

Geoenvironmental impact of Okpara coal mine, Enugu, Southeastern Nigeria

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ABSTRACT

Water, sediments and mine dumps samples were collected around the Okpara coal mine in Enugu area of southeastern Nigeria, for analysis for physicochemical parameters, inorganic ions/salts, and heavy metals abundance. The intension was to investigate the impact of coal mining activities on the geoenvironment. The measured pH range of 2.84– 6.05 qualifies the water as acidic to moderately acidic, and consequently unsuitable for human, vegetation, aquatic life and wildlife. The SO_4^{2-} ion, which is an indicator for acid mine drainage (AMD) pollution in most mine waters, displayed moderate concentrations, thereby implying insufficient pyritization. On the other hand, the excessive concentration of NO_3^- and PO_4^{3-} in the water calls for concern as it renders the water prone to eutrophication and numerous potential health risk, especially for pregnant women and infants. Heavy metal results show that iron comprised the most abundant metal in all the media sampled. This similarity in trend for the three media supports the idea of Fe being the element of main interest. In the sampled water, aluminum, iron manganese and nickel are respectively higher by 21.50, 17.13, 16.75 and 2.55 times the maximum allowable limits for the relevant chemical specie in the Nigerian Standard for Drinking Water Quality (NSDWQ). This excessive Al, Fe, Mn and Ni, coupled with the generally acidic nature of the water portend doom for the ecosystem. In particular, acid and iron polluted waters are not favourable for fish growth and survival of other aquatic biota. Also, acidic and ferruginous waters are responsible for the corrosion of mine plants and equipment, formation of scales in delivery pipes as well as pollution of mine surface environments, thereby also affecting the surface ecology. Additionally, high iron composition of sediments and mine dumps imply precipitation of ferric hydroxide which, if unchecked, may result in the complete layering of stream bottom, filling in crevices in rocks and making substrates unstable and unfit for habitation by benthic organism. Evaluation of the comparative abundance of the inorganic ions/salts (Ca, Mg, Na, K) and heavy metals in the water, sediments and mine dumps revealed that these components are much more concentrated in the sediments and mine dumps than in the water. The danger in this is that the sediments and mine dumps serves as a pool that can release toxic heavy metals into the water column by various processes of remobilization.

Keywords: Acid mine drainage (AMD), impact, Enugu, Nigeria

INTRODUCTION

The impacts of mining activities on terrestrial and aquatic environments are mostly associated with changes in hydrogeological systems, hydrological transformation of soils and surface flows, contamination of soils and surface water reservoirs, as well as pollution of the atmospheres [1]. Waste rocks generated from coal mining often constitute sources of heavy metal pollutants [2], while tailing ponds or piles may give rise to pollution of water bodies. Runoffs from coal mines can dissolve heavy metals, notably, copper, lead, zinc, manganese, mercury, molybdenum, into ground and surface water bodies [3], and some of these metals are carcinogenic to health and causes other health-related problems.

Coal mines in arid and semi-arid, western and North America have no significant acidification of water bodies due to low pyrite content and acid neutralizing carbonates in soils and near surface sediments [4]. However, cases of surface and groundwater contamination are prevalent in the Nigerian coal mine areas[5, 6, 7, 8]. The sources of

pollution to these water bodies often includes mine wastes that are dumped along the banks of stream channels and water pumped out of mines into surrounding streams. Pollutions which affect chemical quality of both surface and ground water in the Enugu area are frequently linked to coal mining operations in the Enugu coal mines [5, 6, 7, 8]. The Enugu coal mine district covers 270,000 hectares of coal basin, which supported the largest amount of commercial mining in the past. It has an estimated coal reserves of 49 million tones [9].

The present study focused on the environmental impact assessment of Okpara coal mine in the Enugu area. The aim of the work was to know the real impact associated with the acid mine drainage (AMD) in the Okpara mine and surrounding areas, with the aid of physical and chemical analyses of water, sediment and mine dumps. The impetus for the study was the consideration that streams and ponds often affected by effluents from coal mines can constitute sources of municipal, irrigation and/or industrial water. Also, acid impacted mine water can dissolve heavy metals, and the presence of these in the geoenvironment can produce detrimental health effects.

Location and Accessibility

The Okpara coal mine area, which is delimited by longitudes 06° 22' E to 06° 24' E and latitudes 07° 26' N to 07° 29' N (Fig. 1), is situated in Akwuke in present- day Enugu West, formally Enugu South, Local Government Area of southeastern Nigeria. It is located about 6.5km from Enugu – Port Harcourt express way. In terms of relief, the highest elevation of about 216m above sea level was measured at the mine site, while the lowest elevation is about 16m. The valleys in the area are characterized by ravines and gorges.

