

BOOK OF PROCEEDINGS ^{PF 1860}

OF

14TH AGM/CONFERENCE

ISSN 1117 - 4307

Theme: Enhancing Mining Investments for Industrial Revolution of Nigeria



MINNA 2014

A Publication of
NIGERIAN SOCIETY OF MINING ENGINEERS

Omanayin, Y.A.
~~Amadi~~

**WATER QUALITY ASSESSMENT AROUND KATAEREGI ARTISANAL GOLD
MINING SITE, NORTH-CENTRAL NIGERIA**

Omanayin, Y.A., Ogunbajo, M.I., *Amadi, A.N., Abdulfatai, I.A., and Mamodu, A.

Department of Geology, Federal University of Technology, Minna, Nigeria

*Corresponding Author's email Address: geoama76@gmail.com

Abstract

Hydrochemical assessment was conducted on streams, mine ponds and hand-dug wells around Kataeregi gold mining site, along Minna-Bida road, North-central Nigeria. This was done in order to evaluate the suitability of the water in the area for both domestic and irrigational purposes. Fifteen quality parameters: Temperature, pH, TDS, EC, SO₄, NO₃, HCO₃, Cl, Ca, Mg, Na, K, Cu, Fe, As and Pb were analysed. The abundance of the major ions was in the order of Ca²⁺ > Na⁺ > Mg²⁺ > K⁺ > Fe²⁺ for cations and HCO₃⁻ > SO₄²⁻ > Cl⁻ > NO₃⁻ > PO₄³⁻ for anions. The water was observed to be earth-alkaline fresh water, which is an indication of water from shallow aquifer system. The results of the field and laboratory revealed that the concentration of most of the parameters were below the maximum permissible limits for a safe drinking water recommended by World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) except for iron, sulphate and lead whose concentrations at some locations were slightly higher than their respective acceptable limits. The high content of iron and sulphate could be attributed to the oxidative weathering of pyrite associated with the gold mineralization in the area while the high lead content observed in the area was due to the weathering and subsequent dissolution of galena, discarded by the artisanal miners during the exploration for gold.

Keywords: Hydrochemical Assessment, Water, Artisanal gold mining, Quality analysis,

Kataeregi, North-central Nigeria

Introduction

Mining activity is usually associated with considerable impacts on the environment and even downstream through surface run off and groundwater movements into large water body that may serve as primary source of water for consumption, consequently affecting health of the immediate host community. Water is an essential commodity for human, plant and animals' existence and survival in any society. Its safety and portability for consumption is as important as its availability. They are naturally harboured in fissures, fractures and highly weathered rocks within the basement terrane and stored in aquifers in the sedimentary formations. Studying the geochemistry of water go a long way in giving important information regarding chemical weathering of rocks and soil and even the suitability of its usage for either domestic, industrial and agricultural purposes.

The chemistry of the natural water stored within or passing through a rock, is greatly influenced

by the composition of the host-rock due to their constant interaction (Amadi et al., 2015). Anthropogenic activities can also alter the relative contributions of the natural causes of variations and introduce the effects of pollution (Srimanta and Uday, 2012). According to World Health Organization (WHO, 2003), about 80% diseases of the world population and more than one-third of the deaths in the developing countries are due to contamination of water, and this justifies the need for the current study. One of the major environmental problems arising from the mining activity is the indiscriminate discharge of mine wastewaters (EEB, 2000). The effluent disposed from gold mines are often associated with potentially toxic elements such as lead, silver, copper, mercury, cyanide and host of others. The availability of these toxic elements in discharged waste water do not only contaminate surface and groundwater, but also responsible for the degradation of aquatic life, animals' species, as well as death and infection of human beings

(Adler and Rustler, 2007)

Gold mining activity has been reported to have impacted negatively on the environment through the discharge of cyanide, mercury and tailings rich in toxic metals (Tarras-Wahlberg et al., 2001). Similarly, activity of artisanal gold mining along River Manyera area, Nigeria has led to land degradation, aquatic life distortion and increments in the concentration of mercury along the River (Oladipo, et al., 2013). Sami (1992) demonstrated that ion exchange, leaching of surficial salts and residential time caused hydrochemical variations on groundwater from a semi-arid sedimentary basin, Eastern Cape, South Africa.

