Seasonal Assessment of Heavy Metal Contamination and Drinking Water Suitability of Surface and Groundwater in Okaba-Odagbo Coal Mining Community, Ankpa, Kogi East, Nigeria

Victor A. Abah[1]; Oludele J. Ayoola[2*]; Abulwasiu Abubakar[3]; Olufemi Samuel A.[4]; Ayuba Rufai[5]

[1,2,3,4,5] Department of Geography and Environmental Management, University of Abuja, Nigeria.
Kogi State University, Anyigba, Nigeria.

Corresponding Author: Oludele J. Ayoola*

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Abstract: Coal mining activities are recognized as significant sources of heavy metal contamination, posing serious threats to surface water, groundwater, and public health in mining communities. This study assessed the seasonal occurrence of heavy metal contamination and evaluated the suitability of surface and groundwater for human consumption in the Okaba-Odagbo coal mining community, Ankpa, Kogi East, Nigeria. Primary data were obtained through field sampling during the dry and rainy seasons. Surface water samples were collected from three strategic locations (upstream, middle course, and downstream) to determine the influence of mining activities along the flow path, while groundwater samples were collected from two functional community boreholes selected using simple random sampling. In total, ten water samples comprising six surface water and four groundwater samples were analyzed for selected heavy metals, including cobalt, fluorine, cadmium, copper, silicon, and selenium, alongside selected physicochemical parameters. Descriptive statistics (mean, standard deviation, and coefficient of variation) were used to summarize the data. The results revealed marked spatial and seasonal variations in heavy metal concentrations. Surface water recorded higher concentrations of heavy metals at the middle course and downstream sections than at the upstream location, indicating the influence of mine effluent discharge, runoff, and sediment transport. Groundwater samples also contained detectable concentrations of heavy metals, suggesting contaminant migration from mining areas into the aquifer system. Although the concentrations of the analyzed heavy metals were generally within the permissible limits prescribed by the World Health Organization (WHO) and the Federal Ministry of Environment (FME), most water samples exhibited acidic pH values below the recommended range and elevated total hardness at several sampling locations. The study concludes that coal mining activities have adversely influenced the quality of both surface water and groundwater in the Okaba-Odagbo mining community. Although most heavy metal concentrations remained within regulatory limits, the combined effects of acidic water conditions and detectable heavy metal concentrations indicate that the affected water sources are unsuitable for long-term human consumption without appropriate treatment. The study recommends continuous environmental monitoring, effective treatment of mine effluents, provision of safe alternative water supplies, and stricter enforcement of environmental regulations to safeguard water resources and protect public health in mining communities.

Keywords: *Urban Recreational Facilities; Spatial Distribution; Ecosystem Services; Park Users; Environmental Sustainability.*

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I. INTRODUCTION

Water is one of the most indispensable natural resources for sustaining life, maintaining ecosystem functions, and promoting socioeconomic development. Safe drinking water is fundamental to human health and is recognized as a basic human right and a key component of Sustainable Development Goal 6 (SDG 6), which seeks to ensure the availability and sustainable management of water and sanitation for all (United Nations, 2015; World Health Organization [WHO], 2022). However, rapid industrialization, urbanization, agricultural intensification, and mining activities have significantly impaired the quality of both surface water and groundwater worldwide, thereby increasing public health concerns (UNEP, 2019; WHO, 2022).

Mining activities are among the most significant anthropogenic sources of environmental pollution due to the release of potentially toxic heavy metals into surrounding soils, surface water, and groundwater (Alloway, 2013). Coal mining, in particular, exposes mineralized rocks to weathering and oxidation, resulting in the generation of acid mine drainage and the mobilization of heavy metals into nearby aquatic systems (Younger, Banwart, & Hedin, 2002). These contaminants may be transported through runoff, seepage, leaching, and infiltration, eventually contaminating streams, rivers, ponds, hand-dug wells, springs, and groundwater aquifers that serve as sources of domestic water (Ako et al., 2014; Adamu, Nganje, & Edet, 2015).

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), arsenic (As), nickel (Ni), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) are considered priority pollutants because they are non-biodegradable, persistent, and capable of bioaccumulating in living organisms (Alloway, 2013). Although some metals such as iron, zinc, copper, and manganese are essential micronutrients at trace concentrations, excessive levels may result in severe health effects, including neurological disorders, kidney dysfunction, liver damage, cardiovascular diseases, reproductive impairment, and various forms of cancer (WHO, 2022). Consequently, monitoring heavy metal concentrations in drinking water has become a major public health priority worldwide (UNEP, 2019).

Seasonal variations significantly influence the concentration, transport, and distribution of heavy metals in aquatic environments. During the rainy season, increased precipitation enhances surface runoff and erosion, facilitating the transport of contaminants from mining sites into rivers, streams, and shallow aquifers. In contrast, during the dry season, reduced stream flow and lower dilution capacity often result in increased concentrations of dissolved heavy metals in water bodies (Rashed, 2010). Seasonal assessments are therefore essential for understanding temporal changes in water quality and for designing effective environmental monitoring and pollution control strategies.

