

Pollution Status Evaluation and Hydrogeochemical Facies Characterization of Surface and Groundwater Resources in Ishiagu Mining District, Southeastern Nigeria

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ABSTRACT

In this study, the impact of the continued uncontrolled mining of lead-zinc on the nature and quality of water sources in the Ishiagu Mining District of Southeastern Nigeria was evaluated. Fifteen water samples within the proposed influence zone at which the mine tailing can contaminate the water sources were targeted. These include samples collected from natural surface waters and groundwater as well as man-made reservoirs. The collected water samples were subjected to physicochemical analyses to ascertain the presence of possible contaminants. The results of the water sample analysis show that the mean values of pH, electrical conductivity and temperature are 4.09, 1.50 μ s/cm, 27.13 $^{\circ}$ C, 0.09 μ g/l respectively while the bacterial oxygen demand stood at 66.59 mg/l. Also, The chemical parameters- Na^+ , Ca^{2+} , Mg^{2+} , K^+ , Cl^- , HCO_3^- , NO_3^- , SO_4^{2-} and PO_4^{3-} had average concentration values of 186.82 mg/l, 100.56 mg/l, 16.52 mg/l, 5.09 mg/l, 687.95 mg/l, 194.54 mg/l, 1.85 mg/l, 0.90 mg/l and 0.11 mg/l respectively. Five water groups were discriminated based on characterization in the Piper trilinear diagram which include; Calcium-Chloride ($\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{Cl}^- + \text{SO}_4^{2-}$), Magnesium-Bicarbonate ($\text{Ca}^{2+} + \text{Mg}^{2+}$ and HCO_3^-), Sodium-Chloride ($\text{Na}^+ + \text{K}^+$ and $\text{Cl}^- + \text{SO}_4^{2-}$), Calcium-Bicarbonate ($\text{Ca}^{2+} - \text{HCO}_3^-$) and Calcium-Sulphate. These results indicate that the Ishiagu Mining District is hydrochemically acidic due to acid mine drainages resulting from mining activities in the area. The results also reveal that the mining zones serve as water source areas and zones of groundwater recharge. The surface water and groundwater resources in the study area have been directly impacted by mining activities in the area as evident in the results of sodium, sulphate, chloride, nitrate and carbonate which are above the WHO permissible limits for drinking water. This renders the water unsuitable for consumption as they pose serious health risks to human beings.

Keywords: Mining, groundwater, surface water, contamination, lead-zinc

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INTRODUCTION

Nigeria currently ranks as one of the nations with the highest reserve of solid minerals in the world. With a solid mineral reserve of over a billion tones, the exploitation, mining and development of these minerals is integral to the growth of the Nigerian economy. With a projected revenue base of \$27 billion by 2025, the mining industry has a potential of contributing 3% of Nigeria's GDP. However, as resourceful as these minerals are to the Nigerian economy, their exploitation comes with a myriad of environmental and hydrological problems. In most parts of Nigeria where mining activities take place; there has been a rise in recorded cases of public health diseases and carcinogenic infections over the last decades. The surge of these diseases may not be unconnected to mining activities taking place in such areas as basic safety regulations guiding mining activities are completely disregarded during mining. The same applies for mine tailings and other waste products of mining which are disposed indiscriminately to the environment.

This is the case in Ishiagu, Ebonyi state, Southeastern Nigeria, which is well known for its abundance of Pb-Zn deposits. The abundance of these deposits in the area makes it the hub of mining activities in the state. The mining district therefore plays a strategic role in the economy of Southeastern Nigeria; however, concerns have been raised by hydrogeologists about the impact of such mining activities on the quality of natural waters in the area. The flagrant disregard for standard mining regulations and continued indiscriminate disposal of mine tailings has the capacity to pollute the surface waters and infiltrate the groundwater system in the process, rendering them unsafe for human consumption.

Nwaugo *et al.* (2009) and Aluyi *et al.* (2006) in their works agreed that anthropogenic activities such as mining in any given area can influence the water quality in that area. This study therefore aims at evaluating the impact of mining activities in Ishiagu on the quality of water in the area. The potential of heavy metals, organic and inorganic materials from mine tailings to constitute pollutants in the area is high as factors capable of mobilizing and distributing them in the hydrologic system are readily available.

This study will focus on investigating the degree and extent of pollution of natural waters in Ishiagu as well as characterizing the surface and groundwater resources in the area with a view of delineating the dominant water facies in the area.