In area where informal mining activity take place, mine waste and rock dumps increase dissolution of solid load in water body affecting it quality (Ogezi, 2005; Aibedion, 2005). There is a relationship between surface or groundwater system pollution and refuse dump in an area (Saxena, 1977), while mining and processing of minerals along the streams can increase the impulse of naturally occurring substances into the locality and increase their concentration from harmless to toxic level (Nnabo et al., 2011).

The gold mineralization in the area occurs in association with pyrite and galena. The local geology as well as the anthropogenic activity (artisanal gold mining) in the area may be responsible for the deterioration of water quality in the area. The danger associated with crude gold mining with respect to water quality formed the pivot on which this research revolved. Since artisanal gold mining is very active in Kataeregi mining site, it becomes imperative to investigate the impact on surface water (stream and mine pond) as well as groundwater from shallow hand-dug wells in the area in order to know the current pollution status and the suitability of such waters for domestic and agricultural purposes. This is necessary to avoid a repeat of lead poisoning in Zamfara State and Rafi Local Government Area of Niger State.

Study Area Description

The study area is located within Kataeregi area, North-central Nigeria and is accessible through Minna - Bida road (Fig. 1). The area is part of Bida Sheet 184 NE and is located between Latitudes 09°21'N to 09°25'N of the Equator and Longitudes 06°17'E to 06°22'E of the Meridian on the scale of 1:25,000 covering a total area of

about 68km² (Fig. 1). It is approximately 40km south of Minna and about 4km North of Kataeregi village. The area consists of low-lying terrain and few gentle hills generally ranging from 106m to 152m, while isolated areas rise up to about 167m notably in the South-eastern part. The study area has an alternating wet and dry season. The rainy season spans between May and October with total annual rainfall of about 1324mm (NIMET, 2010) while the dry season starts from November to April with harmattan occurring between December and February. The average annual temperature ranges in the area is about 30°C (NIMET, 2010). The vegetation is typical guinea savannah grassland with scattered shrubs, short grasses of height 3 to 4.5 meters and trees of up to 15 meters high. The vegetation is commonly thick at the base of the hills and river banks which is a characteristic of rich soils and moist condition for plant growth. The study area is drained by River Chanchaga and its tributaries.

Geology of the Area

Geology and Hydrogeology of the area

The study area is situated within the North-central Nigeria and composed of mixed geological terrain of basement and sedimentary rocks. The major rock units are the Migmatite, granite-gneiss complex occupying about 60%, schist about 20% and Bida sandstone having the remaining 20% (Fig. 2). The central portion of the study area is dominated by schistose rocks that serve as host to auriferous quartz veins in the area. The schists are intercalated with amphibolites observable along the River Chanchaga under the bridge at Gada. This schist had already been mapped and considered as part of the Kushaka Schist Formation (Truswell and Cope, 1963). It was later given distinctive formational name, Ushama Schist Formation on the basis of uncertainties of correlation of the belts lithologies (Turner, 1983; Ajibade et al., 1987). The schist is intruded by plutonic rock and exposed around Sabon Eregi, Kataeregi with xenoliths of phyllites (Truswell and Cope, 1963). North and South-eastern parts of the study area is occupied by migmatite granite-gneiss complex and to the extreme south-western part, is occupied by the Bida sandstone.

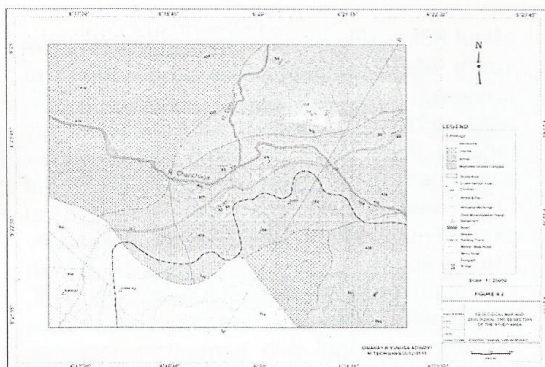


Fig. 2: Geology map of the area

Materials and Methods

A total of seventeen (17) water samples from both mine ponds and streams draining the study area were collected randomly and analysed at the National Water Quality Reference Laboratory, Federal Ministry of Water Resources, Minna. The water samples were collected in pairs of 60ml pre-washed glass for anion determination while pre-washed plastic bottles were used to collect samples for both cation and trace metals determination with addition of two drops of concentrated trioxonitrate (V) acid for

preservation. Sampling was done in January 2014 and the locations of the sample points were also recorded using a hand-held Garmin GPS receiver (Table 1). Relevant physical parameters such as Temperature, pH, total dissolve solid (TDS) and electrical conductivity (EC) were determined insitu with the aid of Milkaukee (Mi 806) combined meter on the water samples collected before taken to the laboratory.

