

## **Anthropogenic Effects of Coal Mining on Water Resources in Parts of Northern Anambra Basin, North–central, Nigeria**

KIZITO O. MUSA<sup>1</sup>, FABIAN A. AKPAH<sup>1</sup>, ERNEST O. AKUDO<sup>1</sup>, JAMILU B. AHMED II<sup>1</sup>,  
ATABO N. ODOMA<sup>1</sup>,  
MARY M. SHAIBU<sup>1</sup>, CHANGDE A. NANFA<sup>1</sup>, JACOB B. JIMOH<sup>1</sup>, MICHAEL S.  
IKUEMONISAN<sup>1</sup>, BINTA MUSA<sup>1</sup>,  
ANSELM O. OYEM<sup>2,3\*</sup>

<sup>1</sup>Department of Geology  
Federal University Lokoja  
PMB 1154, Kogi State  
NIGERIA

<sup>2</sup>Department of Mathematics  
Federal University Lokoja  
PMB 1154, Kogi State  
NIGERIA

<sup>3</sup>Department of Mathematics  
Busitema University  
P.O. Box 236, Tororo  
UGANDA

\*Corresponding Author: [anselmoyemfulokoja@gmail.com](mailto:anselmoyemfulokoja@gmail.com)

**Abstract:** - The coal mining activities within the study area have produced high concentrations of potentially toxic elements with acidity in the water resources leading to pollution and environmental degradation. This paper considers evaluating the level of contamination of most of these potential toxic elements through the determination of physical parameters, and chemical and heavy metal concentrations in water using standard fields and laboratory methods such as an auto meter from Hanna Instruments, the Atomic Absorption Spectrophotometer (AAS), and the Hach DR/2010 spectrophotometer. The results show the mean concentration values of 0.0225mg/l, 0.048mg/l, 0.6346mg/l, 0.0359 mg/l, 0.2506mg/l, 0.0476mg/l, 0.00125mg/l, and 0.7295mg/l for Al, Cd, Cr, As, Fe, Pb, Hg, and Zn, respectively. The mean concentrations of heavy metals in the water samples occur in decreasing order as,  $Zn > Cr > Fe > Cd > Pb > As > Al > Hg$ . The results also reveal the presence of high anthropogenic concentrations of potentially toxic elements such as Zinc (Zn), Chromium (Cr), Iron (Fe), Lead (Pb), Sulfate (SO<sub>4</sub>), and total dissolved solids while, low pH (acidic) values suggests that the water is acidic and of high health risk to humans.

**Key-Words:** - Environmental impact, Heavy metal, Groundwater, Spectropotometer, Hydrogeochemical, Degradation

Received: April 27, 2024. Revised: September 18, 2024. Accepted: October 21, 2024. Published: November 7, 2024.

## 1 Introduction

The industrialization effect and mining activities have always been a threat to the sustainability of a globally friendly environment. Fossil fuel combustion is a key indicator of environmental pollution, degradation, and climate change, [1], [2], [3]. Coal has been proven to be a major source of electricity and is globally used for the generation of heat. The undesirable consequence of arbitral mining of coal is of serious concern due to the high acidity level of natural water bodies resulting from increased heavy metal contamination, [4], [5], [6]. Mining activities directly impact the environment, specifically public health, which can be felt at a long distance from the cause over some time, [7]. Majority of low-income people, estimated at over a billion in total population, are affected globally by contaminated water yearly, [8], [9], [10], [11], [12], [13], [14].

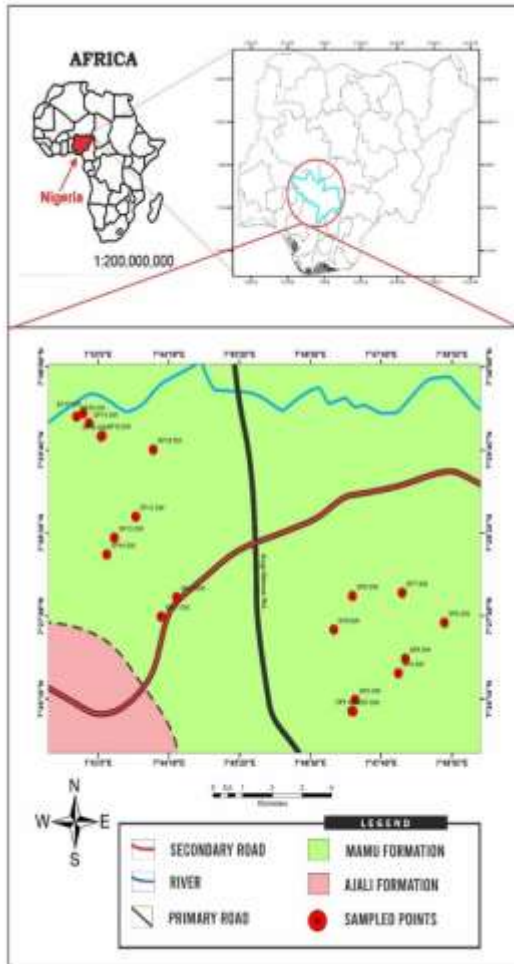
Portable water is essential to all living things and is mainly used for both domestic and industrial purposes, [15], [16], [17]. As it percolates through the surface water and groundwater runoff to the subsurface groundwater, it carries along impurities that, when consumed by rural dwellers without due consideration for their chemical and biological composition, could lead to adverse consequences, [18], [19], [20]. Recently, during the commemoration of World Water Day in 2023, UNICEF raised concerns in Nigeria. An estimated 70% of the water at the point of consumption has been contaminated, which has caused Nigeria to have about the world's highest number of deaths from waterborne diseases among children under five years old. Consequently, UNICEF estimated the number of children who die yearly in Nigeria due to the consumption of contaminated water at 117,000. Pit dewatering occurs during the coal mining process, which might lead to dry springs and ecosystem degradation at the regional level. The environmental impacts in arid and semi-arid regions can be more severe if no precautionary measure is taken. The environmental impacts include an imbalance between the demand and supply of water and water quality issues. Water quality degradation, irrigation water degradation,