Nigeria possesses considerable coal deposits, particularly within the Benue Trough, where mining has contributed substantially to regional economic development (Obaje, 2009). One of the country's major coal-producing areas is the Okaba-Odagbo Coal Mining Community in Ankpa Local Government Area of Kogi East. Coal extraction has been undertaken in this area for several decades, providing employment and energy resources while simultaneously posing environmental challenges associated with land degradation, water pollution, and ecosystem disturbance (Obaje, 2009). The surrounding communities depend largely on nearby streams, rivers, hand-dug wells, boreholes, and springs for drinking, cooking, irrigation, and other domestic purposes. Consequently, contamination of these water sources with heavy metals represents a significant environmental and public health concern.

Groundwater has traditionally been regarded as relatively protected from contamination because soil and geological formations act as natural filters (Brady & Weil, 2017). However, prolonged mining activities can facilitate the migration of dissolved heavy metals into groundwater through fractures, weathered zones, and permeable geological formations (Obaje, 2009). Surface water, on the other hand, is directly exposed to mine drainage, atmospheric deposition, and contaminated runoff, making it particularly susceptible to pollution (Ako et al., 2014). Comparative evaluation of heavy metal concentrations in both surface water and groundwater therefore provides valuable information regarding contamination pathways and potential human exposure.

The suitability of water for drinking depends largely on compliance with established national and international drinking water quality standards. The World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) have established maximum permissible limits for heavy metals in potable water to safeguard public health (WHO, 2022; Standards Organisation of Nigeria [SON], 2015). Water quality assessment based on these standards provides scientific evidence for determining the safety of water resources and guiding environmental management and public health interventions.

Although previous studies have investigated heavy metal contamination in mining environments across Nigeria (Ako et al., 2014; Adamu et al., 2015), there remains limited information regarding the seasonal distribution of heavy metals in both surface water and groundwater within the Okaba-Odagbo coal mining community. Furthermore, comprehensive assessments comparing dry- and rainy-season water quality with established drinking water standards are scarce. This knowledge gap limits the development of effective

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environmental management strategies and public health interventions in the study area.

Therefore, this study assesses the seasonal occurrence of heavy metals in surface water and groundwater in the Okaba-Odagbo Coal Mining Community during the dry and rainy seasons and evaluates the suitability of these water sources for human consumption based on WHO and Nigerian drinking water quality standards. The findings are expected to provide baseline information for environmental monitoring, pollution control, sustainable water resource management, and evidence-based policy formulation in coal mining communities of Nigeria.

II. MATERIALS AND METHODS

➤ *Study Area*

The coal mining site is located at Odagbo, which is a sub-district in Okaba town in Ankpa LGA of Kogi State. Okaba district lies some 16 km NE of Ankpa town, headquarters of Ankpa Local Government Area. The study area is located between latitudes 7º 20′ – 7º 43′ N and longitudes 7º 22′ – 7º 52′ E (Figure 1).

The study area Okaba-Odagbo is a rural settlement located within the Northeastern part of Ankpa Local Government Area of Kogi State in North central Nigeria situated between latitude 7 20 N and 7 30 N and longitude 7 25' E and 7 45' E of the Greenwich meridian. Ankpa falls within the Anambra Basin whose genesis has been linked with the development of the Niger Delta Mio-geosyncline and the opening of the Benue Trough, (Bala and Onugba, 2001). The stratigraphy comprises of cyclic sedimentary sequence that started in the early Cretaceous time, Bannet *et al.*, (1988), Marine and fluviatile sediments comprising friable to poorly cemented sands, shales, clays and limestone were deposited, with occasional coal, peat and thin discontinuous seams of lignite, Campbell (2003).

The sediments have been affected by the major Santonian folding, and a minor Cenomanian folding and uplift, Bannet *et al.*, (1988). The study area is typical of Ajali Formation or the false bedded sandstone and the Mamu Formation. The Ajali consists of thick friable poorly sorted sandstone, typically white in colour but sometimes iron stained Ajali sand is often overlain by a considerable thickness of red earthly sands, formed by the weathering and feruginization of the Formation. Topographically, the area has a relief with lowland and hill landforms. The hill rises up to 330m and 240m to the south and 360m around Odagbo coal mine with an average of 270m elevation situated at the base of Enugu escarpment. The drainage is of dendritic pattern with few tributaries. It is drained by Otokpa stream from the Southwest part towards the Northeast and Ashokpa stream flowing Northeast of Okaba and all being drained by Anambra River from West towards the Eastern part (Egboka and Uma, 1985). Ashokpa is the main stream in the area.