Laboratory Analysis

Chemical parameters analysed include: SO_4 , NO_3 , HCO_3 , Cl , Ca , Mg , Na , K , Cu , Fe , As and Pb in the laboratory. Sulphate ion was determined by spectrophotometric turbidimetry. This method is based on the principle of formation of barium sulphate in the presence of acidified (HCl). The absorbance of the colloidal solution was measured against a standard on UV visible spectrometer at a wavelength of 420nm. Nitrate ion was determined by colorimetry with an UV visible spectrometer (brucine method). Bicarbonate was determined by titration using 0.1M HCl; chloride was determined by standard 0.1M $AgNO_3$ titration. Calcium and magnesium ions

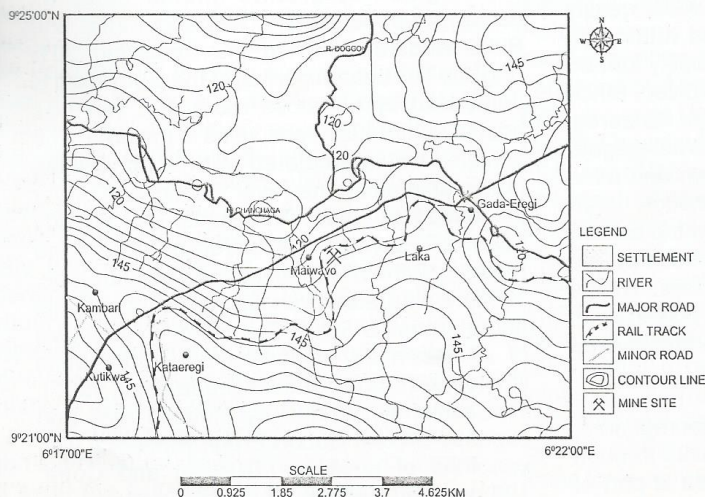


Fig. 1: Map of the Study Area

were determined by EDTA Complexometric method using EDTA solution. Sodium (Na^+) and potassium (K^+) were measured by flame photometry; copper (Cu^{2+}) was determined by colorimetry using CuVer 1 reagent to form purple colour complex. Iron was determined by colorimetry with an UV-visible spectrometer at 520 nm. Arsenic was determined using arsenic visual detection kit. The technique is based on visual observation and matching of resultant colour to the corresponding colour chart while lead was determined using atomic absorption spectrometry. All samples were analysed using standard methods as recommended by the American Public Health Association (APHA, 1995). Results were

compared with World Health Organization Standard (WHO, 2011) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007)

Table 1: Coordinates of sampled points

S/N	Sample Code	Latitudes (N)	Longitudes (E)	Elevation (m)
1	Yw1a	09°22'39.6"	006°19'04.5"	136
2	Yw1b	09°22'39.5"	006°19'04.4"	136
3	Yw1c	09°22'39.6"	006°19'04.5"	136
4	Yw2	09°22'40.5"	006°19'14.9"	117
5	Yw3	09°22'43.8"	006°19'19.7"	120
6	Yw4a	09°22'57.6"	006°19'24.0"	128
7	Yw4b	09°22'57.7"	006°19'24.1"	128
8	Yw5	09°23'05.0"	006°19'20.2"	105
9	Yw6	09°23'10.5"	006°20'09.0"	126
10	Yw7	09°23'15.2"	006°20'58.6"	120
11	Yw8	09°22'28.2"	006°18'39.9"	129
12	Yw9	09°22'58.9"	006°19'45.2"	128
13	Yw10	09°23'10.4"	006°20'09.0"	128
14	Yw11	09°22'59.9"	006°20'52.8"	128
15	Yw12	09°23'30.0"	006°21'10.1"	123
16	Yw13	09°23'21.04"	006°17'50.1"	122
17	Yw14	09°23'14.8"	006°19'35.0"	110