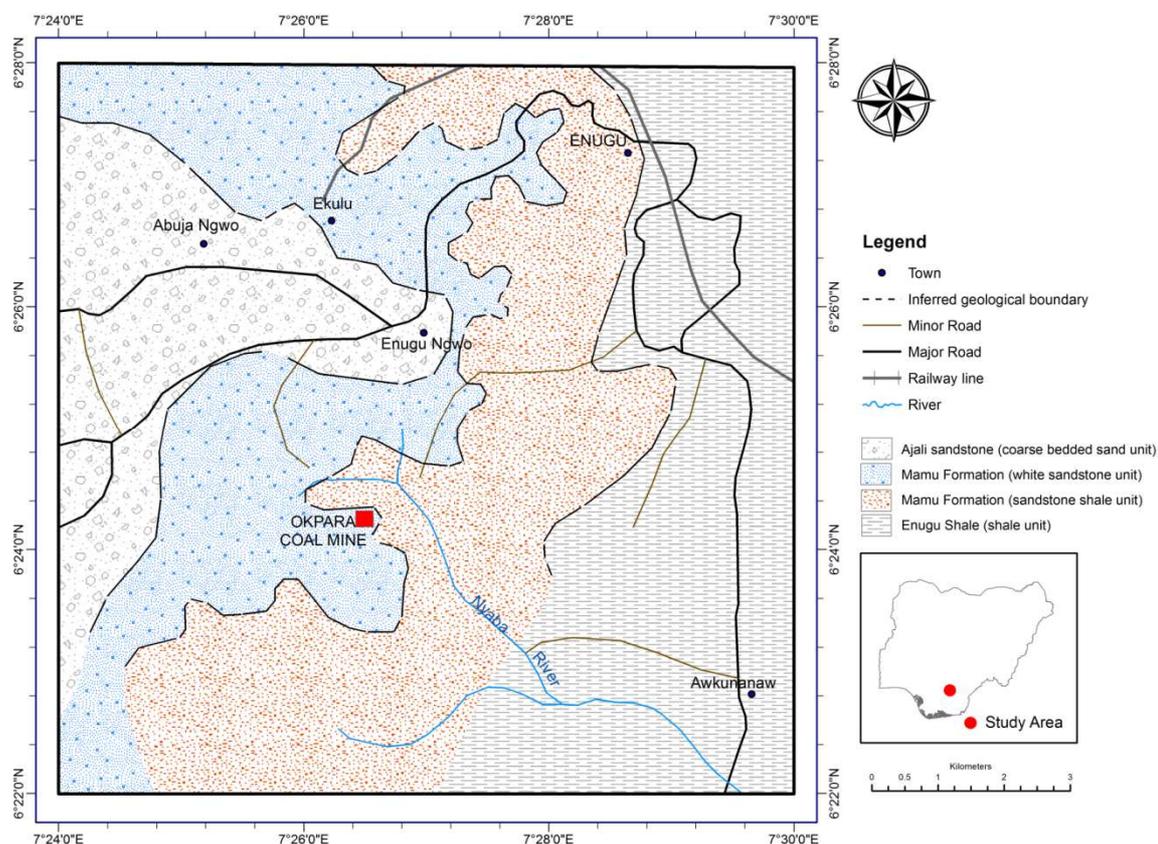


Fig. 1. Geologic map of Enugu and environs, showing the location of the Okpara coal mine

The study area has hot and humid climate with annual temperature in the range of 25°C to 30°C. Two main climatic seasons, namely, dry and wet seasons exist in the area. The dry season starts from November to March while the rainy season lasts from April to October. The rains are usually heavy with the annual mean value being over 1500mm [10]. Vegetation in the area is the scrub forest– type [10], which consists of low Greenland, and scattered trees. The two major streams that drain the study area are: Orob and Nyaba streams. Other smaller streams which rise in the forms of springs flow through deep V– shaped valleys that have incised the soil materials. The streams are seasonal and appear fracture– controlled in their flow paths, giving rise to a trellised drainage pattern [11].

Geology and Hydrogeology

The stratigraphic succession in the Okpara coals mine area consist of three conformable geologic Formations [6], namely, Enugu Shale Formation (Campanian), Mamu Formation (Lower Maastrichtian), and Ajali Sandstone Formation (Upper Maastrichtian).

The Enugu Shale Formation comprise soft to dark grey shale, mudstone and intercalation of sandstone and sandy shale. The Mamu Formation exhibits cyclic sequence which is typically represented from bottom to top by: (1) shale or sandy shale, (2) Coal, which is sometimes shaly at the top, (3) Carbonaceous shale passing down into shale, (4) Sandstone with few shaly layers or alternating sandstone and shale, and (5) Shale or sandy shale. The Mamu Formation contributes nearly all the groundwater entering the Enugu coal mines. The source of recharge is by precipitation [6, 12]. The Mamu sandstones unit has a hydraulic conductivity (k) of 9.2×10^{-3} cm/s and specific discharge of $14.5 \text{ m}^3/\text{year}$ [6]. The Ajali Formation overlies the Mamu Formation. It constitutes the main aquiferous unit with thick friable, poorly sorted, cross-bedded sandstone that are generally whitish with occasional iron stains. These sandstones are overlain by lateritic red earth deposit. The rock units are largely confined at the lateritized overburden where two confined units exist. The lateritic aquifer, which is thinly bedded and discontinuous has a depth of about 0.7m, hydraulic conductivity (k) of 9.2×10^{-3} cm/s and specific discharge (v) of $1.75 \text{ m}^3/\text{year}$ [6]. The associated shallow water table indicates the aquifer susceptibility to contamination [10].

