WATER QUALITY INVESTIGATION WITHIN THE NEIGHBOURHOOD OF KATAEREGI ARTISANAL GOLD MINING SITES, NORTH-CENTRAL NIGERIA

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Abstract

Hydrochemical analysis was performed on water samples obtained from streams, mine ponds and hand-dug wells within the neighbourhood of Kataeregi gold mining site, located along Minna – Bida road in North-central Nigeria. The exercise is aimed at ascertaining the suitability of water from streams and hand-dug wells for both domestic and irrigational purposes. The parameters analysed for comprise of Temperature, Acidity – Alkalinity level (pH), Total Dissolved Solids (TDS), Electrical Conductivity (EC), and concentrations of SO_4^{2-}, NO_3^-, HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cu^{2+}, Fe^{2+}, As^{3+} and Pb^{2+}. Geological field mapping show the area comprise of the Migmatite-Gneiss Complex, Schist, Granite and Sandstone lithologies. The concentrations of Fe^{2+} and Pb^{2+} far exceed World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) prescribed limits for irrigation, potability and other domestic purposes. The high content of iron 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. All water bodies in the area belong to earth-alkaline fresh water, which is an indication of water from shallow aquifer system.

Keywords: *Hydrochemical Assessment, Water, Artisanal gold mining, Quality analysis, Kataeregi, North-central Nigeria*

Introduction

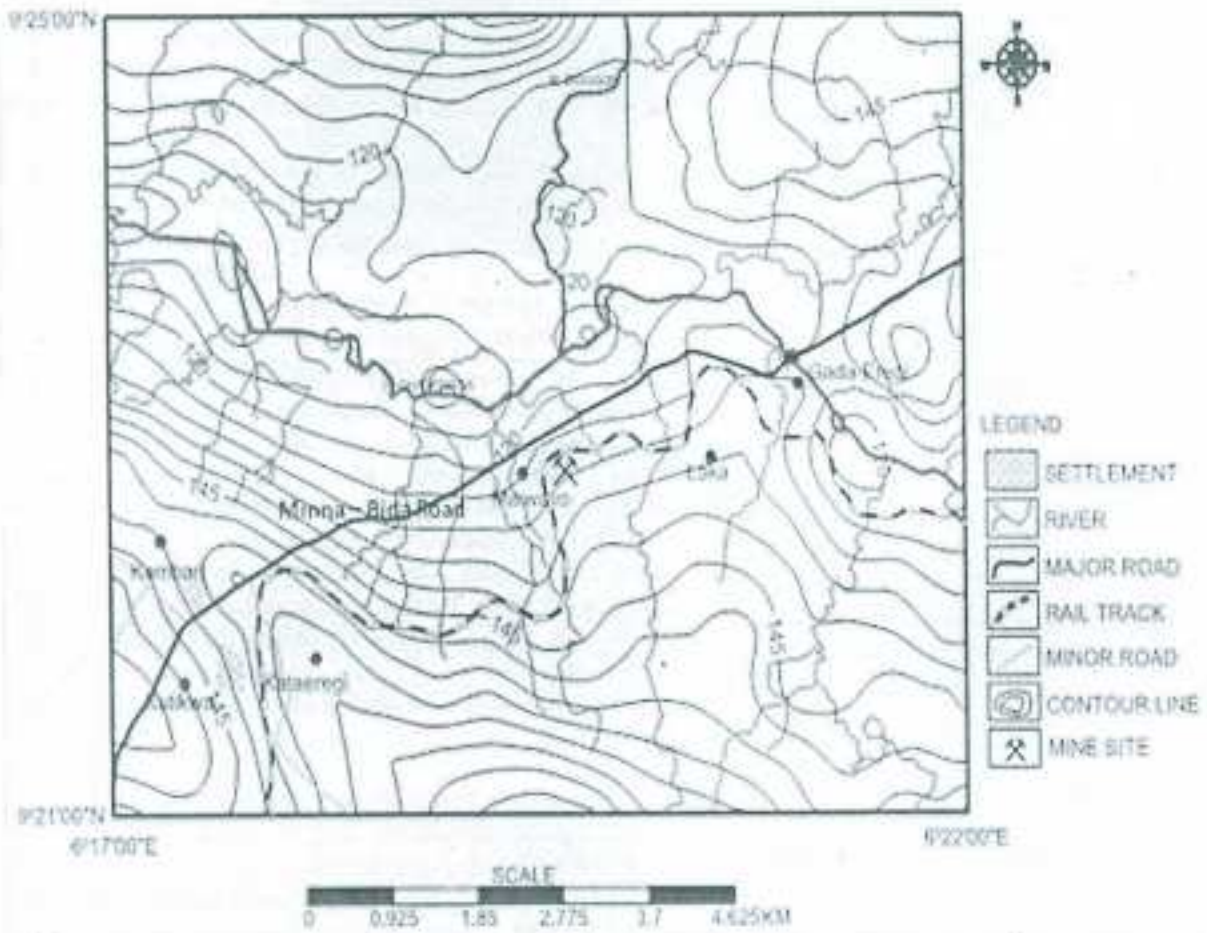
Mining activities do negatively impact on the environment and even in areas farther away. Effluents discharged from gold mines often contain dissolved potentially toxic ions such as Pb^{2+}, Ag^{2+}, Cu^{2+}, Hg^-, CN^-, among a host of others (Tarras-Wahlberg et al., 2001). These eventually reach surface and ground water bodies that may serve as primary source of water for consumption, contaminate and ultimately pollute them. Consequently, aquatic life is degraded, and human beings as well as other animal species subjected to a range of diseases (Adler and Rustler, 2007). Water is an essential commodity for human, plant and animals existence and survival in any society. Its safety and potability is as important as its availability. They are naturally harboured in fissures, fracture and highly weathered rocks within the basement tertian and stored in aquifers in sedimentary formations. Studying the chemistry 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.