biodiversity, and soil quality issues are some other impacts of coal mining, which directly impact agricultural productivity and human health, [21], [22].

Recently, the demand for coal as a source of energy by the major cement companies in Nigeria has led to the discovery and increased intensity of shallow coal mining activities in the study area. Some of the coal mines within the study area spread across the Okaba, Okobo, and Awo Akpali communities. Most companies involved in this arbitrary mining activity are channeling their waste dumping sites into the existing streams and groundwater flow channels, polluting the only available source of potable water supply and creating a high level of environmental degradation in these host communities. The higher concentration of potentially toxic elements in the water is assumed to be anthropogenic rather than natural because the area is heavily mined for coal. Therefore, this research is aimed at investigating the rate of pollution caused by the mine waste contaminants through runoff pathways, with emphasis on the high acid content, influences of the ionic characteristics, and high concentration of potentially toxic elements on the water resources and environment within the research area. This is to establish the level of contamination to further protect the lives of children, women, and adults from pollution-related diseases. Also, it can serve as a baseline study for sustainable planning and development of environmentally friendly coal mining activities.

## 2 Description of the Area

The area is part of the Northern Anambra Basin, which comprises selected coal mining sites within Ankpa and its environs in north-central Nigeria. It falls within Latitude N07°23'30" to N07°29'00" and Longitude E07°45'00" to E07°48'45". The major coalfields are found in the Okaba, Awo Akpali, and Okobo communities. These areas are accessible by trunk B roads; they are also accessible by other minor roads and footpaths. However, mining companies restrict access to most of the mining sites as shown in Fig. 1.



**Fig. 1.** Geologic map of the study area showing the sampling points

The climate of the study area is generally tropical, wet, and dry, [23]. The areas are mostly flat lands towards the west and vast undulating plains mixed with gently sloping hills to the east. The topography of the hills ranged between 200 and 300 meters high. The vegetation is mostly guinea savanna, which is composed of grass savanna and deciduous trees. Human activities like agriculture, mining, and deforestation have led to mainly derived savanna.

Geologically, the Anambra Basin is linked to the formation of the Benue Rift, which emerged as a supercontinent, and the Jurassic opening of the southern Atlantic and Indian Oceans, [24]. [25], reported that the alluvial fans and lacustrine deposits of the Mamfe Formation in the Southern Benue Trough contained the first syn-rift sedimentation, which took place during the

Aptian–early Albian period. Mudrocks, sandstones, and limestones with an estimated thickness of 3,500 meters were filled in this ancestral trough by two cycles of marine transgressions and regressions from the middle Albian to the Coniacian. These sediments belong to the Asu River Group (Albian), the Odukpani Formation (Cenomanian), the Ezeaku Group (Turonian), and the Awgu Shale (Coniacian). The Anambra Basin and the Afikpo Sub-basins simultaneously subsided to the northwest and southeast of the folded belt, respectively, during the Santonian epeirogenic tectonics, causing these sediments to undergo folding and uplift into the Abakaliki-Benue Anticlinorium, [26]. Later on, the Abakaliki Anticlinorium functioned as a point of dispersal for sediments that were moved into the Afikpo Syncline and the Anambra Basin. The Oban Masif, the southwestern Nigeria basement craton, and the Cameroon basement complex also served as sources for the sediments of the Anambra Basin, [27]. The Nsukka Formation marks the beginning of the Nsukka cycle, which is thought to represent a fluvio-deltaic phase of deposition. With the deposition of the Imo Shale, which is thought to be a shallow marine shelf deposit, this cycle came to an end. The Eocene retreat began with the deposition of the Ameki Group and its laterally similar Nanka Formation. The Anambra Basin's depositional patterns were significantly influenced by several elements, including the basin's form, the proximity of sediment source locations, transgression and regression cycles, and paleo-circulation patterns, [28].