Results and Discussion

Physical Parameters

The geochemical analysis of the water samples and their average concentrations is presented in Table 2. The ambient temperature ranges from 26.5°C to 29.6°C with mean value of 27.95°C indicates suitability for human consumption. Since water with lower temperature reveals presence of pollution while those with warm temperature as obtained from the study area is preferred and considered healthy. The pH value ranged from 6.93 to 7.57 with average value of 7.07 which is approximately neutral and recommended for domestic use since it falls within the permissible limit of WHO (2011) and NSDWQ (2007). This neutrality of the water can be attributed to equal ionic exchange between acid and base contents. Electrical Conductivity (EC) indicates the amount of material dissolved in water, the value ranged from 70µs/cm to

1064µs/cm with mean value of 309.24µs/cm. It falls within the WHO, 2011 and NSDWQ, 2007 (1000µs/cm) except for locations where gold is been processed. Values of total dissolve solid (TDS) varies from 30mg/l to 533mg/l with mean value of 166.53mg/l which also falls within the WHO, 2011 and NSDWQ (500mg/l). The slight increment in some EC value may be attributed to variation in geological formations, hydrological processes and prevailing gold mining activities in the area (Srimanta and Uday, 2012).

Chemical Parameters

The concentrations of calcium varied from 20.03mg/l to 121.04mg/l, magnesium from 1.44mg/l to 31.70mg/l, sodium from 8.0mg/l to 51.0mg/l and potassium from 1.0mg/l to 16.01mg/l with the corresponding averages of 41.25, 20.83, 12.58 and 6.58 respectively and in the order of abundance is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ (Figure 3). The values of calcium and magnesium (alkaline earth metals) are lower when compared with the WHO, (2011) and NSDWQ, (2007). Magnesium and calcium ions is usually known to contribute to water hardness, their low concentration indicates soft water in the area (Amadi *et al.*, 2014). Though, slight elevation in the values recorded in some parts can be attributed to the mining activity in the area. The values of bicarbonate varied from 17.0 to 90.0, sulphate from 0.0 to 190.0, chloride from 12.0 to 26.10, nitrate from 2.30 to 8.62 and phosphate from 0.89 to 3.67 concentrations (on the basis of mg/l) with their corresponding averages 32.01mg/l, 31.14mg/l, 17.65mg/l, 4.86mg/l and 2.04mg/l and in the order of abundance: $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-} > PO_4^{3-}$. These values are far below the maximum permissible limit recommended by NSDWQ, (2007). It is an indication of minimal chemical weathering effect and low level of agricultural practices in the area. This is because the people in the area are engaged in artisanal mining. High sulphate concentration was recorded around the mining area and it can be attributed to the oxidative weathering of pyrites in the host rock around Kataeregi gold mining in the region. The concentration of the cations and anions were shown in figures 3 and 4 respectively.

Table 2: Results of the geochemical parameters in water samples from Katarengi area and their average concentrations