Artisanal gold mining activities along River Manyera area in Nigeria generated land degradation, aquatic life distortion and increase in Hg^+ along the river bank (Oladipo et al., 2013). In areas where informal mining activity takes place, mine waste and rock dumps increase dissolution of solid load in water body, thereby negatively impacting water quality (Ogezi, 2005; Aigbedion, 2005). The reported danger often associated with gold mining necessitates the investigation of the chemical quality of water supply sources in the neighbourhood of Kataeregi gold mining sites.

Location, Topography, Climate and Vegetation of the Study Area

The study area is located around Kataeregi Town in 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 and Longitudes 06°17□E to 06°22□E on the scale of 1:25,000 covering a total area of about 68km^2 (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 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.



Local Geology of the Study Area

The area is composed of mixed geological terrain of basement and sedimentary rocks. The rock units are the Migmatite-Gneiss Complex, Schist, Granite and Bida Sandstone (Fig. 2). The central portion of the study area is dominated by schistose rocks that serve as host to auriferous quartz veins where the artisanal mining is taking place. 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-Gneiss Complex, Granite and to the extreme south-western part, is occupied by the Bida Sandstone.

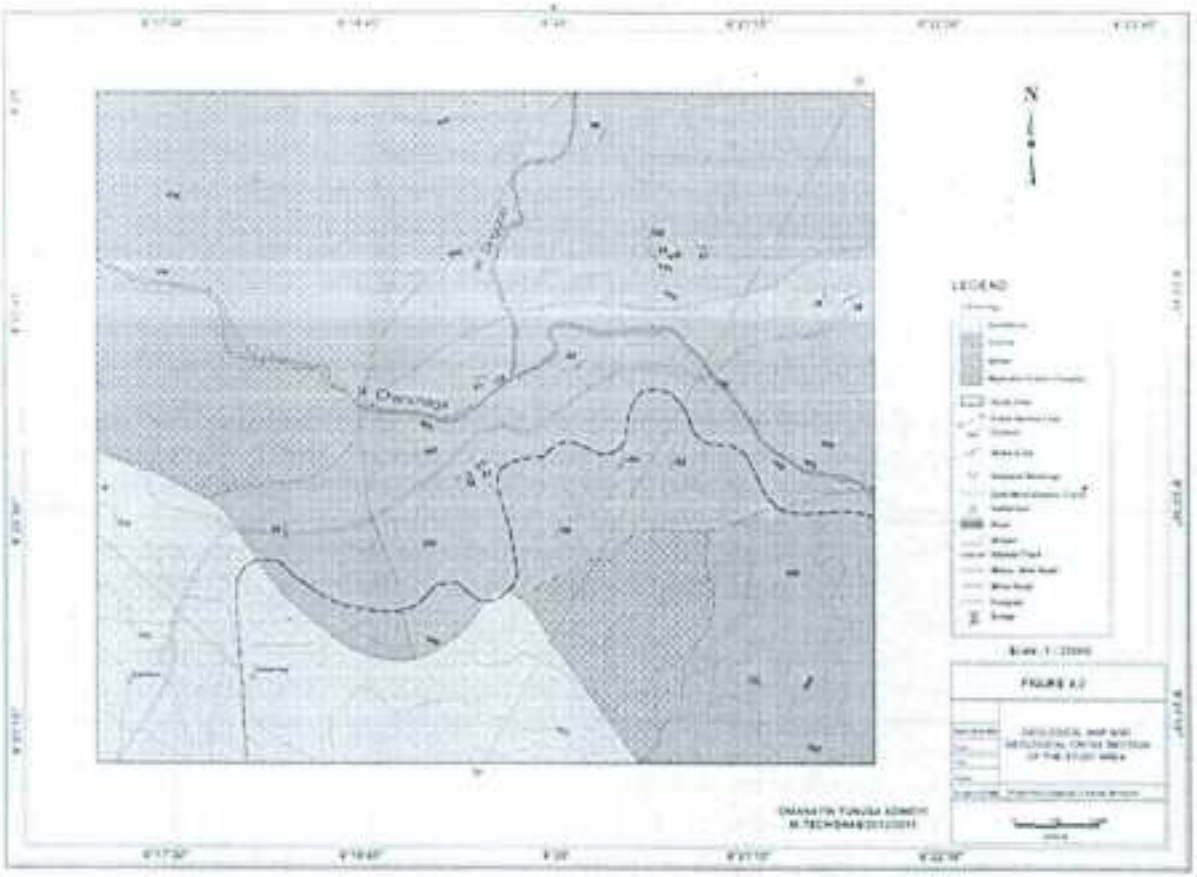


Fig. 2: Geological map of the study area

Materials and Methods

The methods employed in this research involve both field work and laboratory analysis. During the field work, spatial distribution of rock outcrops were observed, studied and located on a map with which the geological map would be generated. Artisanal mining activity was observed to be concentrated in the central portion of the study area. Series of trenches were made by these artisans and there target was the quartz veins that cross-cut the schist outcrops in the area. They dug several ponds with which they process the mined material using gravity separation method and followed by gold amalgam to separate the gold from other heavy metals. The processing areas were sited along the stream channels and banks of River Chanchaga been the main river draining the study area.