### 3 Methodology

Within the study area, twenty (20) random surface and groundwater samples were taken from various locations (Table 1). For each location, a single-liter plastic bottle was used to take the samples, which were then kept in plastic beakers. Before the field sampling, the beakers were carefully cleaned and kept in distilled water that had been acidified for three days with 1.0ml of  $HNO_3$ . Surface water was collected from both upstream and downstream regions of flow, while groundwater samples were collected from pre-existing boreholes that had to run for around five minutes before sample collection. After cleaning

the sample bottles with the aliquot, suspended particles were extracted, and disposable 0.45mm diameter filters were used for filtering. To stop heavy metal precipitation and sorption, the samples were then acidified in the field using 1.0ml of pure  $HNO_3$ . The H19835 Auto Ranging HANNA meter gadget was used to measure physical properties such as total dissolved solids (TDS) to ascertain the inorganic content of the water samples. The sample's temperature and pH were measured using a portable pH meter (WGS 84) that was outfitted with temperature electrode accessories. Laboratory analysis of samples was done using the ICP-OES method.

## 4 Results and Discussion

### 4.1 Physicochemical Compositions and Heavy Metal Concentration

Among the twenty (20) samples analyzed in the study area, only seven (7) had pH values that were within the World Health Organization's acceptable limits, [29]. Sample SP-17 has the lowest pH value of 3.59, indicating that most have low (acidic) pH values (Tables 2 and 3). Low pH values signify the influence of possibly acidic lateritic soil, acid mine drainage, forestry activity, and humus soil, [30], [31], [32]. This is caused by high acidity, which can give the water a sour taste and make it corrosive. The total hardness values ranged between 0.7mg/l and 27.3mg/l, with a mean value of 5.98mg/l. All the water samples exhibit a concentration of hardness below the standard permissible limits of 500mg/l. This suggests that the water is soft even though the hardness is beneficial because people who live in hard-water locations have lower rates of heart disease than people who live in soft-water areas. It also affects the piping and laundry systems in many homes. The values of alkalinity ranged from as low as 36mg/l to as high as 272mg/l, with an average value of 126.7mg/l. Most of the analyzed water has an alkalinity level below the 200mg/l standard acceptable limit. In Samples SP-2 and SP-13, alkalinity falls slightly above the permissible limit, with values of 202mg/l and 272mg/l respectively. This can be linked to the source of this water sample, especially as the majority of

groundwater samples collected from the research region may have come from the rock's mineral components dissolving. The vertical distribution for each of the physical parameters examined in the research region is displayed in Fig. 2.

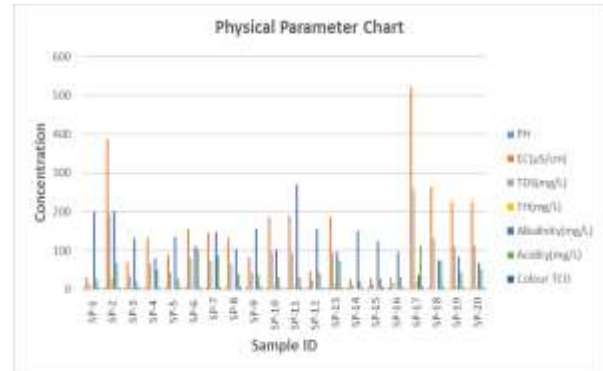


Fig. 2. Bar chart of physical parameters

The electrical conductivity (EC) values ranged from 27.0µS/cm to 520µS/cm, with an average of 158.15µS/cm (Tables 2 and 3). Except for sample SP-17, which displays values of 520µS/cm, well above the recommended 400µS/cm acceptable limit (Figure 3), [29]. Also, sample SP-2, with values of 388µS/cm, shows a very close tendency to the permissible limit. These values above indicate contamination from coal mining activities because of the increased impurities in the water, which can lead to health challenges if the water is consumed without treatment (Table 4).

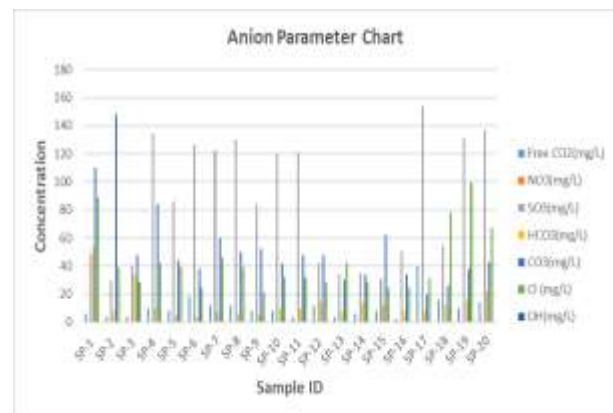
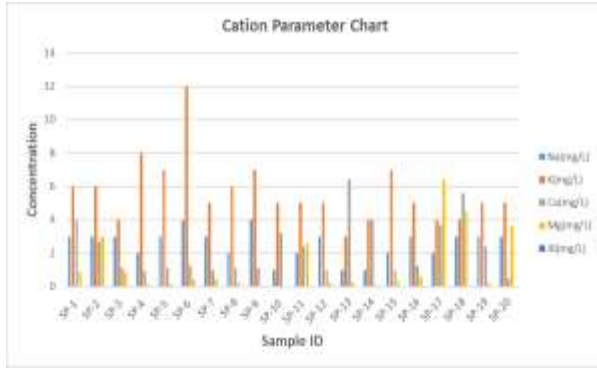