THE STUDY AREA

Location and Geomorphology

The study area is located between latitude 05°55'00"N to 05°59'00"N and longitude 007°32'00"E to 007°36'00"E (Fig. 1). It covers an area of about 84sqkm with prominent settlements such as Ihie, Ngwogwo, Iyalualu, and Amagu. It belongs to Ivo Local Government area of Ebonyi state and has a population of about 15, 000.

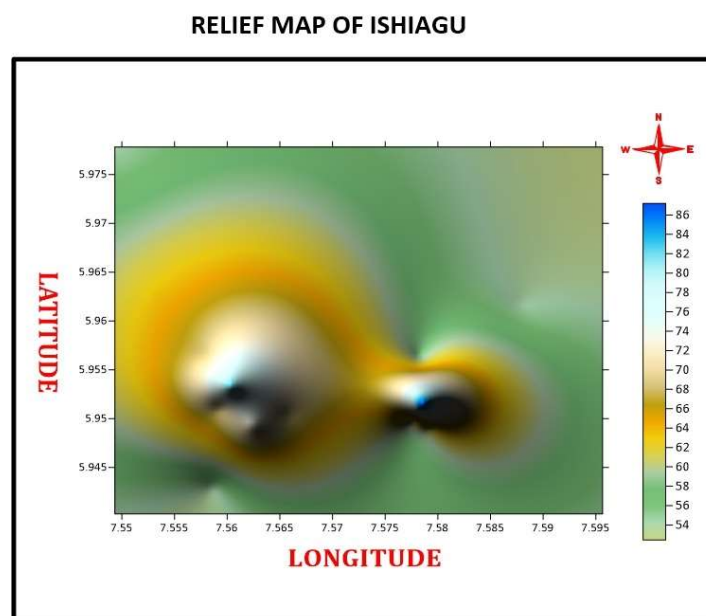


Figure 1: Relief map of Ishiagu

Geomorphologically, the study area has an undulating topography characteristic of the Cross River Plains. Its highest elevation lies at about 110m above the sea level (Fig. 2) and are formed by erosion-resistant igneous intrusive while the low lying areas are underlain by soft rocks.

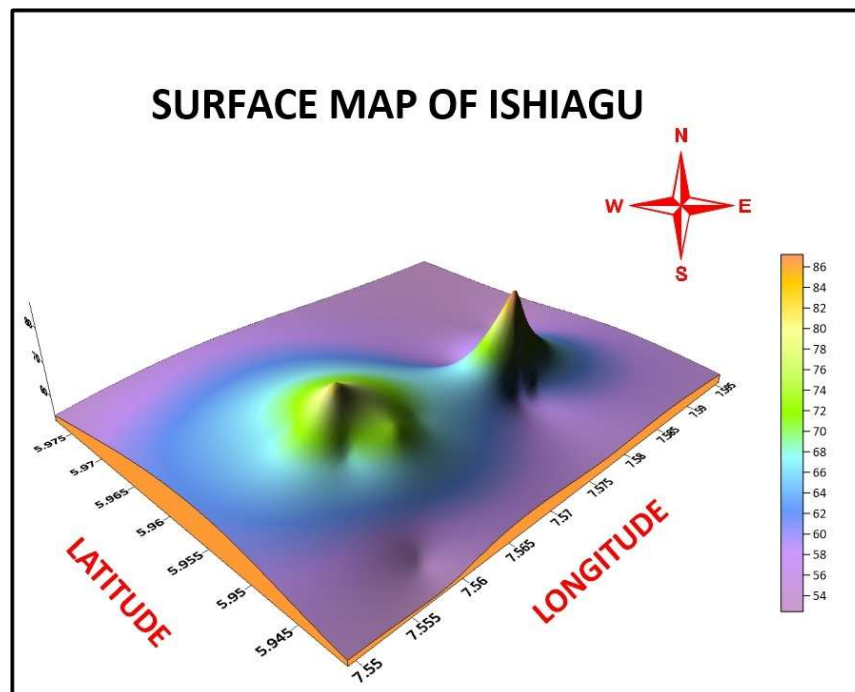


Figure 2: Surface map of Ishiagu

Climate and Vegetation

Ishiagu belongs to the humid tropical climate characterized by two main seasons- dry season which runs from November to March and rainy season which runs from April to October. Ishiagu has an average temperature of 27⁰C (Duze and Ojo, 1982) with an average annual precipitation of about 1925mm which is relatively high (Ofomata, 2002) resulting in adequate supply of water in the area for most part of the year.