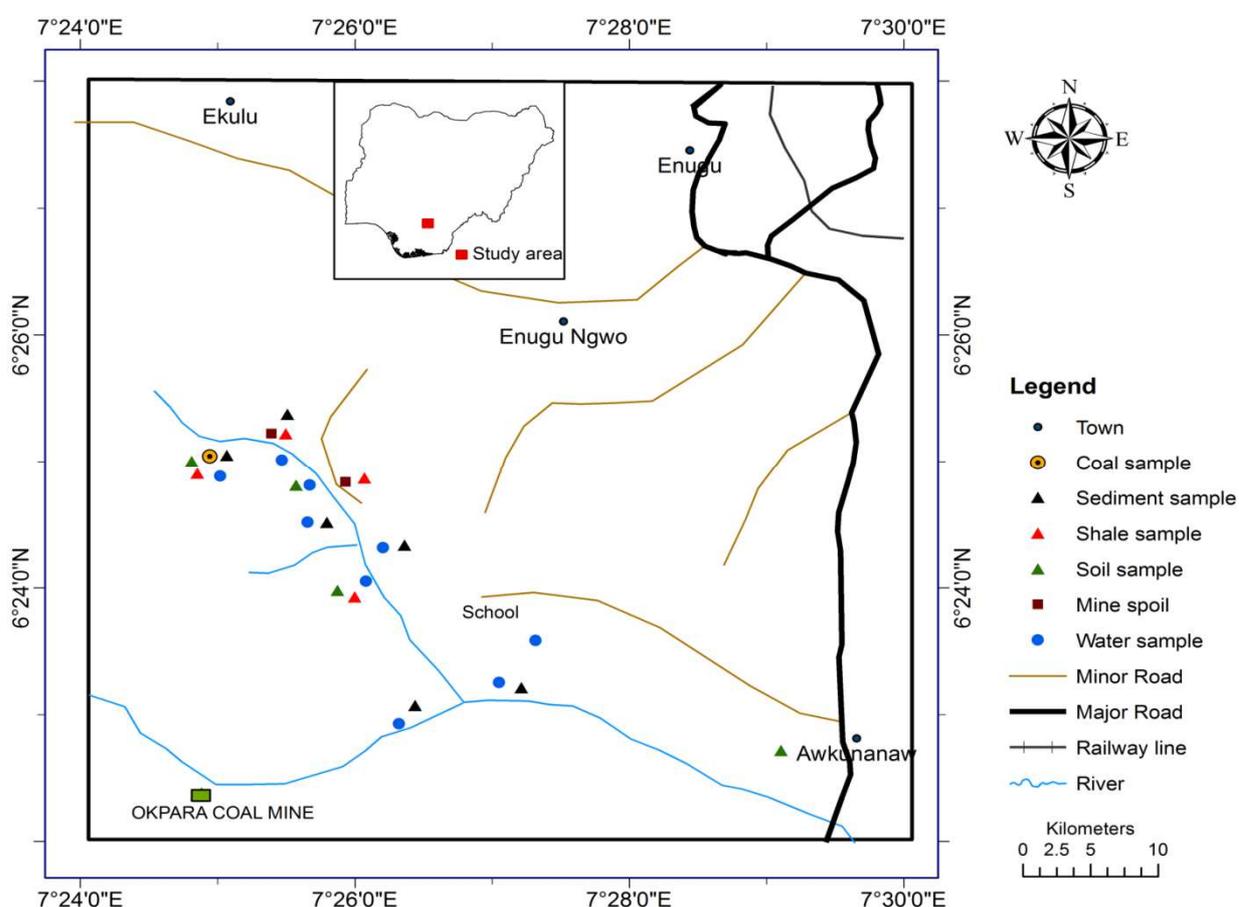


Fig. 2. Sample location map of the Okpara coal mine

MATERIALS AND METHODS

Sampling and Sample Treatments

Water, sediments and mine dumps were collected in the field. A total of nine water samples, seven stream sediment samples and four mine dumps samples were collected. Details on the location of mostly the water samples are given in Table 1, while the sample location map is presented in Fig. 2. The water and sediment samples were collected from sedimentation ponds, stream confluence, stream channels, springs, tributaries, and from hand dug well in the adjoining hamlet, as control. The water sample bottles were rinsed with the water to be sampled three times before sample collections. Water samples for heavy metal analysis were acidified to pH not less than 2. The Mine dumps were collected around the mine site and along the stream banks. At these sites, the mine dumps were scooped with a

hand trowel into clean polythene bags. All the collected samples were adequately labeled, documented and packaged for further investigations

Analytical Procedures

Measurable physical parameters, notably, pH, temperature, electrical conductivity, turbidity and total dissolved solids were determined in the field using standard field equipment, such as digital Mv Redox pH meter, mercury in glass thermometer, conductivity meter WA3000, spectrophotometer Dr 3000 and conductivity meter. Chemical parameters such as major anions were determined from non-acidified water samples, using ion chromatography and titration. Cations, trace and heavy metal contents of the water, stream sediments and mine dumps were analyzed using ICP-MS. All the laboratory were carried out at Oyeoshin Petroc Services laboratories in Ibadan, Southwestern Nigeria.

RESULTS AND DISCUSSION

Water and Sediment Quality

The Physicochemical characteristics and concentrations of inorganic ions/salts in the shallow groundwater and sediment samples from the Okpara coal mine area are summarized in Table 2, together with the maximum allowable limits contained in the Nigerian Standard for Drinking Water Quality (NSDWQ)[13], World Health Organization guideline for drinking water [14] and average values of uncontaminated shale [15] used as background values.

Table 1. Details on the location and medium of collection of water samples in the Okpara coal mine area

Location No	Medium
1	mine pond
2	influent
3	effluent
4	spring
5	Tributary to Orob stream
6	Tributary and confluence
7	Orob stream Channel
8	Orob and River Nyaba confluence
9	Hand dug well

Table 2. Summary results of physical parameters and major inorganic ions/salts composition of shallow groundwaters and sediments from the Okpara coal mine, southeastern Nigeria

Parameters	WATER			SEDIMENTS			SON (2007)	WHO (2011)	* BACK
	N	RANGE	MEAN	N	RANGE	MEAN			
Physicochemical Characteristics	Temperature (°C)	9	26.5 –	26.84	–	–	na	na	na
	pH	9	2.84 –	4.22	7	4.05 –	5.14	6.5 –	na
	eH	–	–	–	7	102 –	131.29	na	na
	Ec(us/cm)	9	4.04 –	269.7	7	18 –	208.43	1000	na
	TDS (mg/L)	9	10 – 538	157.76	–	–	–	500	na
	Turbidity (NTU)	9	0 – 48	14.67	–	–	–	na	na
	TOC	9	26.5 –	26.84	–	–	–	na	na
	Colour (pt/co)	9	0 – 1005	153.11	–	–	–	15	na
Major inorganic ions/salts (mg/L)	Cl ⁻	9	40 – 400	136.67	–	–	–	250	na
	SO ₄ ²⁻	9	63 – 517	108	–	–	–	100	na
	NO ₃ ⁻	9	158 –	567.67	–	–	–	50	50
	PO ₄ ³⁻	9	0.52 –	1.08	–	–	–	na	na
	F ⁻	9	0 – 45	5.08	–	–	–	1.5	1.5
	S	9	2 – 151	33.89	–	–	–	na	na
	Ca	9	1.42 –	8.79	7	100 –	185.7	na	na
	Mg	9	2.62 –	6.77	7	100 –	257.14	0.2	na
	Na	9	6.53 –	14	7	80 –	228.57	200	na
	K	9	1.17 –	12.01	7	200 –	2628.57	na	na

na = not available, *BACKGROUND [15]

As shown in Table 2, all the waters sampled yielded pH < 7, demonstrating the generally acidic nature of the water. Similarly, the investigated sediments can be classified as acidic to mildly acidic with pH in the range of 4.05 – 5.64. The low pH in both the sampled waters and sediments compare favorably with those of other comparable AMD-impacted medium. Offodile[12] and Ezeigbo and Ezeanyim[6] also measured low pH values in waters associated with the Okpara coal mine; while Offodile[12] obtained average pH values of 6.1 in the Ekulu River, Ezeigbo and Ezeanyim[6] recorded pH values of 2.3 in the Okpara coal mines. The measured pH values are not only outside the

prescribed range for portable water [13], it makes the water unsuitable for human, vegetation, aquatic life and wildlife [16, 17, 18, 19, 20]). Acidic waters are also susceptible to dissolution of minerals and release of toxic heavy metals into the aquatic environment.

Table 3. Statistical Summary of trace and heavy metal abundance in water, sediments and mine dumps from Okpara coal mine, southeastern Nigeria

Parameters (in mg/L)	WATER			SEDIMENT			MINE DUMPS			SON (2007)	WHO (2011)	*BAC K-
	N	RANGE	MEAN	N	RANGE	MEAN	N	RANGE	MEAN			
Al	9	0.28 –	4.3	–	–	–	–	–	–	0.2	0.9	8.8
Cd	9	0.0001 –	0.0003	7	0 –	0.001 (0)	4	0.1 – 0.1	0.1 (0)	0.003	0.003	0.3
Co	9	0.0005 –	0.028	7	0.8 – 7.6	4.03	4	2.9 – 3.8	3.32	na	na	19
Cr	9	0.0005 –	0.001	7	21.5 –	131.89	4	41.7 –	47.14	0.05	0.05	90
Cu	9	0.004 –	0.008	7	15.8 –	30.21	4	43.2 –	64.14	1	2	45
Fe	9	0.44 –	5.14	7	24000 –	104,914	4	6200 –	8871.4	0.3	na	4.72
Mn	9	0.031 –	3.35	7	51 – 270	126	4	01 – 44	2.6 (1.2)	0.2	na	850
Mo	9	0.0001 –	0.005	–	–	–	–	–	–	na	na	2.6
Ni	9	0.0001 –	0.051	7	0.9 –	8.22	4	8.7 – 98	9.6	0.02	0.07	50
P	–	–	–	7	140 –	290.29	–	–	–	na	na	700
Pb	9	0.004 –	0.006	7	9.9 – 23	16.18	4	18 – 29	23.72	0.01	0.01	20
V	9	0.0002 –	0.0006	–	–	–	–	–	–	na	na	130
Zn	9	0.017 –	0.254	7	2.2 –	64.14	4	28 – 780	189.8	3	na	95

na = not available, *BACKGROUND [15]

Temperature is another factor of great importance for aquatic ecosystem, as it affects organisms, as well as physical and chemical characteristics of waters [21]. The water temperature recorded during the sampling period ranged from 26.5 to 27.2 °C (Table 2). The measured average temperature (26.84°C) fall within the range (25 to 30 °C) that favours not only fish growth but other aquatic life [16]. The temperature appeared to have no substantial negative impact on the water quality.