Fig. 3. Bar chart showing the concentrations of anions

According to [33], [34], Chloride ( $Cl$ ) analysis in the study of water quality is of major importance because it helps in understanding the link between water and pollution. The values of chloride concentration varied from  $21.27mg/l$  to  $99.26mg/l$ , with a mean value of  $42.87mg/l$  which, fell short of what the [29] recommends for the safe use of water. When assessing the quality of groundwater, two important anion measurements are bicarbonate ( $HCO_3^-$ ) and carbonate ( $CO_3^{2-}$ ). According to [35], geogenic and anthropogenic activities are typically responsible for changes in  $HCO_3^-$  and for regulating the alkalinity of groundwater. Within the area, the bicarbonate ( $HCO_3^-$ ) values varied from  $4mg/l$  to  $54mg/l$ , with an average value of  $13.41mg/l$ , while the carbonate ( $CO_3^{2-}$ ) values ranged from  $20mg/l$  to  $148mg/l$ , with an average value of  $13.41mg/l$ . This number is below the top limit set by, [29], indicating that there are little to no effects of geogenic and human activity on the water in the study area. Sulfate ( $SO_4^{2-}$ ) values within the study area ranged from  $29.5mg/l$  to  $153.8mg/l$ , with a mean value of  $85.6mg/l$  which is below the permissible limits, and implies the water is safe for drinking and domestic uses. According to [36], high concentrations of  $SO_4^{2-}$  in groundwater may cause health-related illnesses such as dehydration, catharsis, gastrointestinal irritation, and diarrhea. According to, [37], [38], organic matter from man-made pollution, such as agricultural fertilizers, is a major source of  $NO_3^-$  in water. The concentration of nitrite ( $NO_3^-$ ) ranged from  $0.009mg/l$  to  $0.143mg/l$ , with an average of  $0.0352mg/l$ . This value falls below the drinking water threshold, indicating that the water is safe to drink. The distribution of all the anions under study is displayed in Fig. 3. According to, [39], [40],  $Na^+$  is one of the most predominant elements in natural water, with larger concentrations found there. If it is found occurring in high concentrations in the potable water supply, patients with heart, kidney, or circulation disorders who consume this water are negatively affected.  $Na^+$  concentration within the area ranged between  $1.0mg/l$  and  $4.0mg/l$ , with a mean value of  $2.55mg/l$  (Tables 1 and 2). This value is below the safe drinking water standard set by, [29]. The high levels of rock-

water interaction in the area are the main reason for the  $Na^+$  presence in the groundwater. This is partially because the surface water is used for the bulk of samples and the metal's concentration suggests little to no rock-water interaction.

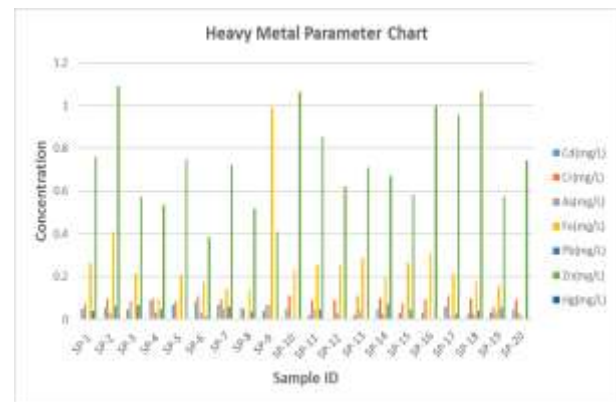
The Potassium ( $K^+$ ) concentration within the area ranged between  $3.0mg/l$  and  $12.0mg/l$ , with  $5.65mg/l$  as the average (Tables 1 and 2). This value is below the safe drinking water standard set by, [29]. While  $K^+$  is thought to be a necessary element for both plants and animals, its high concentration, above the [28] permissible standard, could be harmful to the human nervous and digestive systems, [38], [40]. Tables 1 and 2 show that the mean magnesium ( $Mg^{2+}$ ) concentration in the samples analyzed within the area was  $1.2443mg/l$ , with a range of  $0.0224mg/l$  to  $6.4064mg/l$ . This value is lower than what the [28] recommends. Rock-water interactions or mineral disintegration are the usual causes of high concentrations of this metal. The calcium ( $Ca^{2+}$ ) concentration in the analyzed water sample within the area ranged between  $0.481mg/l$  and  $6.413mg/l$ , with a mean value of  $2.289mg/l$  (Tables 1 and 2). This value falls below the, [29], recommended threshold for safe drinking water. The concentration of aluminum ( $Al^{3+}$ ) in water within the area ranged between  $0.01mg/l$  and  $0.03mg/l$ , with mean value of  $0.02mg/l$  (Tables 1 and 2). The majority of the analyzed water samples from SP- 4, 8, 9, 10, 13, and 15 had values that were greater than the permissive level for drinking water. Anthropogenic activities in water are the reason for the high concentration of aluminum, which can lead to health problems and impact most body organs, including the brain, parathyroid gland, kidney, lungs, liver, and bones. Therefore, the water from this area needs to be sufficiently treated to save the lives of the locals as well as the animals. Fig. 4 shows the variation of major cations analyzed within the area.