The area is covered by tall grasses and small trees characteristic of the sub-savannah vegetation zone and has rich soils suitable for cultivation of crops such as rice, yams, cassava etc.

Geology and Hydrogeology of the study area

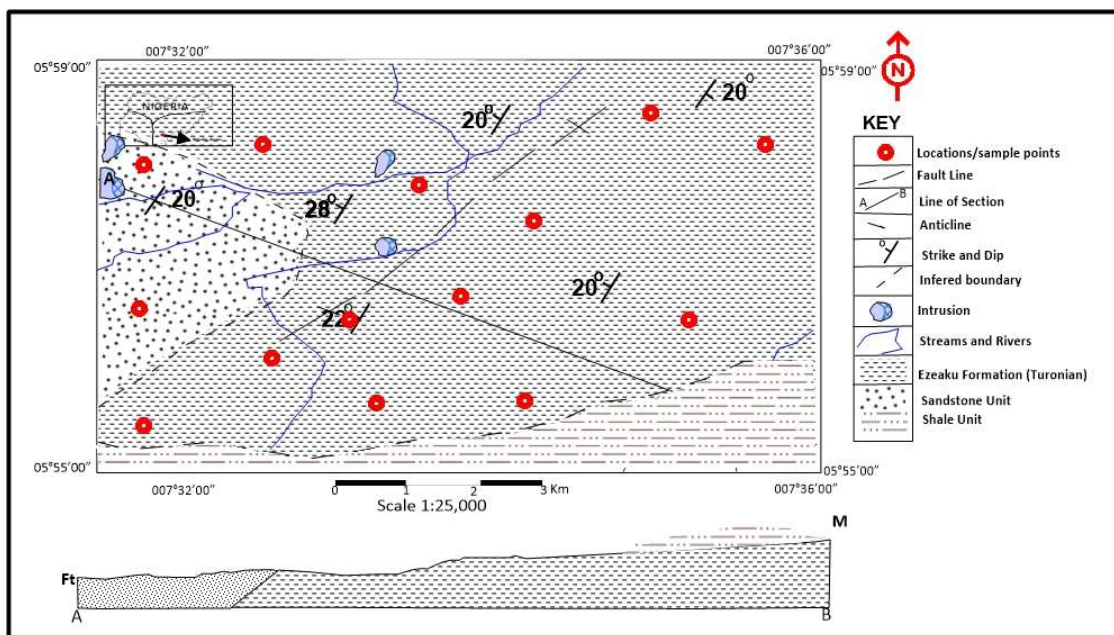


Figure 3: Geologic map showing the sample locations in the study area.

From figure three (3) above, the study area is underlain by two formations namely: the Albian Abakaliki Formation and the Turonian Ezeaku Formation. The Northwest-Southeast dipping Abakaliki Formation belongs to the Asu River Group and consists of two mappable units of shale and sandstones.

The shale units are dark colored indicating the presence of sulphide minerals and large quantity of organic matter indicative of formation in stagnant marine basins (Ezeh, 2009). On the other hand, the sandstone unit is fine to medium grained and calcareous. Unconformably overlying the Abakaliki Formation is a sandstone member of Ezeaku Formation. It grades from siltstone to fine-medium grained sandstone and dips in the southeast direction. The rocks occurring in the study area are extensively fractured, folded and faulted with several minor, basic and intermediate intrusive thought to be sill (Ezepue. 1984).

The predominance of shale formations in the study area makes groundwater a poor source of water in the area. Hence, the indigenes of Ishiagu Mining District depend largely on surface water for their agricultural and domestic use. These surface water bodies include streams, pit lakes and wetlands which occur in abundance within the area.

Rivers and streams occurring in the study area flow in a dendritic pattern. Some of the major surface waters in the area include Ivo River, Ikwo River and Odu River. The main river, Ivo, takes its source from the Udi-Okigwe cuesta and splits into smaller streams such as Ikwo, Ngado, Ihetutu and Ekustreams. The groundwater supplies in the area are mainly from hand-dug wells and very few boreholes.