Parameters, (Mg/l)	Samples														Average value			
	Yw1a	Yw1b	Yw1c	Yw2	Yw3	Yw4a	Yw4b	Yw5	Yw6	Yw7	Yw8	Yw9	Yw10	Yw11		Yw12	Yw13	Yw14
Temp (°C)	26.50	26.5	26.6	27.2	27.0	28.1	28.1	28.9	28.1	29.6	28.6	29.0	29.3	29.3	27.0	26.8	28.6	27.95
pH	7.28	7.28	7.28	7.14	7.57	6.94	6.94	6.94	6.94	6.94	7.16	6.93	6.94	6.94	6.96	7.20	6.93	7.07
TDS	170.0	172.0	171.0	130.0	260.0	530.0	533.0	50.0	80.0	40.0	100.0	90.0	60.0	30.0	50.0	60.0	75.0	166.53
EC (µS/cm)	340.0	342.0	341.0	270.0	530.0	1060.0	1064.0	100.0	160.0	90.0	210.0	180.0	120.0	70.0	110.0	120.0	150.0	309.24
SO ₄ ²⁻	24.0	24.1	24.3	0.0	1.0	188.0	190.0	15.0	0.0	13.0	0.0	1.0	0.0	10.0	12.0	14.0	13.0	31.14
NO ₃ ⁻	4.70	4.80	4.75	2.35	6.42	3.48	3.47	8.62	5.14	4.83	2.30	6.52	5.02	3.63	4.90	6.63	5.12	4.86
HCO ₃ ⁻	35.0	35.5	35.4	46.0	90.0	25.0	25.01	17.0	27.0	21.0	43.0	28.9	23.0	19.2	20.0	27.20	26.0	32.01
CO ₃ ²⁻	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Cl ⁻	22.0	22.10	22.05	17.0	23.0	24.0	24.02	14.0	12.0	15.0	15.0	13.0	13.20	12.0	13.0	26.10	12.50	17.65
PO ₄ ³⁻	2.24	2.25	2.23	1.45	0.89	1.62	1.63	3.04	1.19	3.67	1.32	1.32	2.06	3.01	2.60	2.94	1.25	2.04
Ca ²⁺	41.6	41.65	41.63	27.2	53.7	121.0	121.04	35.3	21.6	22.4	25.6	23.10	21.9	20.03	22.63	39.20	21.70	41.25
Mg ²⁺	1.46	1.47	1.44	15.6	31.7	28.3	28.32	5.86	15.6	9.27	15.3	16.84	11.27	6.89	6.34	5.10	13.02	12.58
Na ⁺	31.0	31.02	31.01	18.0	51.0	30.0	30.03	13.0	8.0	16.0	18.2	10.0	13.0	14.0	14.60	15.17	10.01	20.83
K ⁺	9.0	9.01	9.0	8.0	1.0	16.0	16.01	4.0	4.0	4.0	8.1	4.1	3.9	3.9	3.89	4.0	4.0	6.58
Cu ²⁺	0.07	0.07	0.08	0.04	0.02	0.05	0.05	0.02	0.03	0.04	0.03	0.04	0.03	0.03	0.02	0.03	0.03	0.04
Fe ²⁺	1.35	1.36	1.34	2.21	0.00	0.10	0.11	3.54	0.17	3.46	2.10	0.19	2.02	2.90	3.24	2.30	0.19	1.56
As ³⁺	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Au ⁺	Nd	Nd	Nd	Nd	0.008	Nd	nd	0.006	Nd	0.008	Nd	0.007	Nd	Nd	nd	0.002	0.006	0.006
Pb ²⁺	0.577	0.556	0.580	0.910	0.334	0.702	0.704	0.566	0.384	0.914	0.222	0.384	0.322	0.705	0.940	0.728	0.689	0.601

nd = not detected

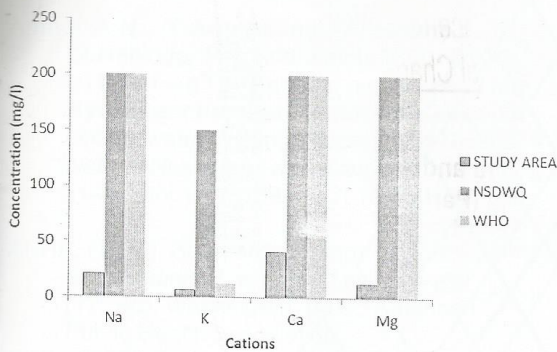


Fig. 3: Correlation of the mean concentration of cations with WHO and NSDWQ Standards

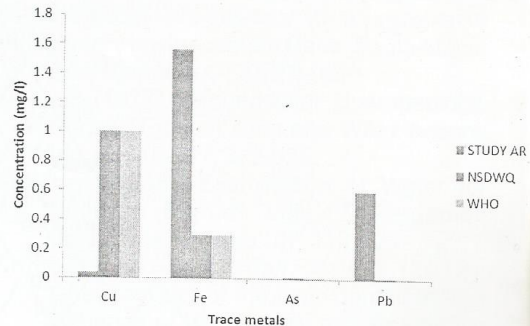


Fig. 5: Correlation of mean concentration of heavy metals with WHO and NSDWQ Standards

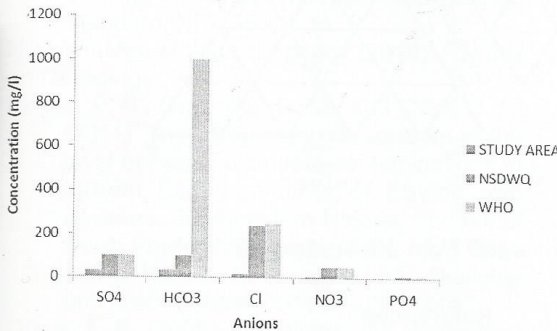


Fig. 4: Correlation of the mean concentration of anions with WHO and NSDWQ Standards

The following trace metals were analyzed: Copper, iron, lead and Arsenic. The concentration of Copper varies from 0.02mg/l to 0.08mg/l with average value of 0.04mg/l which is lower than the WHO and NSDWQ maximum permissible limits of 1.00mg/l. Also, the concentrations of iron vary from 0.0mg/l to 3.54mg/l and lead from 0.222mg/l to 0.940mg/l and represented on an average of 1.56mg/l and 0.60mg/l respectively, and these values exceeds the WHO and NSDWQ maximum permissible limits (0.30mg/l and 0.01mg/l) respectively. Local geology can influence the increase in lead concentration in natural water around the mining site since it is commonly associated with gold mineralization. Also, according to Srimanta and Uday (2012), anthropogenic activity can cause an increase in

lead concentration in natural water as it is extensively used in some pesticides such as lead arsenate. The mean concentration of the trace elements is shown in figure 5.