Electrical conductivity (EC) reflects the level of dissolution of heavy metals and desorption [22]. The conductivity of most freshwaters ranged from 10 to 1000 $\mu\text{s}/\text{cm}$, but may exceed 1000 $\mu\text{s}/\text{cm}$ in polluted waters or those receiving large quantities of land run-off or AMD runoff [23]. Eziegbo and Ezeanyim [6] reported EC value of 1550 $\mu\text{s}/\text{cm}$ in surface water from the Okpara coal mine. However, in the present study, apart from location 7 that had the highest EC value of 1076 $\mu\text{s}/\text{cm}$, all other analyzed samples have EC values that is far less than the 1000 $\mu\text{s}/\text{cm}$ prescribed as limits by the Standard Organization of Nigeria [13]. The high mean EC of 269.7 $\mu\text{s}/\text{cm}$ recorded depicted the water as being laden with ions which are obviously dissolved from the mine dumps by the AMD. The highest EC value was measured in the sample that had the lowest pH value and highest TDS, thereby confirming that dissolved heavy metals are enhanced in acidic waters. Electrical conductivity of the sediment also varies widely, from 18 to 630 $\mu\text{s}/\text{cm}$ with location 2 having the highest value of 630 $\mu\text{s}/\text{cm}$.

The Total Dissolved Solids (TDS), which give a good indication of salinity, ranged from 10 to 538 mg/L in the investigated waters. The Standard Organization of Nigeria pegs acceptable limits for TDS of portable water at 500 mg/L [13]. TDS contents above 1000 mg/L is considered high enough to cause serious electrolyte corrosion [24]. The mean value of TDS of the analyzed water (157.76 mg/L) falls within acceptable range [13], and therefore based on TDS the water is considered safe for drinking and for crop production [25]. The low measured total dissolved solid was possibly due to low dissolution of sulphate, presence of buffers such as calcium, carbonates and bicarbonates [2] or dilution.

In terms of major dissolved components (Table 2), the general trend among the mean values of the cations in the water shows $\text{Na}^+ > \text{K}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$. Sodium content, which is the most abundant, vary between 6.53 and 54.7 mg/L with mean and standard deviation being 14 ± 14.50 mg/L. Next on the line is potassium, a biophilous element [26] with low geochemical mobility. Potassium ranged in composition from 1.17 to 27.85 mg/L with mean value of 12.01 ± 8.44 mg/L. The spatial variation of potassium in the waters of the study area is given in Fig. 3. The sodium and potassium in the waters are most likely sourced through dissolution of feldspars from adjoining basement areas. Calcium and magnesium, which follows potassium in abundance, are responsible for temporary hardness in water. Calcium ranged from 1.42 to 20.17 mg/L with mean and standard deviation of 8.79 ± 5.33 mg/L. The highest level was recorded at location 7 and the least at location 2. Calcium is also biophile, and therefore its low concentration can be explained in terms of the low solubility of feldspathic minerals that comes in contact with the waters [27]. Magnesium has mean and standard deviation of 6.77 ± 3.50 mg/L. Pagenkopf *et al.* [28] reported values of 28 mg/L and 53 mg/L of magnesium and calcium respectively in the Tongue River near Decker coal mine. The magnesium content of the sampled waters are probably sourced from magnesium carbonates.