Mineralization in the study area

The study area is well known for the abundance of lead-zinc veins in the area (fig. 4). The lead-zinc deposits were formed as a result of leaching of metals from sediments that were heated by circulating connate waters which occurred between the Albian and Cenomanian times (Olade and Morton, 1980). The fault zones are the main zones of mineralization (Ezeh, 2009) and the dominant constituents of the mineral veins include siderite, galena and sphalerite (Ezepue, 1984). Secondary minerals in the area were formed by metasomatic alteration (Mamahet *al.*, 2000) and include anglesite, cerussite and smithsonite

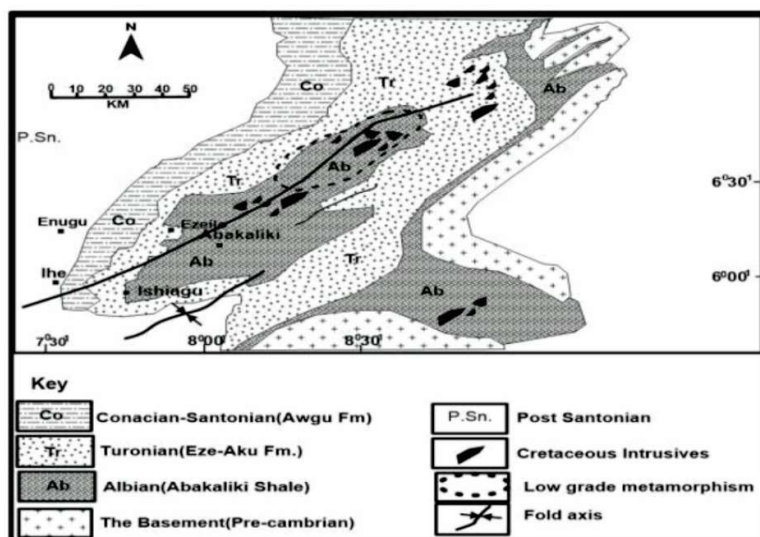


Figure 4: Geological Map of the area; map of the geologic setting of Ishiagu and Abakaliki lead-zinc vein alignment according to Akande and Erdtmann, 1988.

Mining in the study area

Lead/zinc deposit were discovered in the area in the 1950s (Bogue, 1952) and this has made Ishiagu the epicenter of mining activities in Ebonyi state. The primary occupation of the local population is mining and they have been instrumental in extraction of some of the ores over time. With the end of organized mining in the area following the exit of most mining companies,

manual mining and excavation of the minerals by the locals replaced the use of machinery. The minerals (mainly galena) are usually dug out and handpicked thereby exposing the geologic materials in the area to weathering. Intensive weathering is aided by heavy rainfall and undulating relief causing the release of metallic components of the rocks into the soil and surrounding waters either as aqueous species or in dispersed forms of the constituting mineral or as precipitates of new minerals (Ezeh and Chukwu, 2009).

MATERIALS AND METHODS

Fifteen water samples were collected from the study area including 3 rivers and streams, 2 pit lakes, 2 wetlands, 2 quarry reservoirs, 4 hand-dug wells, and 3 boreholes (Table 1).

Chemically free sterile containers were used in the sampling and rinsed with sample fluids prior to collection. Care was taken to remove the top film of the surface waters and hand-dug wells before they were collected. In the case of borehole water, the taps were allowed to run for five minutes before collecting them. The sampling followed guidelines provide by the American Public Health Association (APHA, 2012). The samples were adequately labeled and preserved in an ice chest while been transported to the laboratory for chemical analysis. Chemical analyses of the samples were carried out at Fatlab laboratory, Ibadan.

Parameters such as pH, electrical conductivity (EC), and temperature were measured on the field with the aid of EXTECH multi-parameter water quality meter (model 341350A). All temperature measurements were taken at 10am in the morning. pH 7 buffer solution was used to stabilize certain chemical species in the samples before they were taken to the laboratory.

The concentration of the anions were determined by digital titration while the cations were determined using the Buck model 210/211 AAS graphite furnace and 220 AS Auto-sampler.