**Fig. 4.** Bar chart showing the concentrations of cations

Water samples were analyzed for heavy metals, such as Arsenic (*As*), Iron (*Fe*), Manganese (*Mn*), Zinc (*Zn*), Lead (*Pb*), Cadmium (*Cd*), and Mercury (*Hg*). These elements are continuously released into water bodies by the chemical weathering of rocks and minerals. When present in high concentrations, they may be potentially fatal, [41], [42]. Anthropogenic activities resulting from pollution can also increase the concentration of these heavy metals, [43], [44]. In Tables 1 and 2, Lead (*Pb*) concentration in the area ranged between 0.015mg/l and 0.072mg/l, with a mean value of 0.0476mg/l. The concentrations at SP- 5, 10, 12, 13, 15, and 20 were less than 0.001mg/l, which is below the drinking water guidelines specified by [29]. This shows that most of the water samples had values over the threshold, and needed to be treated before consumption to avoid negative effects. The concentration of iron (*Fe*) varied between 0.02mg/l and 0.99mg/l, with a mean value of 0.25mg/l (Tables 1 and 2). At the following locations; SP-1, SP-2, SP-3, 10, 11, 12, 13, and 15, the concentration of Fe surpasses the WHO's allowable limit, [29]. Chromium (*Cr*) concentrations varied from 0.07 mg/l to 0.112 mg/l. These results are higher than the permitted limit (Tables 1 and 2). Cadmium (*Cd*) concentrations at locations SP-, 4, 5, 6, 7, and 8 vary from 0.055 mg/l to 0.088 mg/l, all of which are above the permissible limit. Cadmium (*Cd*) values in SP-4, 5, 6, 7, and 8 varied from 0.055 mg/l to 0.088 mg/l, which is likewise greater than the allowed limit, [29]. The concentration of zinc (*Zn*) in the analyzed water ranged from 0.411 mg/l to 1.092 mg/l. These

values surpass the acceptable threshold of, [29]. The concentration of mercury (*Hg*) within the area ranged between 0.001 mg/l and 0.002 mg/l, with a mean value of 0.001 mg/l. Figure 5 depicts the vertical spread of these heavy metal concentrations. Pearson correlation analysis describes the interactions between the various hydrogeochemical parameters in groundwater. [45], [46], reported that a stronger correlation is shown by a correlation coefficient of more than 0.7, whilst a moderate correlation is shown to be between 0.5 and 0.7. Similarly, *EC* and *TDS*, *EC* and *TH*, *EC* and *Mg*, *TDS* and *TH*, acidity and *CO<sub>2</sub>*, *Mg*, and *NO<sub>3</sub>*, have stronger correlation coefficients, as *Pb* and *EC*, *Pb* and *TDS*, *Pb* and *Mg*, *Pb* and *SO<sub>3</sub>*, *EC* and acidity, *EC* and *CO<sub>2</sub>*, *EC* and *NO<sub>3</sub>*, *TDS* and acidity, *TDS* and *NO<sub>3</sub>*, *TH* and *Mg*, *TH* and *NO<sub>3</sub>*, acidity and *Mg*, *CO<sub>2</sub>* and *Mg* and *CO<sub>2</sub>* and *SO<sub>3</sub>* have moderate correlation coefficients as shown in Fig. 5.



**Fig. 5.** Bar chart of heavy metal concentrations

#### 4.2 Hydrochemical Facies

According to, [47], combining graphical and statistical techniques is a reliable, unbiased tool used in the classification of a large number of samples. To determine the hydrochemical makeup of the water samples and to understand other factors affecting the water in the area, a Piper trilinear diagram was utilized, [48]. Figure 6 shows the hydrochemical facies of water samples in the study area, which have mixed types of sodium chloride, calcium sulfate water, and sodium bicarbonate in decreasing order. The area's predominant hydrochemical facies is sodium chloride as a result of mining and

agricultural activities. The plot also showed that strong acid base ( $SO_4^{2-} + Cl^-$ ) outweighs weak acids ( $CO_3^{2-} + HCO_3^-$ ) within geochemical zone 4, which contains 80% of the water samples. The Durov diagram further collaborates with the findings of the Piper pattern in Fig. 7 while the Scholler diagram shows the order from the highest to the lowest concentrations of the elements. The hydrochemical trend of groundwater is  $SO_4 > Cl > HCO_3 > K > Na > Mg$  as displayed in Figure 8. The result shows that sulfate acid weathering is more prevalent than carbonic acid weathering within the area.