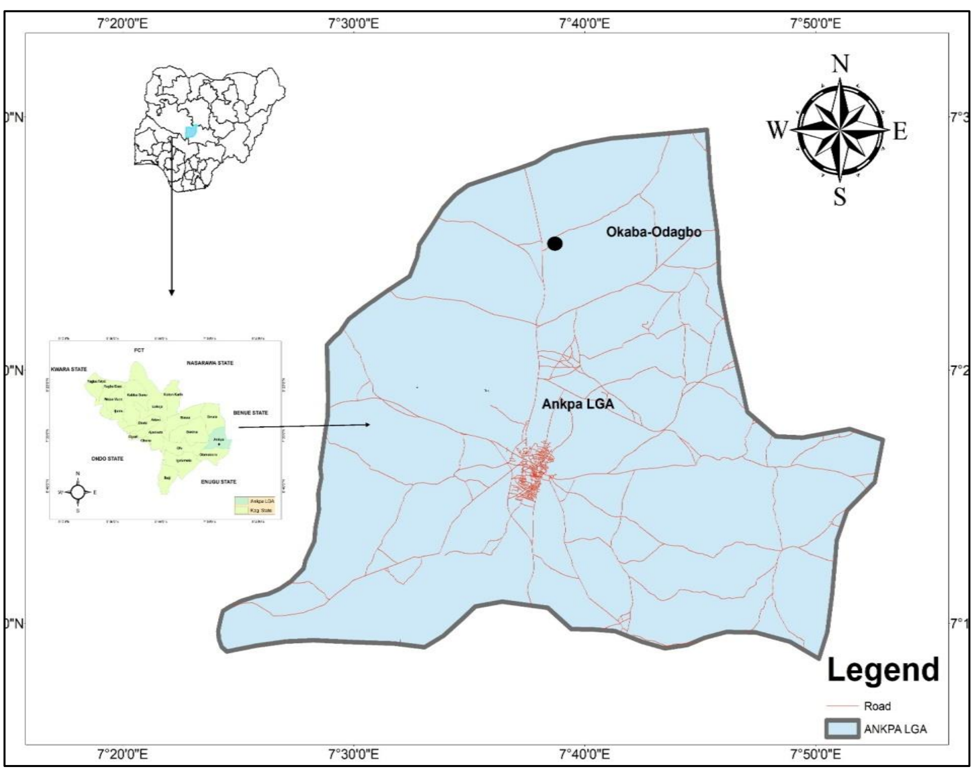

Fig 1: Map of Ankpa LGA showing the Study Area, Okaba-Odagbo
Source: ArcGis 10.1

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➢ *Sampling Procedure*

The research design involve the determination of the type and source of data, the sampling strategy, the data collection method and statistical analysis used to represent the result findings so as to correlate the relationship among variables being experimented. A well-designed methodology ensures the data collected are reliable, valid and capable of providing meaningful insights into the overall objectives of the study to address the highlighted problems. This method was used to investigate and assess the in concise the effects the heavy metals have on the health of residents living in Okabo-Odagbo communities that are consuming the polluted water as a result of the coal mining.

This study employed both the primary source of data collection as the method involves both qualitative and quantitative studies. The primary data required for this study includes data obtained directly from the field on the heavy metal contents of surface and ground water sampled from the mining sites (Manganese, Chromium, Cadmium, Arsenic, lead, Nickel, copper and Mercury).

Simple random sampling technique was used in selecting boreholes in the study area. The study area Okaba-Odagbo covers a total area of about 16km^2. Okaba settlement has a total of 3 functioning boreholes while Odagbo has 2 functioning boreholes. Samples were collected in Okaba and Odagbo settlement of Ankpa Local Government Area of Kogi State. Two (2) water samples were collected from one borehole in Okaba settlement and one borehole in Odagbo settlement for dry and rainy season, making a total of four water samples (4) for ground water. Borehole water was considered as it is their major source of domestic water supply. The borehole is 28m deep in Okaba and 22m in depth at Odagbo which is in slope compared to Okaba and were said to be about 19 to 21 years old. The distance of the borehole at Odagbo is located at 0.63km away from mining sites and 3.6km away to the mining sites at Okada making a total of 4.23km for the both communities to the mining sites.

For surface water, samples were collected at three points in a flowing stream, which are upstream, middle course and downstream; that is three (3) surface water sample for dry season and three for rainy season, making a total of six (6) surface water samples at 0.41km from mining site at Odagbo and 3.5km at Okaba. The selected points were chosen to determine the impact before the mining, at the mining and after the mining sites respectively. Statistical analyses were carried out using descriptive statistical tools.

III. RESULTS AND DISCUSSION

➢ *Surface Water quality in the Dry Season*

Figure 1 shows that highest value of cobalt (0.038mg/l), fluorine (1.28mg/l), silicon (0.04mg/l) are recorded in the downstream of the water, while lowest value for cobalt (0.01mg/l) is recorded at the upstream, fluorine (1.82mgt/l) silicon (0.24mg/l) were recorded at the middle course and the same value was record for cadmium (0.002mg/l) and selenium (0.002mg/l). Therefore, this finding reveals that water in the downstream are more polluted as compared to water at upstream and middle courses respectively which is indicative of the excessive discharge of waste water from the mine sites directly into the water bodies and subsequent flow in downward direction.