Table 1: Overview of Water Samples Collected

L O C A T I O N	G E O R E F E R N C E N U M B E R		E L E V A T I O N	S A M P L E T Y P E
	L a t i t u d e	L o n g i t u d e		
L o c a t i o n 1	N5 ⁰ 57 ¹ 04.5 ¹¹	E7 ⁰ 34 ¹ 42.5 ¹¹	9 m ?	P i t L a k e
B a s i n w a t e r	N5 ⁰ 57 ¹ 02.9 ¹¹	E7 ⁰ 34 ¹ 36.6 ¹¹	6 8 m	Q u a r r y R e s e r v o i r
O g w u a z u	N5 ⁰ 56 ¹ 56.9 ¹¹	E7 ⁰ 34 ¹ 45.1 ¹¹	6 2 m	W e t l a n d
I v o R i v e r	N5 ⁰ 56 ¹ 24.9 ¹¹	E7 ⁰ 35 ¹ 44.3 ¹¹	5 5 m	R i v e r
N g w u g w o l y i	N5 ⁰ 57 ¹ 22.4 ¹¹	E7 ⁰ 34 ¹ 42.1 ¹¹	5 8 m	S t r e a m
N g w u g w o	N5 ⁰ 57 ¹ 42.7 ¹¹	E7 ⁰ 35 ¹ 16.6 ¹¹	5 4 m	W e t l a n d
A m a g u	N5 ⁰ 57 ¹ 01.3 ¹¹	E7 ⁰ 33 ¹ 57.1 ¹¹	6 9 m	H a n d d u g w e l l
N d u z e l h i e	N5 ⁰ 56 ¹ 56.9 ¹¹	E7 ⁰ 33 ¹ 44.4 ¹¹	7 3 m	P i t L a k e
I k w o R i v e r	N5 ⁰ 56 ¹ 34.6 ¹¹	E7 ⁰ 33 ¹ 31.1 ¹¹	5 4 m	R i v e r
I y i a l a l u	N5 ⁰ 57 ¹ 00.4 ¹¹	E7 ⁰ 33 ¹ 33.8 ¹¹	7 9 m	B o r e h o l e
I g b i a m a o n y e	N5 ⁰ 57 ¹ 08.3 ¹¹	E7 ⁰ 33 ¹ 29.6 ¹¹	7 2 m	B o r e h o l e
U z o h u A m a e z e	N5 ⁰ 58 ¹ 40.1 ¹¹	E7 ⁰ 32 ¹ 57.6 ¹¹	5 4 m	H a n d d u g w e l l
A m a e w u z u - A m a e z e	N5 ⁰ 57 ¹ 46.8 ¹¹	E7 ⁰ 33 ¹ 10.7 ¹¹	6 3 m	H a n d d u g w e l l
I h e t u t u - A s a	N5 ⁰ 57 ¹ 22.5 ¹¹	E7 ⁰ 33 ¹ 28.7 ¹¹	6 9 m	H a n d d u g w e l l
O g b u k a l h e	N5 ⁰ 57 ¹ 11.8 ¹¹	E7 ⁰ 33 ¹ 36.7 ¹¹	8 3 m	B o r e h o l e

RESULTS AND DISCUSSION

The results of the analyzed physicochemical parameters of the water samples are presented in Table 2.

Table 2: Results of analyzed physicochemical parameters

L o c a t i o n	p H	Conductivity $\mu\text{s.cm}$	Temperature $^{\circ}\text{C}$	BOD mg/l
Location 1	4 . 0 3	6 . 5 0	2 5 . 3	1 8 . 5
Basin water	4 . 0 2	6 . 4 5	2 4 . 9	9 5 . 4
O g w u a z u	4 . 0 0	3 . 6 0	3 1 . 4	2 5 . 7
I v o R i v e r	4 . 0 5	0 . 0 9	2 3 . 0	1 4 4 . 8
N g w u g w o l y i	4 . 0 2	0 . 3 8	2 9 . 4	3 5 . 6
N g w u g w o	4 . 0 1	0 . 4 9	2 9 . 1	6 5 . 8
A m a g u	4 . 0 0	0 . 5 5	2 6 . 0	1 6 3 . 5
N d u z e l h i e	4 . 0 5	0 . 4 5	2 7 . 0	2 0 . 3
I k w o R i v e r	4 . 0 1	0 . 1 4	2 5 . 8	3 2 . 8
I y i a l a l u	4 . 0 8	0 . 4 0	3 0 . 2	7 5 . 4
I g b i a m a o n y e	4 . 0 3	0 . 5 9	2 8 . 2	5 2 . 3
U z o h u A m a e z e	4 . 0 6	0 . 8 8	2 2 . 5	7 1 . 9
A m a e w u z u - A m a e z e	4 . 9 0	0 . 9 2	2 6 . 6	1 2 2 . 5
I h e t u t u - A s a	4 . 0 8	0 . 3 4	2 9 . 0	1 8 . 6
O g b u k a l h e	4 . 0 7	0 . 7 6	2 8 . 5	5 5 . 8

