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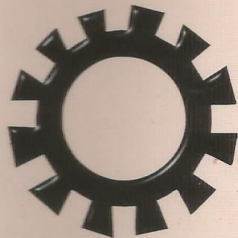
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Geology and environmental impact of artisanal gold mining around kataeregi area, North-Central Nigeria

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Abstract

Geology and effect of artisanal gold mining was investigated in Kataeregi and environ, North-central Nigeria with the aim of determining its host rock and assessing ihe impact of such activity on the surrounding. Geological field mapping show the area comprise of the Migmatite-Gneiss complex, Schist, Granite and Sandstone lithologies. The geochemical analysis of the representative rock samples indicates probable Au, Ag and Hg mineralization (0.16ppm, 2.53ppm and 0.21ppm respectively on the average). Au is hosted by auriferous quartz veins within the Schist rock. Geochemistry of the sediment samples revealed the sediments are enriched with elements such as Au (0.23ppm), Ag (2.59ppm), Hg (0.21ppm) and Mo (1.14ppm). The water is earth-alkaline fresh water with high alkaline content, and mostly sulphate type. The average concentration of these elements in rocks and sediments were compared with published average crustal abundances of the elements in upper continental crust and the water compared with Nigerian Standard for Drinking Water Quality and World Health Organization Standards. Mining activity has impacted the environment with land degradation, loss of vegetation and erosion of soils. Trace elements like Hg in rocks and sediments, and Pb in water from the study area are potential toxic elements that can render water unfit, causes slow growth rate in plant and reproductive disorder in man.

Introduction

Artisanal gold mining is always seen as a small-scale industry that has less impact on the environment and health. However, the associated toxic trace elements can contaminate the environment, get mobilized and transmitted through water and food chain and cause damage to plant, animal and human (Waziri, 2014). This is depending on the type of mineralization, geological settings of the place, human settlements, meteorological conditions, ambient air quality, water bodies, agricultural and forest land. Potential toxic materials that result from either during extraction such as the application of mercury (amalgamation), cyanide (cyanidation) or even the use of gravity concentration methods such as panning and sluicing during processing poses health problems (Ako *et. al.*, 2014).

One of the major environmental problems arising from the mining activity is the indiscriminate discharge of contaminated water also refers to as effluent disposal (EEB, 2000). The effluent disposed from gold mines are often associated with potential 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). Impact of artisanal gold mining due to the release of excessive mercury, cyanide and other associated toxic elements with the mineralization that later find their ways into the ecosystem is of great concern in countries like Peru (Hrushka and Medina, 2001), Brazil (Lacerda and Salomons, 1998), and Ecuador (Appleton *et al.*, 2001). The research is therefore aimed at determining the host rock and assessing the impact of artisanal gold mining in Kataeregi area with respect to sediment and water contamination and the possible human risks.

Materials and Methods

Study Area and Sampling Method

The study area is located in Kataeregi, Katcha local government area of Niger State in north-central Nigeria. The area is part of Bida Sheet 184 NE and is located between Latitudes 09°21'N and 09°25'N and Longitudes 006°17'E and 006°22'E (Figure 1). Relief consists of low-lying terrain and few gentle hills generally ranging from 106m to 152m, while isolated areas rise up to about 167m and is traversed by New Minna-Bida Federal road and Minna-Kataeregi railway line. It is characterized based on hand specimen by the migmatite-gneiss complex, mica schist, granite and sedimentary rock (Bida sandstone) (Figure 2). The area is highly drained by series of streams that flow to join the main River Chanchaga found within the study area. Most

of these streams are seasonal in nature, only active during rainy season except few in dry season

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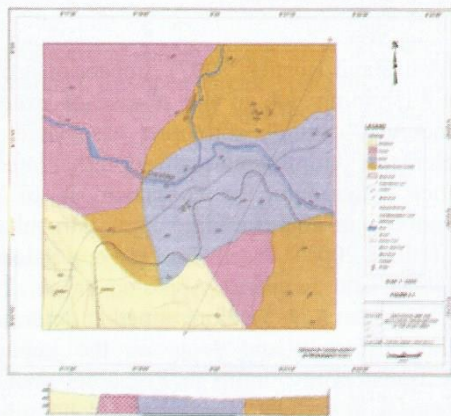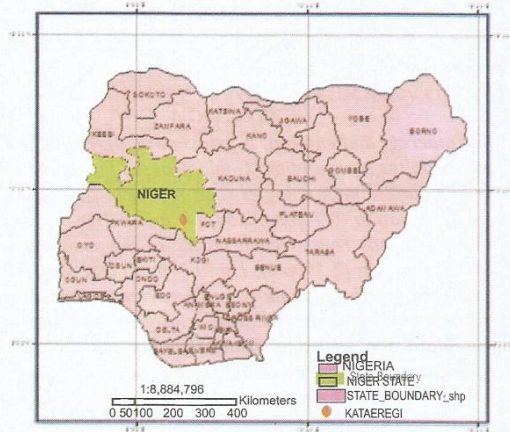STATE_BOUNDARY_shp
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Figure 2: Geological map and cross section of Kataeregi area