Generally, the value of all heavy metals recorded on the surface water is higher than the value recorded on the control site with the middle course recording the highest value and upstream recording the lowest, the lowest value of heavy metal recorded at the upstream is due to no influence of mining activities. This shows water at the middle course is highly polluted with heavy metal properties emanating from mining activities. This result is in conformity with the findings done by Abalaka and Aga (2016), as they emphasize that direct and indirect discharge of ore wastes and other mining processes have a direct effect on surface water both within and the surrounding environs. This shows that mining processes result in discharge of large number of toxic wastes, which need to be stored and treated before disposal. It is likely expected that during high rainfall this surface water will be drained into the community river used for domestic activities which are likely to affect the health of the consumer of this water. According to Santosa (2013) Acid Mine Drainage (AMD) frequently occurs with mines, polluting waterways and destroying terrestrial habitats in large areas surrounding the mines. As observed in some parts of the mine areas where waste water discharges are affecting the plant ecological development, stunted growth culminating in the sparsely distribution in the population of plants and even the reduction in microorganisms in their natural habitation.

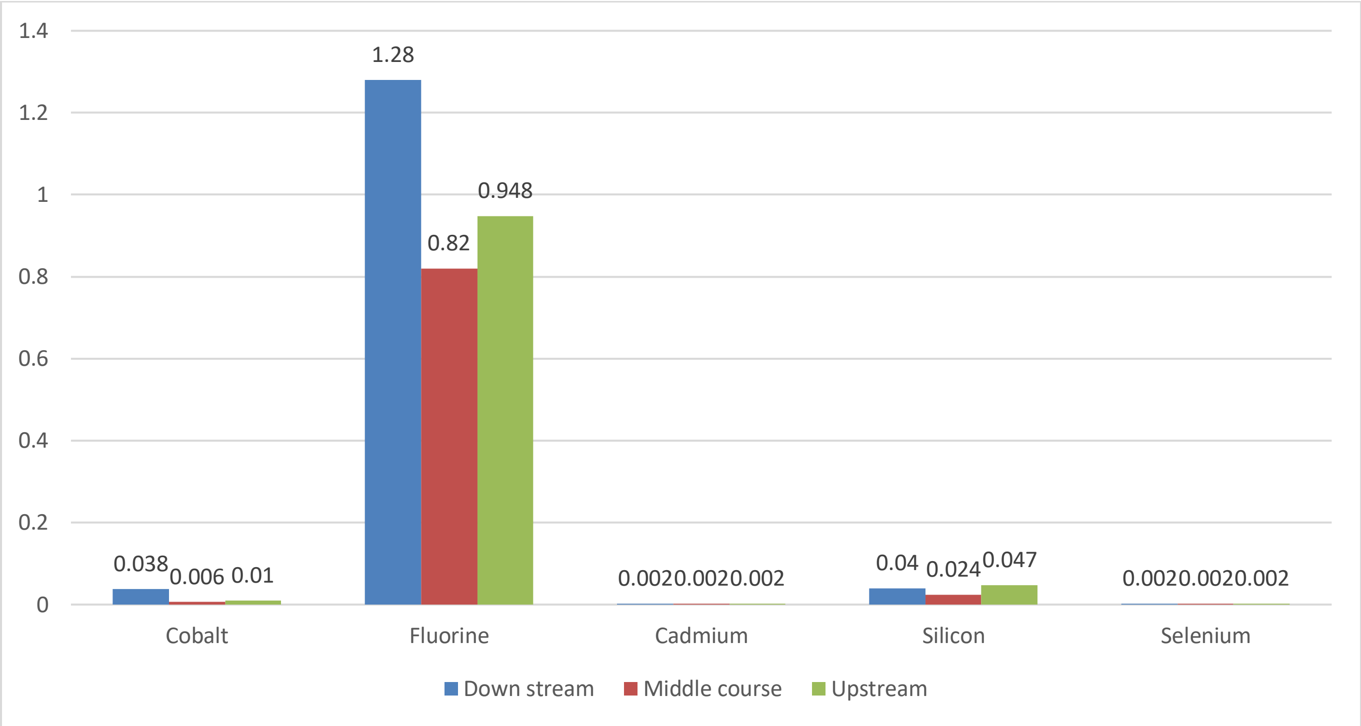

Fig 1: Heavy Metal Content in Surface Water During the Dry Season
Source: Author's Field work, 2023.

➢ *Underground Water Quality During the Dry Season in the Study Area*

From the result obtained in the Figure 2, shows that the highest value of cobalt (0.055mg/l) in borehole one (BH1) is lower than its value 0.63mg/l recorded by Okegye and Gajere (2015), fluorine (0.794mg/l) which is similar to the result recorded by Tijani et al., (2014) of 0.686, cadmium (0.003mg/l) recorded in the borehole water which is lower than value recorded by Okegye and Gajere (2015) of 0.03, while highest value of copper (0.04mg/l) is recorded in borehole one which is lower than the value recorded by Tijani et al., (2018) of 0.184, and within the value recorded by Okorie and Egila (2014) of 0.04, silicon (0.058mg/l) and selenium (0.058mg/l) which were recorded in borehole water two (BH2).