The results show a pH range of 4.00 to 4.90 in the surface and groundwater samples indicating a geochemical environment that is acidic which may be due to acid mine drainage associated with mining activities in the area. Also, the electrical conductivity values which is summarizing parameter reflecting the total dissolved ions in the water samples vary from 0.09 $\mu\text{s/cm}$ to 6.50 $\mu\text{s/cm}$. The electrical conductivity results indicate that human activities in the area ranging from mining to quarrying may have resulted in the incorporation of dissolved components of the overburden soils and rocks with the water samples thus affecting the overall water chemistry (Akubugwo et. al., 2015, Elueze et al., 2004). Temperature results range from 22.5 $^{\circ}\text{C}$ to 31.4 $^{\circ}\text{C}$. This high temperature values are responsible for high metal activity in the water bodies thus facilitating increased chemical reactions and biological interactions (Sherene, 2010). The biochemical oxygen demand, which describes the quantity of oxygen-demanding microorganisms present in the water, varies from 18.5 mg/l to 122 mg/l. The values of biochemical oxygen demand (BOD) signify the presence of organic, inorganic and oxygen-demanding bodies in the water.

Observations also show that the biochemical oxygen demand increased with distance from mining zones. This may not be unconnected with the decrease in heavy metals content in the water samples thus allowing for increased microbial activities (Nwaugo et al., 2011). This is a clear indication that the effects of mining were reduced away from the source.

Chemical parameters

The results of the chemical parameters analyzed in the water samples are presented in Table 3. The ranges of the chemical parameters are as follows: Ca^{2+} (6.76 – 473.54), Mg^{2+} (2.61 – 32.57), K^+ (0.53 – 16.23), and Na^+ (7.36 -945.12). Others are PO_4^{4-} (0.000 – 0.277), Cl^- (28.8 – 3708.0), SO_4^{4-} (0.011 – 3.085), NO_3^- (0.004 – 11.822), and HCO_3^- (61.0 – 353.8). The mean concentration of the cations (Table 4) are therefore in the order $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ while for the anions, it is in the order $\text{Cl}^- > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{4-} > \text{PO}_4^{4-}$ (Table 4).

The consistently greater values of Ca^{2+} compared to Mg^{2+} show that the origin of the waters is primarily meteoric as there is little or no contribution from connate waters that may have contributed magnesium. This observation is further corroborated by the high Cl^- concentration which suggests that the chemical characteristics of the water are influenced by recharge from meteoric waters (Olayinka et al., 1999).

The presence of Na^+ , Cl^- and Mg^{2+} in the water samples are sourced from salt deposits occurring in the area such as magnesite and dolomite which are washed from the soils and rocks into the water bodies. This corroborates with the work of Housecroft et al., 2008.

The source of HCO_3^- in the area, with mean concentration of 194.54 mg/l, can be attributed to CO_2 charge recharge (Tijani, 1994, Elueze et al., 2004). SO_4^{4-} presence in the water samples could be attributed to contaminants from the mined Zn and Pb ores in the area.

Also, the presence of K^+ , PO_4^{4-} , and NO_3^- can be attributed to the use of organic and inorganic fertilizers by farmers in the area (Bruning-Fann et al., 1993). These fertilizers are easily washed into the surface water bodies because they are commonly applied near river banks where crops are planted.

Table 3: Results of analyzed chemical parameters

Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	PO4- (mg/l)	Cl- (mg/l)	SO4- (mg/l)	NO3- (mg/l)	HCO3- (mg/l)
432.01	31.52	3.11	882.02	0.00	2520	1.715	0.874	91.5
473.54	32.57	3.82	945.12	0.00	3708	1.838	1.446	91.5
178.21	32.58	16.23	536.24	0.277	1908	0.134	0.013	128.1
20.12	2.61	2.23	7.36	0.00	360	0.013	0.041	6.1
34.35	12.31	9.94	28.42	0.00	360	0.011	1.283	207.4
28.63	9.74	8.53	60.23	0.00	216	0.327	0.009	237.9
23.46	18.76	1.64	26.57	0.00	576	0.344	0.027	350
20.11	17.75	8.11	16.48	0.00	648	1.205	0.466	323.3
6.76	6.85	2.45	12.26	1.191	288	0.011	0.086	97.6
25.64	12.23	2.51	28.01	0.00	648	0.485	0.033	189.1
62.48	10.85	0.78	25.63	0.109	648	0.169	0.004	341.6
39.78	10.22	2.53	106.27	0.00	488	2.523	4.142	91.5
68.69	18.78	9.75	82.13	0.00	241.2	3.085	7.328	353.8
34.78	11.67	4.22	23.57	0.00	320	0.52	0.221	170.8
59.86	19.34	0.53	22.03	0.00	126	1.152	11.822	183

