect water quality in the Enugu environs.

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