The finding revealed that water from the two borehole sources is polluted with different heavy metals in different concentrations. The finding shows that mining activities affect the borehole water in the study area. This implies that those who consume this water are at risk of ingestion of heavy metal pollutants and its possible health implication due to gradual heavy metal accumulation in their body systems (Bioaccumulation), Olabisi and Babajide (2021). Hence, the implication is that they are prone to diseases associated with the said heavy metals.

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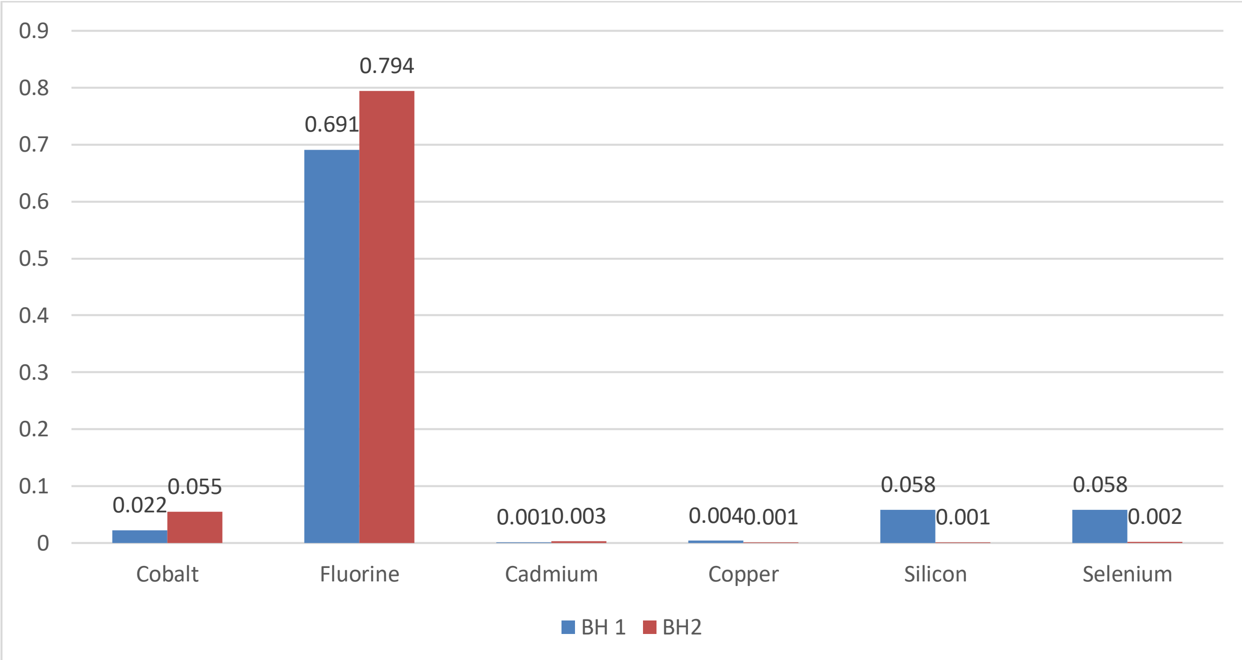

Fig 2: Heavy Metal Content of Water in Dry Season of the Underground Water
Source: Author's Field work, 2023.

- *Surface Water Quality in the Rainy Season*

Figure 3 indicated the highest value of cobalt (0.05mg/l), fluorine (1.41mg/l) recorded in downstream part of the water, and lowest value for cobalt (0.07mg/l) is recorded at the upstream while same value was recorded for cadmium (0.003mg/l) and selenium (0.002mg/l) on all sampling points. The high value of Fluorine from this source is a call for a concern as it is known to be very irritating and dangerous to the eyes, skin and lungs. This at room temperature makes human eyes and nose hurt while at high temperature makes it difficult to breathe and over exposure can even cause death in cases of severe lungs damage.

The finding revealed that water from downstream are more polluted as compared to water from the upstream and middle course, this could be from the capacity of the sediments in the flowing streams to trap the heavy metals from the mining sites, the lowest value of heavy metal recorded at the upstream is due to no influence of mining activities. These relative enrichments agree with the observations of Ezeh (2007) that sediments often hold more than 99 percent of total amount of metals present in aquatic system. Changes in the properties of overlying water column would cause dissolved heavy metals to precipitate and accumulate in the sediments (Ezeh and Chukwu, 2011). The danger here is that the sediments and mine dumps also serve as a pool that can release the heavy metals into the water columns by various processes of remobilization (Fauzi, 2014) thereby rendering them available for intake by biological systems. High levels of heavy metals are a nuisance to the aquatic environment due to their toxicity and adverse effects on both plants and animals including human beings (Sule, 2011). In particular, acute exposure to high concentration of heavy metals can kill organism directly, while long term exposures to lower acidic nature of the water is bound to impact negatively on the ecosystem. In particular, the acid polluted waters are bound to cause ample stress for fish and other aquatic biota (Mahipal et al., 2016). Pollution of water at the downstream is due to high human influences at the downstream, most especially high level of open defecation, the study implies that water at the downstream is not portable for human consumption.