Seventeen water samples from hand-dug wells, mine ponds and streams draining the study area were collected systematically 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 concentration of anions determination while pre-washed plastic bottles were employed to collect samples for both cations and trace metals concentration determination. Two drops of concentrated trioxonitrate (V) acid were added to the samples to preserve them. Locations of the sample points were also recorded using a hand-held Garmin GPS receiver (Table 1). Temperature, pH, TDS and EC attributes of the water samples were determined in situ with the aid of Milkaukee (Mi 806) combined meter. Subsequent analysis was conducted in the laboratory.

Laboratory Analysis

Respective concentrations of SO_4^{2-}, NO_3^-, HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cu^{2+}, Fe^{2+}, As^{3+} and Pb^{2+} were determined. Sulphate ion was determined by spectrophotometric turbidimetry. This method is based on the principle of formation of barium sulphate in the presence of HCl. The absorbance of the colloidal solution was measured against a standard on UV visible spectrometer at a wavelength of 420nm. Nitrate ion concentration was determined by colorimetry with an UV visible spectrometer (brucine method). Bicarbonate ion concentration was determined by titration using 0.1M HCl; chloride ion concentration was determined by standard 0.1M $AgNO_3$ titration. Concentrations of Calcium and Magnesium ions were

determined by EDTA Complexometric method using EDTA solution. Concentrations of Na^+ and K^+ were measured by flame photometry; concentration of Cu^{2+} was determined by colorimetry using CuVer 1 reagent to form purple colour complex. Ionic concentration of Iron was determined by colorimetry with an UV-visible spectrometer at 520nm. Arsenic concentration 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)