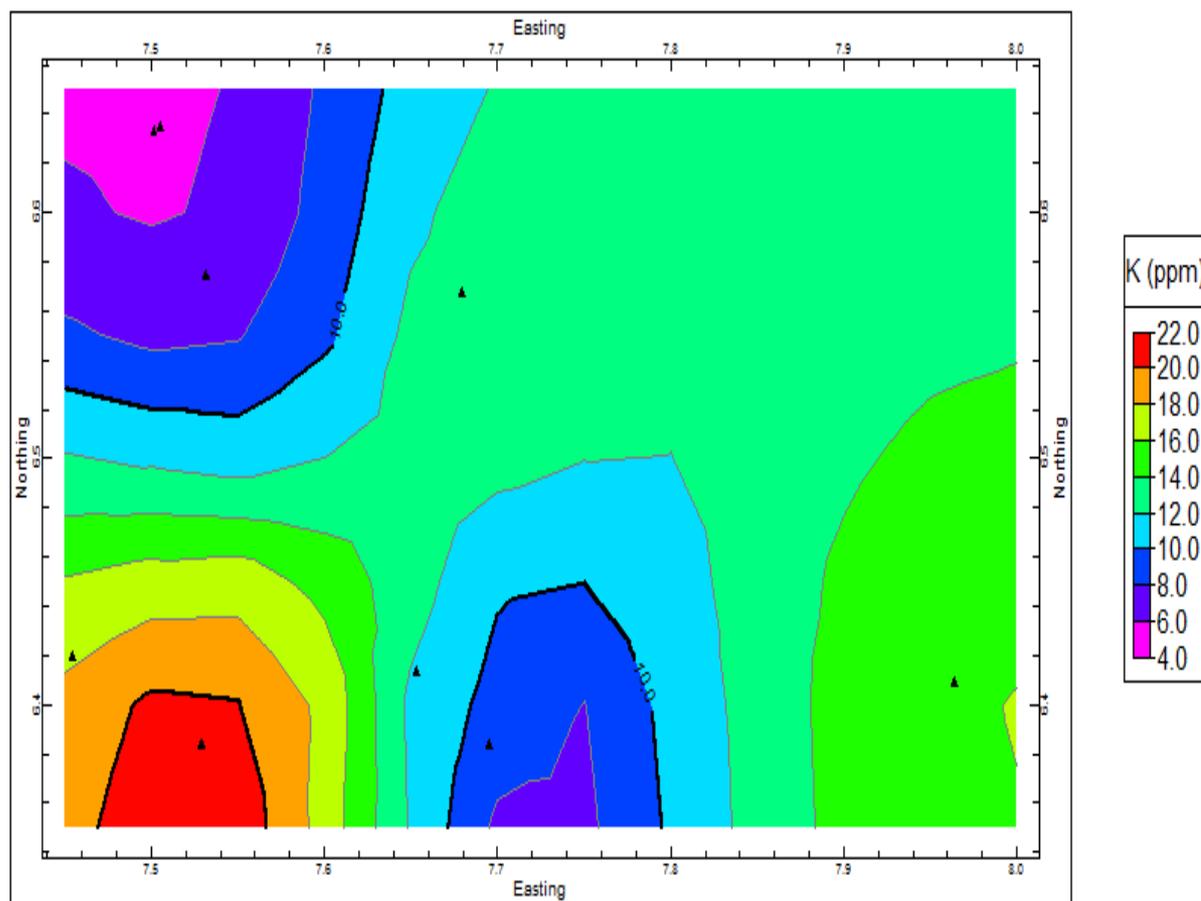


Fig.3. Spatial distribution of potassium in the waters of the study area

As shown in Table 2, the general trend among the mean major inorganic salts contents of the sediments shows $K > Mg > Na > Ca$. A comparative appraisal of the abundance of the inorganic ions/salts (Ca, Mg, Na, K) in the water, sediment and mine dumps revealed that these components are much more concentrated in the sediments and mine dumps than in the sampled waters (Table 2). For instance, in the sediment, Ca varies from 100 to 300 mg/kg as against the 8.79 ± 5.33 mg/L mean Ca concentration in the water; Mg varies from 100 to 400 mg/kg as against the 6.77 ± 3.5 mg/L mean Mg concentration in the water; Na varies from 80 to 60 mg/kg as against the 14 ± 14.5 mg/L mean Na concentration in the water; and K varies from 200 to 6600 mg/kg as against the 12.01 ± 8.44 mg/L mean K concentration in the water. Similarly, the contents of these inorganic salts in the sediments are far in excess of what obtains in the uncontaminated shale of Turekian and Wedepohl[15], which is regarded as the background standard. The dominant anion levels (mg/L) in the waters are in the order: $NO_3^- > Cl^- > SO_4^{2-} > PO_4^{3-}$. Chloride concentration in the sampled waters ranged from 40 to 400 mg/L with mean and standard deviations (SD) of 136.67 ± 401.7 mg/L. Apart from two locations, all the other water samples are below the 250mg/L Cl^- permissible limits prescribed by the Standard Organization of Nigeria [13]. Eziegbo and Ezeanyin[6] reported 230mg/L as mean value of chloride in groundwater of Enugu town. Excess chloride causes salty water taste. The chloride are probably sourced from coal vitrains[4], even though chloride can also come from salt water intrusion. The SO_4^{2-} ion is an indicator for AMD pollution because sulfates are not affected by changes in pH. The concentrations of SO_4^{2-} in the sampled waters varied from 63 to 517 mg/L with mean and standard deviations of 108 ± 149 mg/L. The spatial distribution of sulphates in the water of the study area is given in Fig. 4. Apart from sample no. 7 which had the highest sulphate contents of 517 mg/L, the sulphate concentrations in the waters appear lower than expected, even though the mean value exceeded the 100mg/L permissible limits prescribed for drinking water by the Standard Organization of Nigeria [13]. The unsatisfactory level of sulphate in the waters can be attributed to insufficient pyritization[22]. Sulphates in excess of 250mg/L causes laxative effects, according to Ezeigbo and Ezeanyim[6].