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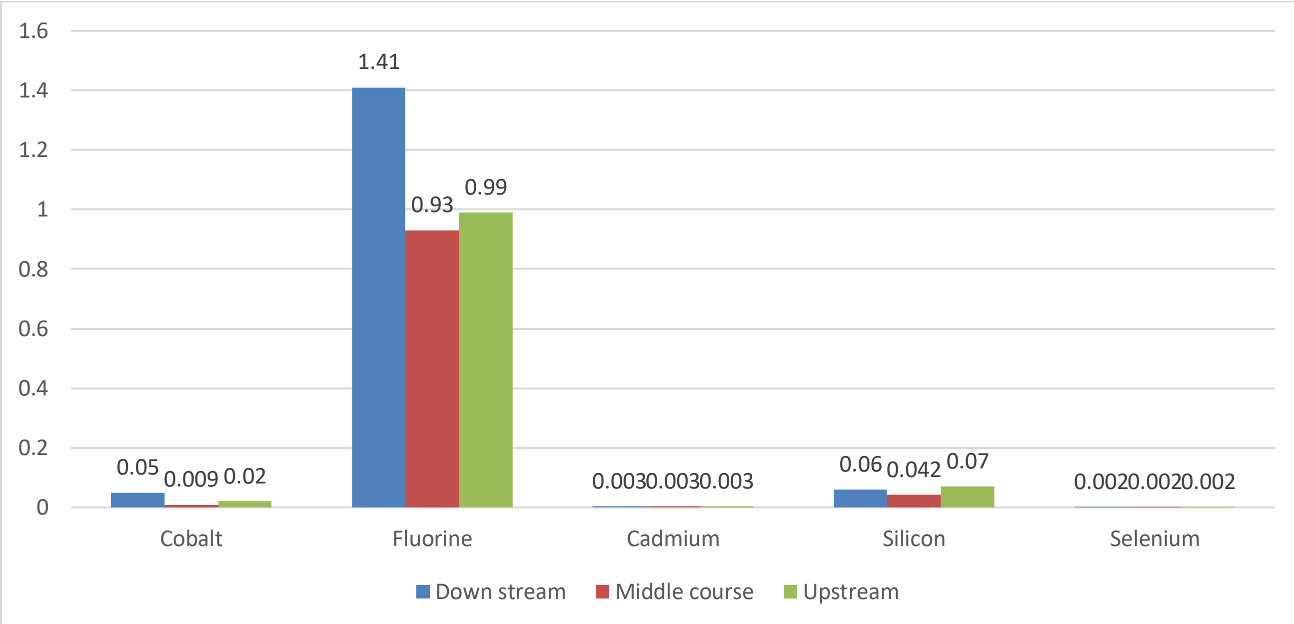

Fig 3: Heavy Metal Content of Water in Rainy Season of the Surface Water
Source: Author's Field work, 2023.

➢ *Underground Water Quality in the Rainy Season in the Study Area*

Figure 4, shows the highest value of cobalt (0.075mg/l) as indicated above is higher than value recorded by Seini and Okparaku (2021) of 0.002, fluorine (0.97mg/l) lower than the value recorded by Sikakwe et al., (2016) of 1.03, the fluorine concentration in the waters is slightly higher than 0.5 in all locations. This contradicts the observations of Singh *et al*. (1998) that fluorine (F) ion rarely exceeded 0.2mg/l in mine water, it therefore implies that mining activities could increase amount of fluorine in water. The cadmium value (0.003mg/l) recorded in borehole two (BH2) is higher than value recorded by Seini and Okparaku (2021) of 0.002, while copper (0.005mg/l) is higher than value recorded by Seini and Okparaku (2021) of 0.001, silicon (0.06mg/l), selenium (0.072mg/l) are recorded in the borehole water one (BH1).

The finding reveals that this borehole water is polluted with different level of heavy metal concentrations depending on their various degrees of chemical properties. This implies that those who consume this water are at risk of heavy metal pollutants and at risk of health impact of heavy metal accumulation in their body systems.