Results and Discussion

Physical Parameters

Table 2 contains the average values of the determined physico-chemical parameters, and Nigerian Standard for Drinking Water Quality and World Health Organization Standards. The ambient temperature ranges from 26.5°C to 29.6°C with mean value of 27.95°C. Lower water temperatures would indicate presence of pollutants. The pH value ranged from 6.93 to 7.57 with average value of 7.07. This is approximately neutral and recommended for domestic use because it lies within the permissible limit of WHO (2011) and NSDWQ (2007). The neutrality of the water can be attributed to equal ionic exchange between acid and base contents. Electrical Conductivity value ranged from 70µS/cm to 1064µS/cm with mean value of 309.24µS/cm. This is within the prescribed WHO (2011) and NSDWQ (2007) ranges except for locations where gold is been processed. Values of Total Dissolve Solids vary from 30mg/l to 533mg/l, and averages at 166.53mg/l. This is within the WHO and NSDWQ prescribed limit range.

Chemical Parameters

The concentration of Ca^{2+} vary from 20.03mg/l to 121.04mg/l, Mg^{2+} from 1.44mg/l to 31.70mg/l, Na^+ from 8.0mg/l to 51.0mg/l and K^+ from 1.0mg/l to 16.01mg/l. Their respective averages are 41.25, 20.83, 12.58 and 6.58 mg/l. Their order of abundance is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ (Figure 3). The concentrations of values of Ca^{2+} and Mg^{2+} (alkaline earth metals) are lower when compared with the WHO and NSDWQ standards (Table 2). Magnesium and Calcium ions are usually known to contribute to water hardness. Thus, their low concentration indicates soft water in the area (Amadi *et al.*, 2014). Concentration of HCO_3^- varied from 17.0 to 90.0, SO_4^{2-} from 0.0 to 190.0, Cl^- from 12.0 to 26.10, NO_3^- from 2.30 to 8.62 and PO_4^{3-} from 0.89 to 3.67mg/l. Their respective averages are 32.01mg/l, 31.14mg/l, 17.65mg/l, 4.86mg/l and 2.04mg/l. These values are far below the maximum permissible limit recommended by NSDWQ, (2007). It is an indication of minimal chemical weathering effect in the area. However, high SO_4^{2-} concentration was recorded around the mining site and it can be attributed to the oxidative weathering of 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:
Summary of the physico-chemical parameters of water samples and standards

Parameters (mg/l)	Range	Average conc. of 17 samples	NSDWQ, 2007	WHO, 2011
Temp (°C)	26.5 – 29.60	27.95	Ambient	Variable
pH	6.93 – 7.57	7.07	6.50 – 8.50	7.0 – 8.5
TDS	30.00 – 533.00	166.53	500.00	1000.00
EC (µS/cm)	70.00 – 1064.00	309.24	1000.00	1000.00
SO_4^{2-}	0.00 – 190.00	31.14	100.00	100.00
NO_3^-	2.30 – 8.62	4.86	50.00	50.00
HCO_3^-	17.00 – 90.00	32.01	100.00	1000.00
CO_3^{2-}	0.00 – 0.00	0.00	100.00	100.00
Cl^-	12.00 – 26.10	17.65	240.00	250.00

PO_4^{3-}	0.89 – 3.67	2.04	10.00	10.00
Ca^{2+}	20.03 – 121.04	41.25	200.00	200.00
Mg^{2+}	1.44 – 31.70	12.58	200.00	200.00
Na^{+}	8.00 – 51.00	20.83	200.00	200.00
K^{+}	1.00 – 16.01	6.58	150.00	12.00
Cu^{2+}	0.02 – 0.08	0.04	1.00	1.00
Fe^{2+}	0.00 - 3.54	1.56	0.30	0.30
As^{3+}	0.00 – 0.00	0.00	0.01	0.01
Au^{+}	0.002 – 0.008	0.006	-	-
Pb^{2+}	0.222 – 0.940	0.601	0.01	0.01

NSDWQ = Nigerian Standard for Drinking Water Quality, WHO = World Health Organization Standards