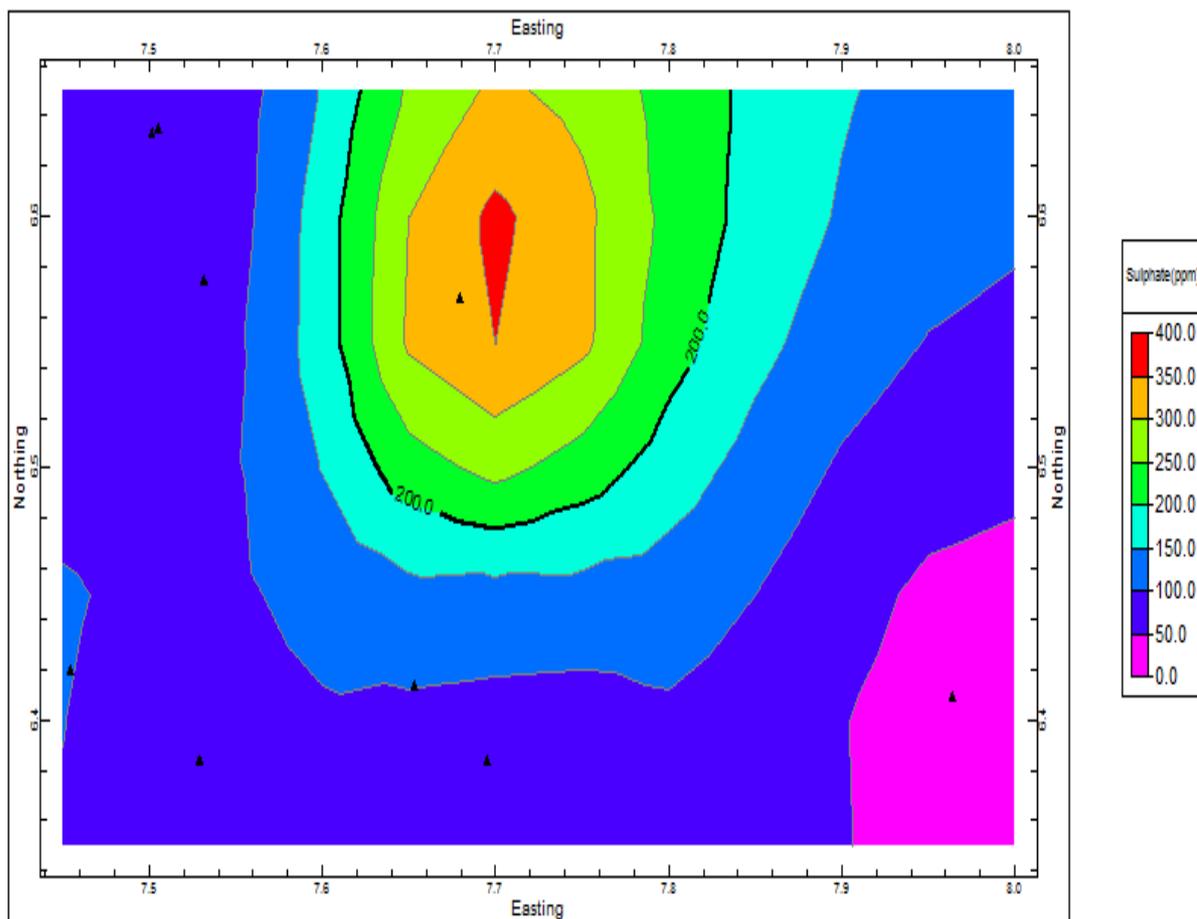


Fig. 4. Spatial distribution of sulphate in the waters of the study area

Nitrates and Phosphorous were the main nutrients measured in the water samples. The concentrations of NO_3^- in the waters varied from 158 to 1012 mg/L with mean and standard deviations of 567.67 ± 250.4 mg/L. The spatial distribution of nitrate in the water of the study area is given in Fig 5. As shown (Table 2, Fig 5), all the water samples (with the exception of sample no 8) display NO_3^- values that is far in excess of the 50 mg/L permissible limits prescribed for drinking water [13, 14]. The high level of NO_3^- calls for concern as it renders the water prone to potential health risk, particularly for pregnant women and infants [29, 30]. Elevated NO_3^- concentration is known to result in cyanosis in infants [31]. The concentrations of PO_4^{3-} ranged between 0.52 and 2.19 mg/L with mean and standard deviations being 1.08 ± 0.74 mg/L. There is currently no Standard Organization of Nigeria and World Health Organization official guideline as to the concentration PO_4^{3-} that is considered safe for drinking water. However, the PO_4^{3-} concentrations in most natural waters vary between 0.005 and 0.020 mg/L [23], and as low as 0.001 mg/L in pristine waters [31]. Considering these values, the measured PO_4^{3-} in the sampled waters, appear to be very high as it far exceeds the levels in most natural waters [23]. High concentrations of phosphate are largely responsible for eutrophic conditions in the water body [31, 32]. The concentration of NO_3^- and PO_4^{3-} revealed that apart from AMD pollution, the investigated waters have probably also been significantly affected by other anthropogenic inputs. Considering the lustrous vegetation that adorns the region, it is not out of place to suggest that the high NO_3^- and PO_4^{3-} concentrations in the shallow groundwater are sourced mostly from fertilizers used for farming activities in the area; while the phosphate probably comes from phosphate fertilizers [27], the sources of the nitrates are most likely legumes and nitrogenous fertilizers.

The concentrations of fluorine in the sampled waters varied from 0 to 45 mg/L with mean and standard deviations of 5.08 ± 14.1 mg/L. The spatial distribution of F^- in the water of the study area is given in Fig. 6. Apart from sample no. 9 which has the highest F^- contents of 45 mg/L, the fluorine concentrations in the waters is less than 0.5 in all other locations. This corroborates the observations of Singh [34] that F^- ion rarely exceeded 0.2 mg/L in mine water. The Sulphur concentration varies from 2 mg/L at location 2 to 151 ppm at location 7, with mean value of 33.89 ± 42.23 mg/L, which is quite high.

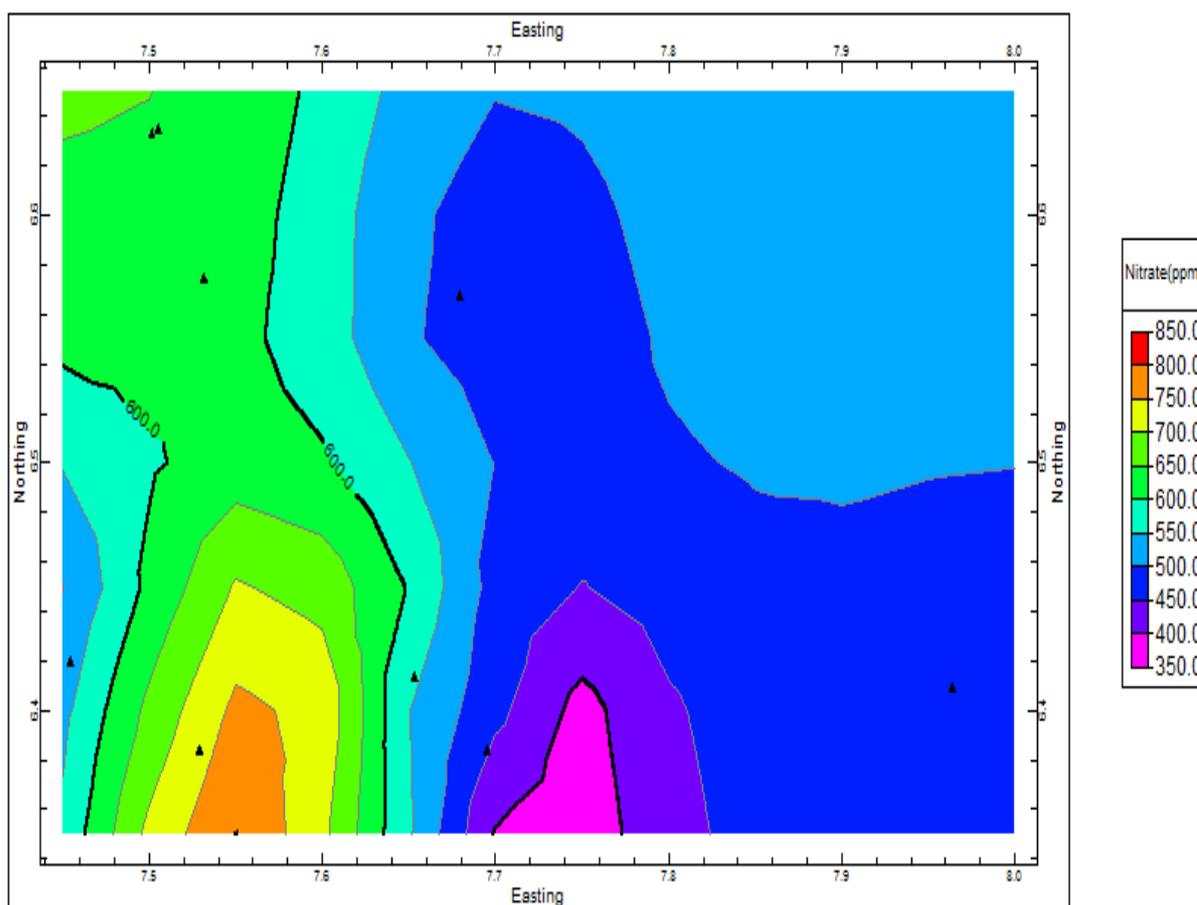


Fig. 5. Spatial distribution of nitrate in the waters of the study area

To further evaluate and interpret the shallow groundwater composition in the study area, major ions were expressed in units of milliequivalents per liter (meq/L) and plotted on Piper trilinear diagram (Fig. 7). Details regarding the geochemical interpretation of water samples on the Piper's trilinear diagram can be found in Piper [35] and Hem [36]. As shown (Fig. 7), the water in the study area displays high $\text{Cl}^- + \text{SO}_4^{2-}$ relative to $\text{HCO}_3^- + \text{CO}_3^{2-}$ in the anion triangle. In the cation triangle, the alkaline earth elements ($\text{Ca}^{2+} + \text{Mg}^{2+}$) exceed the alkali elements ($\text{Na}^+ + \text{K}^+$) even though $\text{N}^{\text{a}+}$ is the leading cation in the water studied. Indication is that the shallow groundwater chemistry is dominated by alkaline earths (Ca^{2+} , Mg^{2+}) and strong acids (SO_4^{2-} , Cl^-). Thus, the hydrochemical facies is the $\text{Ca}^{2+} + \text{Mg}^{2+} - \text{Cl}^- + \text{SO}_4^{2-}$ facies, which agrees with the works of Ezeigbo and Ezeanyim [6] and Utom *et al.* [8].