WATER TYPES

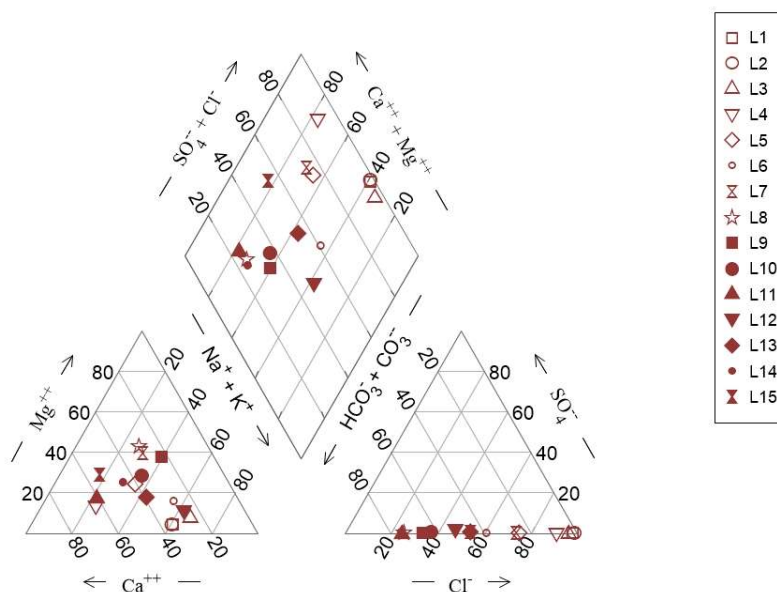


Fig. 5: The piper trilinear plots of samples measured in the area.

The analyzed hydrochemical parameters of the surface water and groundwater samples were plotted on a Piper trilinear diagram (fig. 5) to discriminate and characterize the water types occurring in the study area.

From figure 5 above, the piper diagram sample from L4 plots within the area of Permanent hardness of water which is water rich in ($\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{Cl}^- + \text{SO}_4^{2-}$ Calcium chloride type). Samples obtained from L15, 7, 5 13, and 12 plots within the central portion of the diamond, which is an area of mixed water. While the samples obtained from L14, 11, 8, 10, and 9 plots on left side of the diamond which is an area of Temporary hardness known as Magnesium bicarbonate type (Lastly samples obtained from L6, 3, 2, and 1 plots on the right side of the diamond $\text{Ca}^{2+} + \text{Mg}^{2+}$ and HCO_3^- . which is an area of Saline water type also known as Sodium Chloride water type ($\text{Na}^+ + \text{K}^+$ and $\text{Cl}^- + \text{SO}_4^{2-}$).

Additionally, water sample from L14, 11, 8, 10, and 9 falls within the Ca-HCO_3 water which is typical of shallow, fresh ground waters. Other Samples falls on the Ca-SO_4 waters, which is typical of gypsum ground waters and mine drainage. Samples obtained from L6, 3, 2, and 1 falls on $\text{Na}^+ - \text{Cl}^-$ waters which are typical of marine and deep ancient ground waters. From the lower triangle all samples plots along the Ca, Na, K, HCO_3 and Cl water type.

Piper diagram divides water into four basic types according to their placement near the 4 corners of the diamond. From the diagram the water samples plots at the left ($\text{Ca}^{2+} + \text{Mg}^{2+}$ and HCO_3^-) which is an area of Temporary hardness, the lower ($\text{Na}^+ + \text{K}^+$ and $\text{HCO}_3^- + \text{CO}_3^{2-}$) which is an Alkali Carbonate water and central part of the diamond, which is an area mixed water.