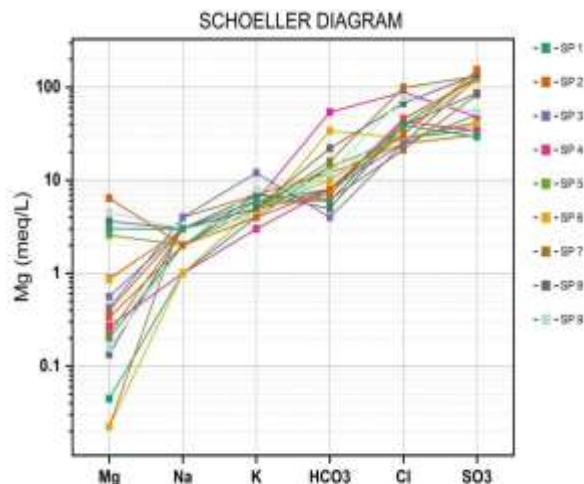


Fig. 8. Schoeller diagram from the sample points.

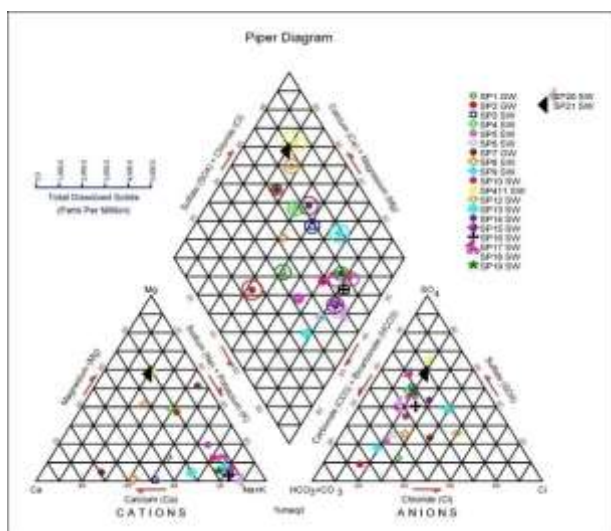


Fig. 6. Piper trilinear diagram showing the water facies

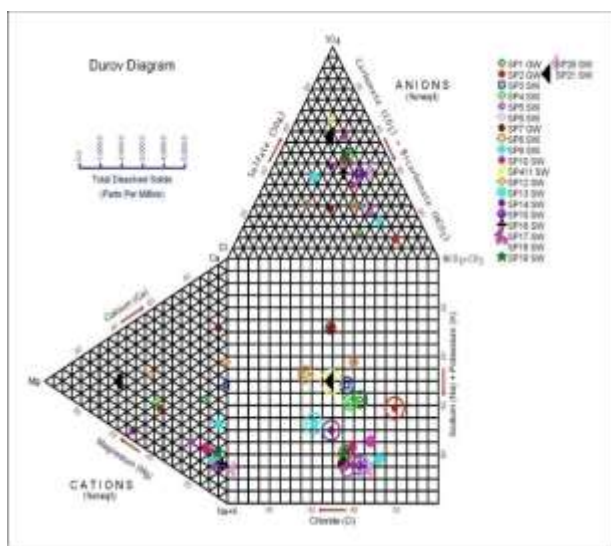


Fig. 7. Durov diagram

### 5 Conclusion

There is a significant increase in anthropogenic concentrations of potentially toxic elements, mostly heavy metals (*Cd, Fe, As, Pb, Zn, Cr, Al, and Hg*) as compared to the acceptable threshold, [28]. The concentration value for most of the physical parameters, cations, and anions (electrical conductivity, total dissolved solids, total hardness, alkalinity, chloride, potassium, sodium, magnesium, bicarbonate, hydroxide, nitrate, and sulfate) fall within the permissible limits. However, in most cases, the concentration values continue to increase with the increase in the intensity of coal mining. The values of concentration for pH, *Al*, and all the heavy metals fall above the permissible range. The hydrogeochemical facies showed  $Na^+$  and  $K^+$  as the dominant ionic species for cations while  $SO_4^{2-}$  and  $Cl^-$  are the dominant ionic species for anions. The sodium/potassium chloride water is dominant due to the excessive use of fertilizers and landfill leachate. The area is characterized by notable concentrations of strong acids due to the increased mining activities and the presence of high anthropogenic concentrations of potentially toxic elements. These low pH (acidic) values in the analyzed water samples suggest that the water is acidic and is of high health risk to humans. Also, when the organic material breaks down, it can release carbonate ions into the water; hence,

the presence of carbon dioxide ( $CO_2$ ) indicates the presence of anthropogenic sources.

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**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

**Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself**

No funding was received for conducting this study.