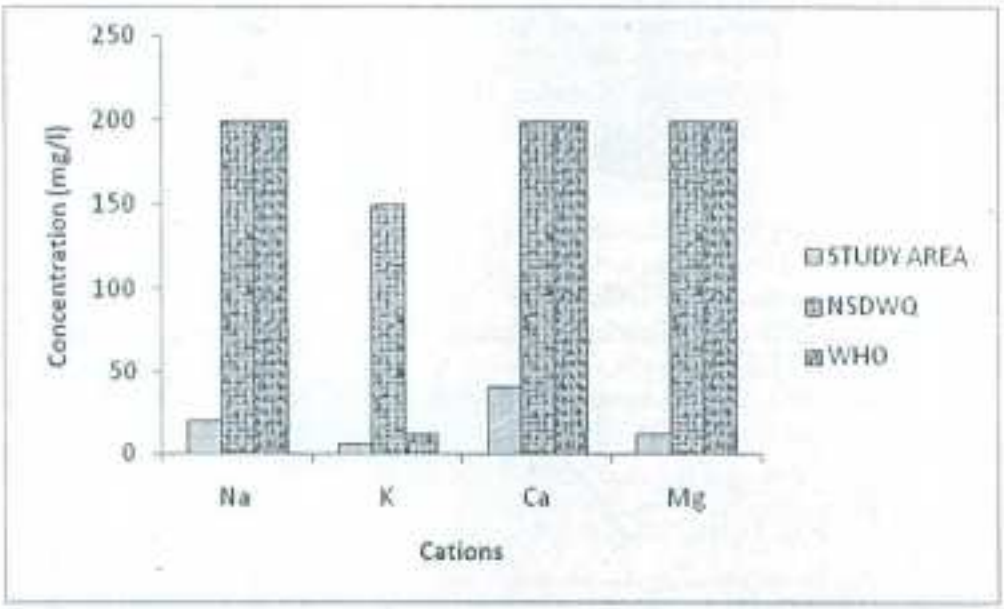


Fig. 3: Correlation of the mean concentration of cations with WHO and NSDWQ Standards

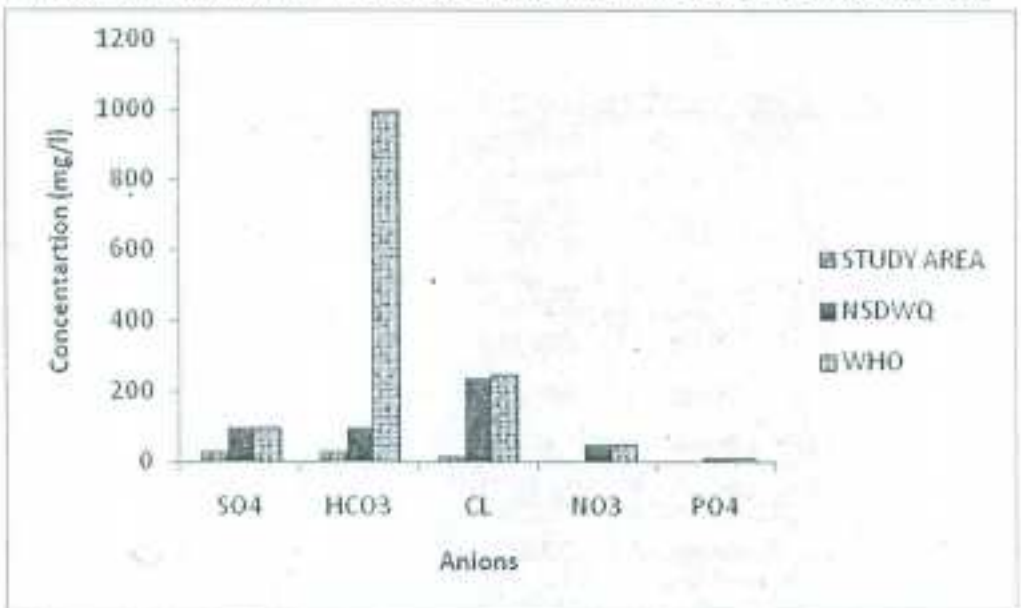


Fig. 4: Correlation of the mean concentration of anions with WHO and NSDWQ Standards

The concentration of Cu^{2+} varies from 0.02mg/l to 0.08mg/l. Its average value is 0.04mg/l. This is lower than the NSDWQ maximum permissible limits of 1.0mg/l. The concentrations of Fe^{2+} varies from 0.0mg/l to 3.54mg/l and Pb^{2+} from 0.222mg/l to 0.940mg/l. Their respective average concentration values are 1.56mg/l and 0.60mg/l. These values exceed the 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.