Hydrochemical Facies

The variation in the hydrochemical phases of water can be assessed and interpreted by plotting their major cation and anion in the piper trilinear diagram (Srimanta and Uday, 2012). The geochemical evolution of mine pond and stream water in the study area was however done and described from Piper diagram.

The result shows that major ion composition plotted on a Piper trilinear diagram reveals that maximum samples (Yw1a, Yw1b, Yw1c, Yw5, Yw7, Yw11, Yw12 and Yw13) clustered at group-e (SO_4^{2-} type), four samples (Yw2, Yw3, Yw8 and Yw10) clustered at group-d (HCO_3^- type), three samples (Yw6, Yw9 and Yw14) clustered at group-b (Predominantly $HCO_3^- + SO_4^{2-}$ type) and the last two samples (Yw4a and Yw4b) remain in group-c (Sulphatic water type) (Figure 6). This indicates that mine pond and stream water in study area falls within earth-alkaline fresh water with high alkaline content, and the water is mostly sulphate type. This may be controlled by input from the oxidative weathering of pyrites associated with gold mining and intense chemical weathering that take place along the stream channels

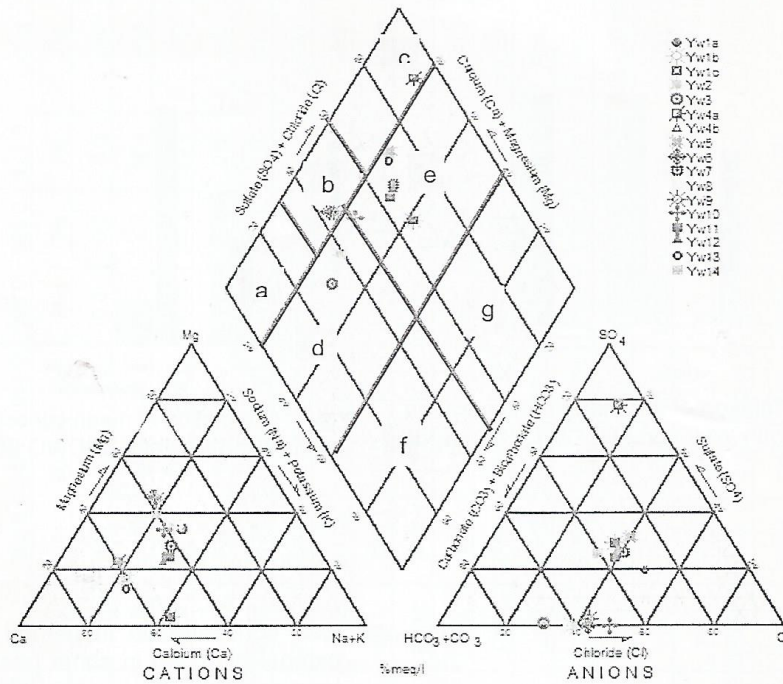


Fig. 6: Piper Diagram of water from the study area

Conclusion

The study of water quality around Kataeregi gold mining area as revealed from the geochemical analysis, hydrochemical classification and charts deduced in relation to WHO (2011) and NSDWQ (2007) indicates earth-alkaline fresh water with high alkaline content, and the water is mostly sulphate type and considered suitable for human use. The physical and some chemical parameters studied are far below the permissible maximum limit required in NSDWQ. However, possible water contaminant in the area are Fe, SO_4 and Pb. Fe and SO_4 contamination could be due to oxidative weathering of pyrite associated with the gold mineralization. Lead contamination could be attributed to input from the local geology of the area and human activity. Measures should be put in place for adequate removal of sulphate while reduction in concentration of iron is advised since it is needed but in minimal quantity in the body to prevent guitar. Also, the use of herbicides for agricultural practices should be discouraged and indiscriminate disposition of mine waste be prevented.

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