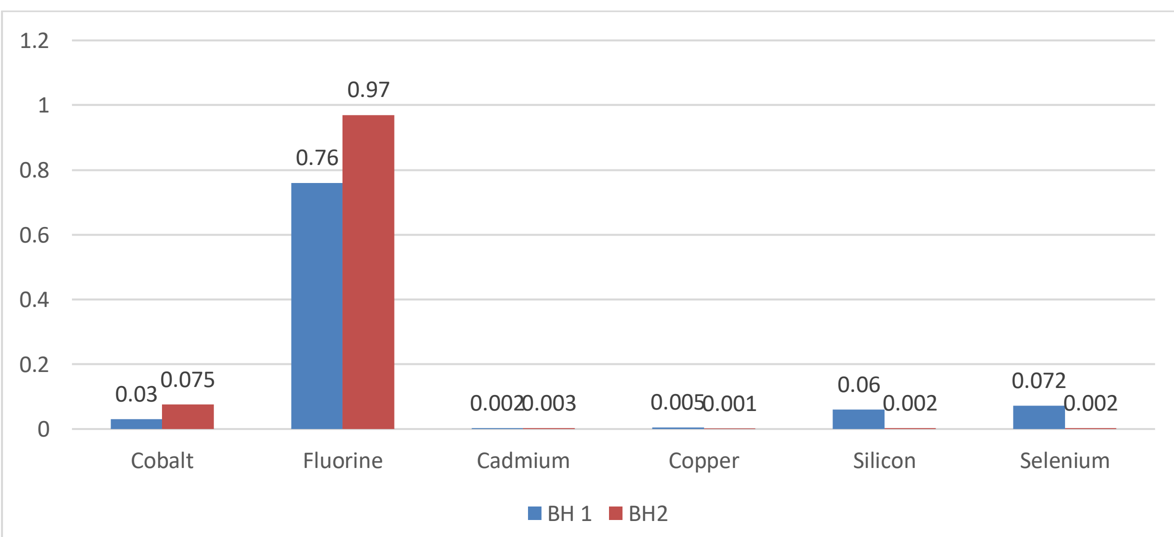

Fig 4: Heavy Metal content of Water in Rain Season of the underground water
Source: Author's Field work, 2023.

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➢ *The Suitability of Water for Human Consumption*

The result revealed that water collected at almost all the sampling points are acidic and are below standard set by Federal Ministry of Environment (FME) of 6-9 and World Health Organization (WHO) of 6.5-9.5 except for water sample collected at upstream for dry season (6.04) and rainy season (6.22). Even though they are below the standard limit of WHO and FME, too much acidic condition of any given environmental settings may not inhibit the sodium level of any living organisms as they are vital for life supports.

The value of total dissolved solids (TDS) in the water ranged from 18.9 to 358 which are below FME (500) and WHO (1000) standard suggestive of normal allowable limits.

The value of Total Hardness shows that its value for dry and rainy seasons in downstream (346 and 350) and middle courses (492.1 and 500.1), borehole one (64.5 and 65.0) and borehole two (111.6 and 115.0) respectively are above WHO set standard of 30, except for that of upstream which is (29.9 and 30.0).

The study revealed the values obtained for all sampling sites for phosphate, sulphate, electrical conductivity, sodium, potassium, cobalt; fluorine, cadmium, copper, silicon and selenium are all within FME and WHO safety standard for water consumption. This revealed that water from middle course, downstream, boreholes are acidic which can be as a result of heavy metal ingestion from the mining sites especially as it flows through acid polluted water. Also, the pH value increases from upstream to downstream water sources; the runoff pH slightly affected the water pH at the point of discharge with a slight increase downstream. The study confirms the assertion by Carlson, & Adriano, (1993) that impact of coal ash leachates on receiving waters, apart from increased elemental concentrations cause changes in water pH with implications for trace element mobility. The findings revealed that that thou, the values are within FME and WHO limit, the high pH value and concentration of heavy metal like Potassium, cobalt silicon and selenium makes it unsuitable for consumption.

Table 1: Water Quality of the Study Area Showing the Elemental Compositions of the Sampled Water

S/N	**Parameters**	**Down stream**		**Middle course**		**Upstream**		**BH 1**		**BH2**		**FME**	**WHO**
		Dry Season	Rainy Season	**Dry Season**	Rainy Season	**Dry Season**	Rainy Season	**Dry Season**	Rainy Season	**Dry Season**	Rainy Season		
1	pH	2.14	2.39	4.11	4.45	6.04	6.22	5.22	5.22	5.09	5.23	**6-9**	6.5-9.5
2	Turbidity	28.1	30.0	88.2	97.1	24.1	24	4.87	5.07	4.76	5.54	-	
3	D.O	5.27	5.85	65.10	6.30	4.86	5.26	5.15	6.65	6.09	6.54	**7.5**	
4	TDS	289	358	94.6	99.0	18.9	20.0	75.7	76.0	176.8	179.0	**500**	1000
5	T Hardness	346	350	492.1	500.1	29.9	30.0	64.5	65.0	111.6	115.0	-	30
6	Phosphate	0.013	0.015	0.009	0.011	0.008	0.014	0.002	0.002	0.002	0.003	6.5 – 8.5	0.05
7	Sulphate	10.1	10.7	4.90	5.10	5.87	6.07	5.89	6.70	0.02	0.07	**100**	250
8	Conductivity	813	837	202	222	291	397	141.2	169.8	401	407	1000	1000
9	Sodium	2.054	2.194	2.111	2.216	10.07	11.29	7.316	7.326	10.11	11.31	200	200
10	Potassium	5.132	5.492	4.819	5.209	5.181	6.850	2.109	2.157	6.081	6.800	-	-
11	Cobalt	0.038	0.050	0.006	0.009	0.010	0.020	0.022	0.030	0.055	0.075	-	-
12	Fluorine	1.280	1.410	0.820	0.930	0.948	0.990	0.691	0.760	0.794	0.970	1.5	
13	Cadmium	0.002	0.003	0.002	0.003	0.002	0.003	0.001	0.002	0.003	0.003	<1 (*) 0.02 (**)	0.003
14	Copper	ND	ND	ND	ND	ND	ND	0.004	0.005	0.001	0.001	0.1	0.5
15	Silicon	0.040	0.060	0.024	0.042	0.047	0.070	0.058	0.060	0.001	0.002	-	-
16	Selenium	0.002	0.002	0.002	0.002	0.002	0.002	0.058	0.072	0.002	0.002	-	-