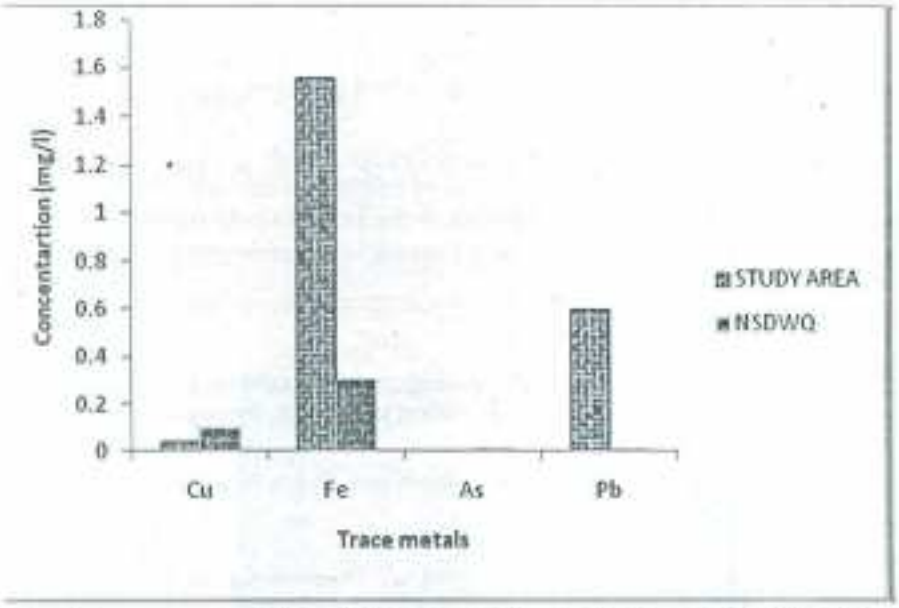


Fig. 5: Correlation of mean concentration of heavy metals with WHO and NSDWQ Standards

Hydrochemical Facies

The geochemical evolution of water samples from mine pond, stream water and hand-dug wells in the study area was done and described from Langguth diagram.

Langguth trilinear plot (Figure 6) reveals that eight 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). This indicates that both hand-dug wells, 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.

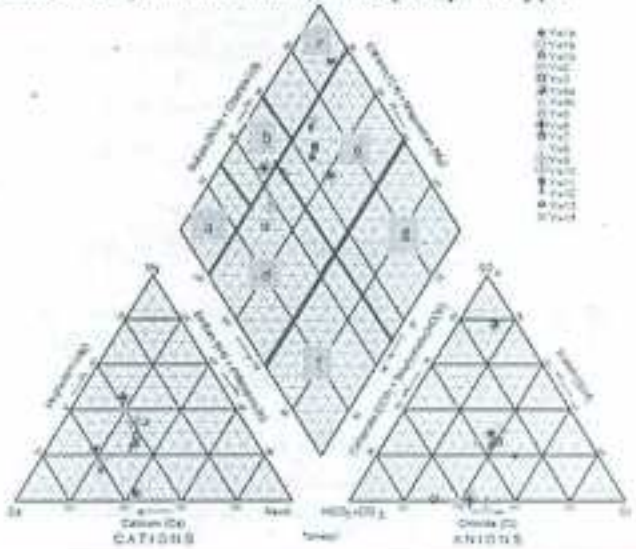


Fig. 6: Water classification plot from the study area (After Langguth, 1966)

Conclusion

Geological field mapping has revealed the area comprise principally four lithologies namely, the Migmatite-Gneiss Complex, Granite, Schist and Sandstone (Nupe basin). It has also shown the activity of artisanal gold mining is ongoing.

The results obtained from the physico-chemical analysis, hydrochemical classification and charts deduced from both surface and ground water samples from the study area in relation to WHO (2011) and NSDWQ (2007) indicates earth-alkaline fresh water with high alkaline content, 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. The gold mineralization in the area probably occurs in association with pyrite and galena due to high concentrations of Fe^{2+} and Pb^{2+}. Hence, possible water contaminants in the area are Fe^{2+}, SO_4^{2-} and Pb^{2+}. Fe^{2+} and SO_4^{2-} contamination could be due to oxidative weathering of pyrite associated with the gold mineralization. Pb^{2+} 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 help prevent goitre. Also, the use of herbicides for agricultural practices should be discouraged and indiscriminate disposition of mine waste be prevented.

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