**Conflict of Interest**

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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**Table 1.** Sampling Points Within the Study Area

Samples No.	Location	Coordinates	
		Latitudes	Longitudes
SP1 GW	Awo Akpali	07°26'01.55"N	007°47'11.7"E
SP2 GW	Awo Akpali	07°26'01.3"N	007°47'12.9"E
SP3 SW	Awo Akpali	07°26'10.8"N	007°47'14.9"E
SP4 SW	Awo Akukunda	07°26'33.0"N	007°47'57.2"E
SP5 SW	Awo Akukunda	07°26'45.0"N	007°48'05.0"E
SP6 SW	Awo Akukunda	07°27'15.0"N	007°48'42.3"E
SP7 SW	Awo Akukunda	07°27'39.8"N	007°48'01.0"E
SP8 SW	Awo Akpolokuta	07°27'09.2"N	007°46'54.1"E
SP9 SW	Awo Akpolokuta	07°27'37.2"N	007°47'12.3"E
SP10 SW	Okaba	07°27'36"N	007°44'20"E
SP11 SW	Okaba	07°27'20"N	007°44'05"E
SP12 SW	Okaba	07°28'43"N	007°43'40.1"E
SP13 GW	Okaba	07°28'25.4"N	007°43'19.2"E
SP14 SW	Okaba	07°28'11.6"N	007°43'11.7"E
SP15 SW	Okobo	07°29'49.7"N	007°43'06.4"E
SP16 SW	Okobo	07°29'50.2"N	007°43'07.3"E
SP17 SW	Okobo	07°30'08.8"N	007°42'48.6"E
SP18 SW	Okobo	07°29'38.7"N	007°43'57.3"E
SP19 SW	Okobo	07°30'0.57"N	007°42'54.5"E
SP20 SW	Okobo	07°30'06.01"N	007°42'42.2"E

**Table 2.** Physio-Chemical Parameters and Heavy Metals Concentrations Compared with WHO (2017) Standard Limit

Parameters	W.H.O	SP-1	SP-2	SP-3	SP-4	SP-5	SP-6	SP-7	SP-8	SP-9	SP-10	SP-11	SP-12	SP-13	SP-14	SP-15	SP-16	SP-17	SP-18	SP-19	SP-20
Ph	6.5-8.5	5.6	6.5	6.5	6.26	6.62	6.23	6.09	6.26	6.54	4.22	4.64	6.54	6.03	6.47	6.68	6.89	3.59	4.14	3.96	3.93
EC(μS/cm)	400	31	388	70	134	89	155	147	134	84	186	190	48	187	27	29	30	520	264	224	226
TDS(mg/L)	500-1000	16	194	35	67	44	80	74	67	43	97	95	24	94	12	14	15	257	132	110	113
TH(mg/L)	500	5.7	27.3	4.4	1.3	1.3	2.7	2.4	1.6	0.8	6.3	9	1.5	13.8	0.7	2.1	1.4	20.1	2.1	8.8	6.3
Alkalinity(mg/L)	200	200	202	132	80	136	112	148	104	156	104	96	156	272	152	124	96	36	76	84	68
Acidity(mg/L)	200	28	68	20	52	28	104	88	40	36	32	32	44	72	20	28	32	112	72	44	52
Free CO <sub>2</sub> (mg/L)	<30	5.99	4.00	4.00	9.99	7.99	17.98	11.99	11.99	7.99	7.990	3.995	11.986	3.995	5.993	8	2	40	16	10	14
Colour TCU	15	5	5	5	5	5	5	5	6	6	5	5	5	5	4	6	5	6	7	5	5
Na(mg/L)	200	3	3	3	2	3	4	3	2	4	1	2	3	1	1	2	3	2	3	3	3
K(mg/L)	12	6	6	4	8	7	12	5	6	7	5	5	5	3	4	7	5	4	4	5	5
Ca(mg/L)	100	4.008	2.7254	1.1222	0.962	1.122	1.283	0.962	1.122	1.122	3.206	2.405	0.961	6.413	4.008	0.962	1.222	3.687	5.611	2.405	0.481
Mg(mg/L)	150	0.8736	3.024	0.8512	0.1568	0.1344	0.4256	0.403	0.2016	0.0224	0.0224	2.576	0.224	0.2688	0.0448	0.336	0.56	6.4064	4.5024	0.224	3.6288
NO <sub>3</sub> (mg/L)	50	0.021	0.095	0.028	0.025	0.020	0.013	0.011	0.009	0.011	0.009	0.009	0.023	0.057	0.012	0.014	0.024	0.090	0.050	0.040	0.143
SO <sub>4</sub> (mg/L)	250	48.3	29.5	39.7	134.3	86.2	126.6	122.5	130.1	83.7	120.6	121.0	42.1	34.2	35.1	30.7	50.7	153.8	54.6	131.3	137.3
HCO <sub>3</sub> (mg/L)	125-350	54	8	34	10	5	4	7	6	6.2	10	10	14	8	14	12	8	8	12	16	22
CO <sub>3</sub> (mg/L)	250	110	148	48	84	44	38	60	50	52	42	48	48	30	34	62	34	20	26	38	43
Cl (mg/L)	250	88.63	39.00	28.36	42.54	39.00	24.82	46.09	39.00	21.27	31.91	31.91	28.36	42.54	28.36	24.82	24.82	31.36	77.99	99.26	67.36
OH(mg/L)	0.003	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	0.7	0.4	ND	ND
Cd(mg/L)	0.03-0.05	0.05	0.057	0.046	0.088	0.069	0.087	0.069	0.055	0.039	0.049	0.02	<0.001	0.02	0.045	0.03	0.03	0.058	0.026	0.035	0.046
Cr(mg/L)	0.01	0.072	0.1	0.085	0.1	0.086	0.112	0.094	0.051	0.07	0.11	0.091	0.093	0.112	0.099	0.075	0.092	11	0.1	0.059	0.092
As(mg/L)	0.3	<0.001	0.032	<0.001	0.034	<0.001	0.029	0.05	<0.001	0.067	<0.001	0.049	0.028	0.043	0.028	<0.001	<0.001	0.015	0.026	0.037	0.029
Fe(mg/L)	0.2	0.263	0.41	0.217	0.1	0.21	0.172	0.149	0.138	0.99	0.233	0.254	0.25	0.288	0.195	0.264	0.31	0.217	0.176	0.157	0.02
Al(mg/L)	0.01	<0.01	0.01	0.03	0.01	0.01	<0.01	0.02	0.02	0.03	<0.01	<0.01	<0.01	0.03	<0.01	0.03	0.03	<0.01	<0.01	0.02	0.03
Pb(mg/L)	0.01-3	0.039	0.062	0.065	0.05	<0.001	0.015	0.059	0.038	0.048	<0.001	0.048	<0.001	<0.001	0.072	0.046	<0.001	0.028	0.04	0.057	<0.001
Zn(mg/L)	0.01	0.758	1.092	0.575	0.534	0.751	0.386	0.72	0.52	0.411	1.064	0.854	0.623	0.71	0.67	0.584	1	0.954	1.064	0.578	0.742
Hg(mg/L)	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	0.002	<0.001	<0.001