Source: Author’s Field work, 2023.

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IV. CONCLUSION AND RECOMMENDATION

This study assessed the seasonal occurrence of heavy metals in surface water and groundwater within the Okaba-Odagbo coal mining community and evaluated the suitability of these water sources for human consumption. The findings demonstrate that coal mining activities have significantly influenced the quality of both surface water and groundwater in the study area. Although the concentrations of the analysed heavy metals were generally within the permissible limits recommended by the Federal Ministry of Environment (FME) and the World Health Organization (WHO), noticeable spatial and seasonal variations were observed. For surface water during both the dry and rainy seasons, downstream and middle-course sampling points consistently recorded higher concentrations of heavy metals than upstream locations, indicating the cumulative effects of mine wastewater discharge, runoff, and sediment transport. The relatively lower concentrations observed upstream reflect the absence or minimal influence of mining activities. These findings confirm that mining operations are the principal source of heavy metal enrichment in the aquatic environment and that contaminants are transported downstream through natural drainage processes.

Similarly, groundwater from the boreholes contained detectable concentrations of cobalt, fluorine, cadmium, copper, silicon, and selenium during both seasons, suggesting that mining activities have influenced subsurface water quality through seepage and infiltration. Although the concentrations remain within acceptable regulatory limits, continuous consumption of such water may result in gradual bioaccumulation of heavy metals, thereby increasing long-term health risks to the local population. The study further revealed that most water samples were acidic, with pH values below the recommended standards of the WHO and FME, except for the upstream samples. Acidic water conditions enhance the mobility and availability of heavy metals, thereby increasing their environmental persistence and potential uptake by humans and aquatic organisms. In addition, the high total hardness recorded at the middle course, downstream, and borehole locations further reflects the influence of mining-related geological and hydrochemical processes on water quality.

Although most physicochemical parameters and heavy metal concentrations complied with national and international drinking water standards, the combined effects of acidic pH, elevated hardness, and detectable heavy metals indicate that the water sources cannot be considered entirely safe for long-term human consumption without appropriate treatment. The findings therefore suggest that continued mining activities, if not properly managed, could further degrade water quality and increase ecological and public health risks in the Okaba-Odagbo coal mining community.

RECOMMENDATIONS

- Surface water and groundwater within the Okaba-Odagbo coal mining community should be monitored routinely during both the dry and rainy seasons to detect changes in heavy metal concentrations and physicochemical characteristics before they exceed permissible limits.
- Mining companies should ensure that all mine wastewater and acid mine drainage are adequately treated before discharge into nearby streams and rivers. Appropriate wastewater treatment facilities should be installed and maintained to reduce heavy metal contamination.
- Government agencies and mining operators should provide alternative potable water sources, such as treated municipal water or properly maintained boreholes equipped with water purification systems, to reduce dependence on contaminated surface water.
- Effective acid mine drainage (AMD) control measures, including neutralization systems, constructed wetlands, sedimentation ponds, and proper mine waste management, should be implemented to minimize the release and mobility of heavy metals into surrounding water bodies.
- The Federal Ministry of Environment, National Environmental Standards and Regulations Enforcement Agency (NESREA), and Kogi State environmental authorities should strengthen compliance monitoring and enforce environmental regulations governing mining activities, wastewater discharge, and mine closure practices.
- Regular medical screening should be conducted for residents living within and around the mining community to identify early signs of heavy metal exposure and prevent chronic health effects associated with bioaccumulation.
- Environmental education programmes should be organized to educate community members on the potential health risks associated with consuming untreated water from mining-affected sources and to promote safe water handling and household water treatment practices.
- Degraded mining sites, waste rock dumps, and tailings disposal areas should be rehabilitated through revegetation, proper containment, and erosion control measures to reduce sediment transport and heavy metal leaching into water bodies.
- Future studies should include a broader range of heavy metals (e.g., lead, arsenic, mercury, chromium, nickel, and iron), microbiological parameters, and health risk assessment indices to provide a more comprehensive evaluation of drinking water safety in the mining community.
- Government agencies, mining companies, researchers, and host communities should adopt an integrated watershed management approach that combines pollution prevention, environmental restoration, continuous monitoring, and community participation to ensure the sustainable management and protection of surface water and groundwater resources in the Okaba-Odagbo coal mining area.

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