Heavy Metals Aspect

The distribution of heavy metals in the various media (water, sediment and mine dumps) that were sampled within the study area are summarized in Table 3, and compared to the maximum allowable limits for drinking water in Nigeria [13], World Health Organization guideline for drinking water [14] and average values of uncontaminated shales [15] that is taken as the background values.

As shown in Table 3, the heavy metals in the sampled water are in the order: $\text{Fe} > \text{Al} > \text{Mn} > \text{Zn} > \text{Ni} > \text{Co} > \text{Cu} > \text{Pb} > \text{Mo} > \text{Cr} > \text{V} > \text{Cd}$, thereby projecting Fe as the most abundant heavy metal, and Cd as the least (Table 3). Some heavy metals (for instance, Fe, Al, Mn, Ni) have mean concentrations that exceeded the maximum permissible limits of SON [13], and probably WHO [14], while others (e.g. Zn, Pb, Cd, Cu, Cr, and Mo) displayed mean concentrations that are within acceptable limits of the relevant guidelines (Table 3). Incidentally, the heavy metals (Fe, Al, Mn, Ni and Mg), whose mean concentrations exceeded the maximum permissible limits for portable water are common trace metals that are often associated with AMD from coal mine sites (Rose and Cravotta, 1998). Elevated concentrations of aluminum, iron and manganese, in particular, have been reported in many AMD-impacted environments [37, 38, 39, 40, 41]. In the present study, aluminum, iron, manganese and nickel are higher by 21.50, 17.13, 16.75 and 2.55 times the maximum allowable limits for the relevant chemical species in the Nigerian Standard for Drinking Water Quality (NSDWQ) [13]. This excessive Al, Fe and Mn, coupled with the generally

acidic nature of the water is bound to impact negatively on the ecosystem. In particular, the acid polluted waters is bound to cause ample stress for fish and other aquatic biota [42, 43, 44, 45]. Also, acidic and ferruginous waters are often responsible for the corrosion of mine plants and equipment, formation of scales in the delivery pipes as well as pollution of the mine surface environments, thereby affecting the surface ecology [46].