Note: Values above WHO (2017) standard are highlighted in bold, while others within WHO (2017) standard are highlighted in italics, and all others are below WHO (2017) permissible limits.

**Table 3.** Statistical Values of Physiochemical Parameters and Heavy Metals Compared with WHO Standard Limit, [29]

Parameters	W.H.O	MIN	MAX	MEAN	SD
PH	6.5-8.5	3.59	6.89	5.6845	1.124874
EC (µS/cm)	400	27	520	158.15	126.5923
TDS (mg/L)	500-1000	12	257	79.15	62.91789
TH (mg/L)	500	0.7	27.3	5.98	7.061206
Alkalinity (mg/L)	200	36	272	126.7	54.51518
Acidity (mg/L)	200	20	112	50.2	27.23697
Free CO <sub>2</sub> (mg/L)	<30	2	40	10.29395	8.214856
Colour TCU	15	4	7	5.25	0.638666
Na (mg/L)	200	1	4	2.55	0.887041
K (mg/L)	12	3	12	5.65	1.954078
Ca (mg/L)	100	0.481	6.413	2.28948	1.699512
Mg (mg/L)	150	0.0224	6.4064	1.24431	1.80369
NO <sub>3</sub> (mg/L)	50	0.009	0.143	0.0352	0.035903
SO <sub>4</sub> (mg/L)	250	29.5	153.8	85.615	44.84599
HCO <sub>3</sub> (mg/L)	125-350	4	54	13.41	11.73362
CO <sub>3</sub> (mg/L)	250	20	148	52.95	30.14958
Cl (mg/L)	250	21.27	99.26	42.87	22.49071
OH (mg/L)	0.003	0.3	0.7	0.466667	0.208167
Cd (mg/L)	0.03-0.05	0.02	0.088	0.048368	0.020003
Cr (mg/L)	0.01	0.051	11	0.63465	2.439807
As (mg/L)	0.3	0.015	0.067	0.035923	0.013425
Fe (mg/L)	0.2	0.02	0.99	0.25065	0.192499
Al (mg/L)	0.01	0.01	0.03	0.0225	0.00866
Pb (mg/L)	0.01-3	0.015	0.072	0.047615	0.015819
Zn (mg/L)	0.01	0.386	1.092	0.7295	0.215282
Hg (mg/L)	-	0.001	0.002	0.00125	0.00005

**Table 4.** Water Classification in the Area Based on EC Values

Class of Water	EC (µS/cm)	Sample points
Excellent (C1)	<250	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16
Good (C2)	250-750	3, 17,18,19, 20
Permissible (C3)	750-2000	Nil
Doubtful (C4)	2000-3000	Nil
Unsuitable (C5)	>3000	Nil