QUALITY OF NATURAL WATER SOURCES IN THE ISHIAGU MINING DISTRICT

Different water quality criteria have been developed by different organizations and regulatory agencies over the years to serve as standards in defining the quality of water. These water quality standards therefore define specific limits above which water is deemed to be contaminated and may not be used for certain purposes except they are treated (Elueze, 2004). The quality of water is largely dependent on its chemistry which is defined by certain physical and chemical parameters (Tijani, 1994).

Table 4 presents a summary of the physical and chemical parameters of analyzed surface and groundwater samples in the study area, their mean values and W.H.O (2012) acceptable levels.

Table 4: summary of the physical and chemical parameters and the WHO (2012) standards for drinking water

Measured parameters	R a n g e	Overall mean	Acceptable level
p H	4.00 - 4.90	4 . 0 9	6 . 5 - 8 . 5
E C $\mu s / c m$	0.09– 6.50	1 . 5 0	1 0 0 0
Temperature ^o C	22.5- 31.4	2 7 . 1 3	1 2 0 - 6 0 0
B O D m g / l	18.5 - 122	6 6 . 5 9	1 0 0
C a l c i u m m g / l	6.76 – 473.54	1 0 0 . 5 6	2 5 0
Magnesium mg/l	0.53 – 16.23	1 6 . 5 2	2 0
Potassium mg/l	3 . 8 - 6 5	5 . 0 9	2 5 0
Sodium m g / l	7.36 -945.12	1 8 6 . 8 2	2 5 0
Phosphate m g / l	0.000 – 0.277	0 . 1 1	2 5 0
Chloride m g / l	28.8 – 3708.0	6 8 7 . 9 5	5 0
Sulphate m g / l	0.011 – 3.085	0 . 9 0	0 . 0 0 3
Nitrate m g / l	0.004 – 11.822	1 . 8 5	0 . 0 5
Carbonate m g / l	61.0 – 353.8	1 9 4 . 5 4	0 . 3

The physical parameters including pH, EC, temperature fall within the WHO (2012) acceptable limits for drinking water. Similarly, the Biochemical Oxygen Demand of the water samples falls within the WHO (2012) acceptable limits. Based on the work of Todd, 1980, the mean concentration of electrical conductivity in the water samples make them suitable for irrigation activities.

The inorganic elements of calcium, magnesium, potassium and phosphate also fall within the WHO (2012) acceptable limits for drinking water. However, the concentration of sodium, sulphate, chloride, nitrate and carbonate is far above the WHO (2012) acceptable limits for drinking water. This therefore makes the water very unsafe for consumption. The very high concentration of chlorides is an important index of organic pollution and considered a tracer for ground water contamination. Also, the high value of nitrate may be due to impact of agricultural practices and direct sewage disposal into the rivers and stream (Tredoux et al., 2000).

GROUNDWATER FLOW DIRECTION

The groundwater flow direction could be inferred from the results of the physic-microbial and chemical analyses presented above. The results show a decrease in concentration of the electrical conductivity with a corresponding increase in BOD away from the mining areas. Also, there was a general decrease in the concentration of the cations and anions away from the mining area. This shows that the surface water and groundwater are flowing away from the mining zones indicating that mining area is the water source area and zone of water recharge. This agrees with the findings of Nwaugo et al., (2011), Ezekwe (2010) and Forttin et al., (2000, 2002) that concentration of pollutants decreases away from the source.

CONCLUSION AND RECOMMENDATIONS

The following have been established by this study:

1. The Ishiagu Mining District is hydrogeochemically acidic due to acid mine drainages resulting from mining activities in the area.
2. Anthropogenic activities aided by high temperature condition in the study area have facilitated increased chemical reactions and biological interactions in the water bodies.
3. The water sources in the area have been directly impacted by mining activities in the area as evident in the high mean concentration of sodium, sulphate, chloride, nitrate and carbonate. These inorganic elements have significantly affected the quality of the water in the area.
4. The surface waters and groundwater are not suitable for consumption because of the high contaminant concentration in them.
5. Five water types are dominant in the study area.
6. The mining zones serve as water source areas and zones of groundwater recharge.

It is therefore recommended that proper treatment of water prior to consumption be carried out. Also, further studies should be carried out to assess the heavy metal concentration as well as level of microbial activity in the water sources so as to prescribe extensive treatment measures. Action is also required by the government to legislating strong laws that criminalizes disposal of mine tailings and effluents into the surface water bodies.

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