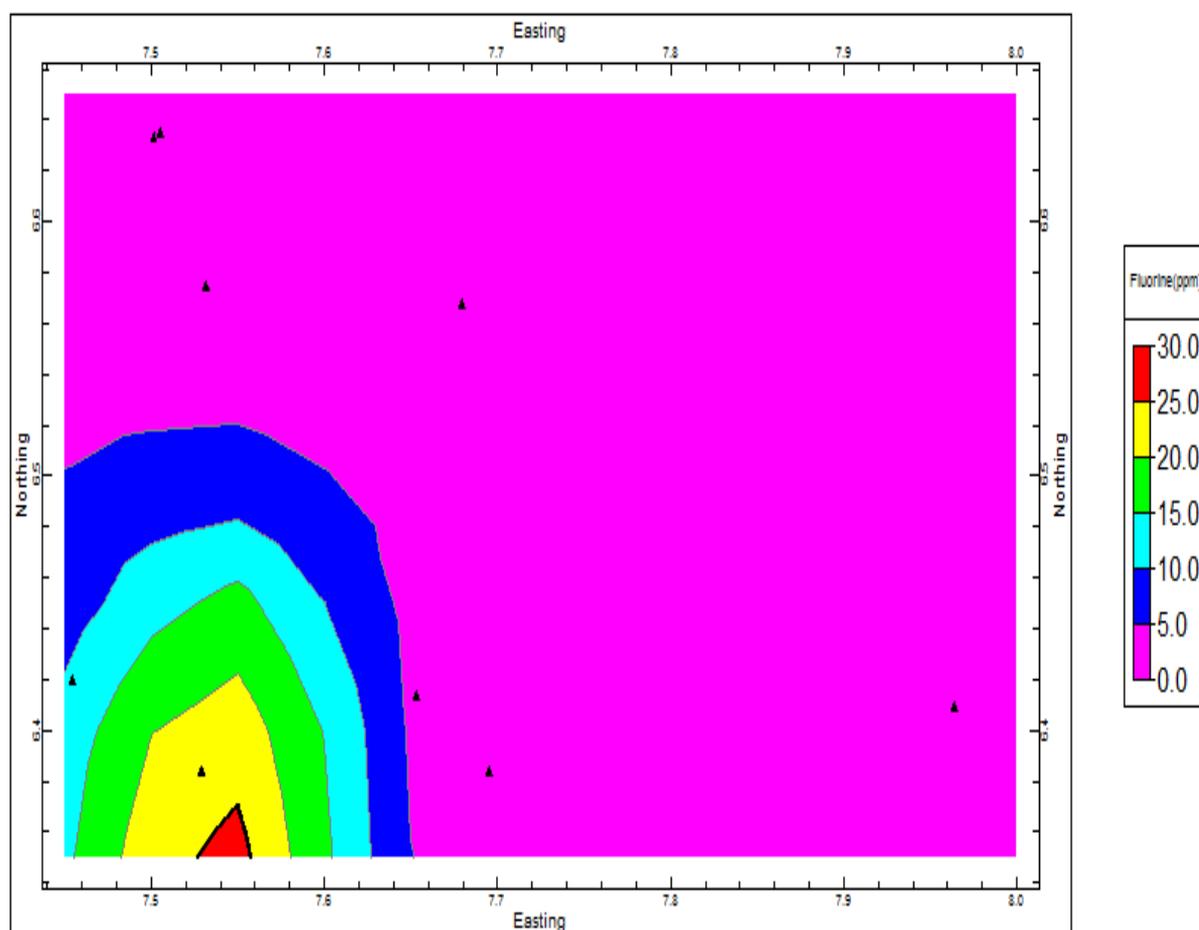


Fig. 6. Spatial distribution of fluorine in the waters of the study area

The mean levels of copper and iron in the sediment (Table 3) which are respectively given as: 30.21 mg/kg and 104,914 mg/kg are higher by 1.47 and 22227 times the background values [15]. In the same way, the respective mean levels of Cr, Fe, Pb and Zn, in the mine dumps, given as: 47.14 mg/kg, 8871.4 mg/kg, 23.72 mg/kg and 189.8 mg/kg are higher by 1.43, 1879.53, 1.19 and 2.00 times the respective background values [15]. Apart from these specified chemical species, the concentration of all other chemical species in the sediment and mine dumps appear to be within acceptable levels of the relevant standards. The heavy metal levels (mg/L) in the sediments are in the order: Fe>P>Cr>Mn>Zn>Cu>Pb>Ni>Co>Cd, while those of the mine dumps are in the order: Fe >Zn > Cu >Cr >Pb> Ni > Co >Mn>Cd (Table 3). Iron is also the most abundant among analyzed heavy metals in the sediment and mine dumps, while Cd is the least, similar to what obtains for the mine water. This similarity in trend supports the idea of Fe being the element of main interest during the AMD. The consequences of having high Fe composition of sediments and mine dumps is that precipitation of ferric hydroxide may result in complete layering of the stream bottom, filling in crevices in rocks and making the substrate unstable and unfit for habitation by benthic organism [47]. Also, worthy of concern (Table 3) is the presence of enrichment loading of various magnitude for heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) occurring in the sediment and mine dumps samples, compared to the relevant concentrations in the mine water. This relative enrichments agree with the observations of Odiete [48] that sediments often holds 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 [49, 50, 51]. The danger here is that the sediments and mine dumps also serves as a pool that can release the heavy metals into the water column by various processes of remobilization [52, 53, 54, 55], 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 [56]. In particular, acute exposure to high concentration of heavy metals can kill organism directly, while long term exposures to lower

concentration causes mortality or other effects, such as stunted growth, lower reproduction rates, deformities and lesions [57].

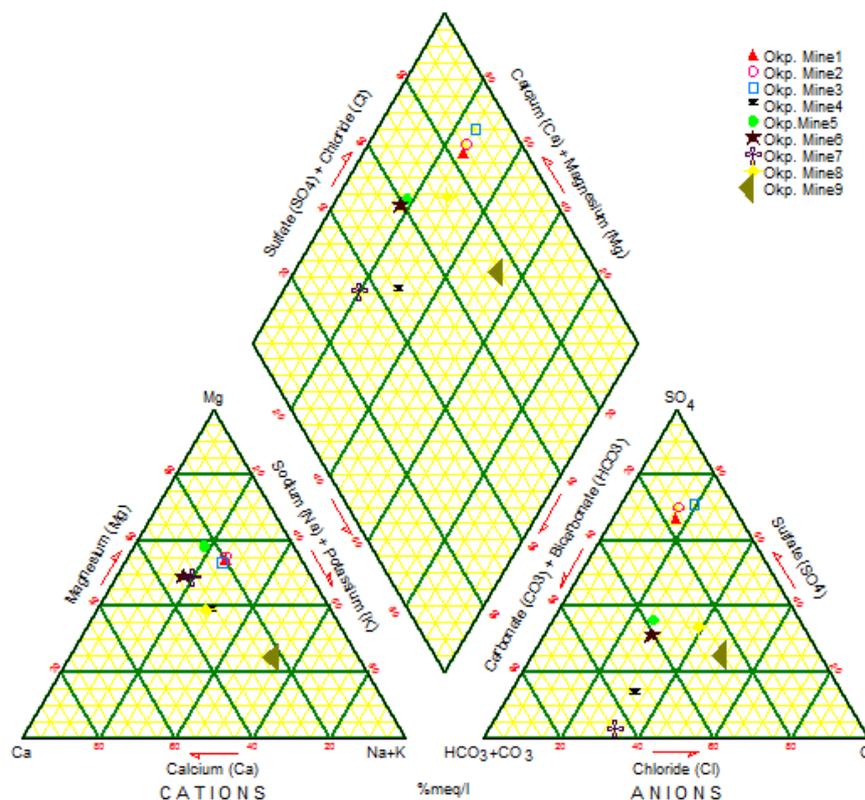


Fig. 7. Pipers trilinear diagrams of the major dissolved solid in waters from the Okpara coal mine areas

CONCLUSION

It is obvious from the present study that acid mine drainage (AMD) around the Okpara coal mine in Enugu area of southeastern Nigeria is associated with many negative impacts. For, instance, the low pH values has the potential to renders the water unsuitable for human consumption, vegetation, aquatic life and wildlife habitation. The elevated sulphates in the water could bring about laxative effects. The excessive concentration of the nutrients such as NO_3^- and PO_4^{3-} makes the water susceptible to numerous potential health risk, especially for pregnant women and infants. High concentrations of phosphate, especially are largely responsible for eutrophic conditions in water bodies. The excessive Al, Fe and Mn, coupled with the generally acidic nature of the sampled water is unfavourable to fish growth and survival of other aquatic biota, among other devastating effects. Acidic and ferruginous waters are also responsible for the corrosion of mine plants and equipment, formation of scales in the delivery pipes as well as pollution of the mine surface environments, thereby affecting the surface ecology. The sediments are not left out as precipitation of ferric hydroxide can result in the complete layering of stream bottom, filling in crevices in rocks and making substrates unstable and unfit for habitation by benthic organism. Furthermore, acidic waters are susceptible to dissolution of minerals and release of toxic heavy metals into the aquatic realm, even though the excessive concentration of iron in the three media sampled, together with the moderate concentration of SO_4^{2-} imply that sorption and co-precipitation of Al and Fe oxides may have been more effective in mobilization and attenuation of the heavy metals than acid induced dissolution. However, whichever way the heavy metals are mobilized and released into the aquatic realm, the emphasis is on the danger imposed. High levels of heavy metals are a nuisance to the environment due to their toxicity and adverse effects on both plants and animals, including human beings. The high concentrations of these heavy metals in the sediments and mine dumps portends imminent danger as the sediments and mine dumps serves as a pool that can release toxic heavy metals into the water column of the area by various processes of remobilization. In view of these negative impacts and hazardous effects, we make the following recommendations:

1. The need for constant monitoring of the quality of both surface- and ground-water in Akwuke and environs, to ascertain if the contaminated mine water has infiltrated portable waters sources. This is because the problem of AMD is not restricted at the source but may extend either laterally or vertically.
2. The need to investigate the health status of human and livestock around the Okpara coal mine area since these populace have over the years depended on the surface and groundwater of the area for their water needs.
3. The need for Government and policy makers to enact suitable legislation that would curb or completely eliminate the menace of acid mine drainage from the Okpara coal mine since active coal mining had since been discontinued in the mine.

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