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) and later given distinctive formational name, Ushama Schist Formation (Turner, 1983 and Ajibade et al., 1987). They considered the Ushama Formation to constitute predominantly by Quartz schist, Mica schist, Quartzite with some amphibolite layers.

The north and south-eastern parts of the study area is occupied by both migmatite-gneiss complex and granites, and to the extreme south-western part, is occupied by the sedimentary rock (Bida sandstone). According to Grant (1978), the northern half of the study area are typified with relatively flat and underlain with similar outcrops observed to be biotite-hornblende-granite during petrographic study. The crystalline rocks are overlain by Cretaceous to Recent sedimentary rocks (Bida Basin) in the southwest of the area. Turner, 1983, Ajibade *et al*., 1987 and Obaje, 2009 are of the opinion that gold-bearing veins, reefs and stringers are often localized by brittle and ductile fault structures or planes of schistosity that traverse phyllites, schists, quartzites, gneisses and contact aureoles of granitoid masses. The principal joint direction as determined from the rose diagram shows a NW-SE trend direction (Figure 3).
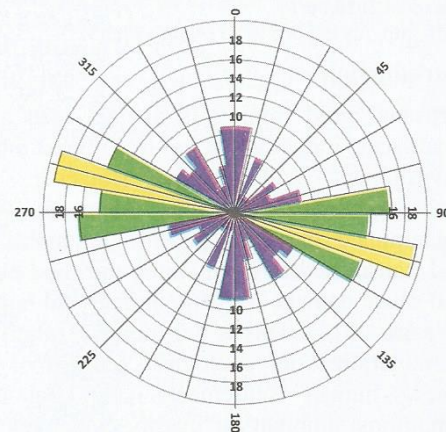

Figure 3: Principal joint directions from Kataeregi area

A total of fifty three (53) samples were collected from the study area; ten rock chips, twenty six from sediments, and seventeen from water samples. The sediments samples were randomly collected from the mine site, mine tailings and streams draining the study area with the aid of hand trowel. Rock chips were collected based on the major rock types found within the study area. The stream sediment samples were taken at a depth of between 0 – 20cm at the confluence and at the centre of some drainage systems, carefully put in polythene bag and labelled appropriately. Water samples were collected in two forms; 60ml prewashed glass bottles were used to collect the one for anion determination while prewashed plastic bottles were used to collect

those for both cation and trace metals determination with addition of two drops of concentrated nitric acid for preservation. Finally, all the samples were sent for analyses.

Laboratory Analysis

The preparation and trace element determination in rocks and sediments were done at the National Geosciences Research Laboratory (NGRL), Nigerian Geological Survey Agency (NGSA), Kaduna. Bulk samples were sun-dried for about 24 hours to remove moisture and about 1kg each of the samples was disaggregated or crushed using porcelain mortar and pestle. Coning and quartering processes were carried out on the samples severally to obtain a representative out of the bulk sample. About 55 – 60g of each rock chip and sediment samples were pulverized (grind to fine powder) using agate pulverizing machine (planetary micro mill pulverisette 7) to pass 100 micro mesh sieves (British Standard). The samples were further re-crushed and re-sieved to ensure homogeneity of the samples and maximum passage through the sieve. From these prepared samples, powdered pellets were produced for each of the sample by weighing 5g of the pulverized sample into a beaker and addition of 1g of binding aid (Starch soluble). The mixture was thoroughly mixed to ensure homogeneity, which was pressed under high pressure (6 "tones") to produce pellets; labelled and packaged for analysis.

Analysis was carried out using Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer of model "Minipal 4" software. In this method, the prepared pellets from each of these thirty six (36) samples was carefully placed in the respective measuring positions on a sample changer of the X-ray machine. The current used was 20kv for the trace elements/rare earth metals. Selected filter was Ag/Al-thin for the trace elements/rare earth metals. The filters were selected based on a guided periodic table for elemental determination. Time allocated for each sample measurement was 100 seconds and the medium used was air throughout. The machine was then calibrated by the machines gain control, after which the respective samples were measured by clicking the respective positions of the sample changer. The elements analyzed include Cu, Zn, Ag, Au, As, Pb, Mo, Hg, Cr, Ni, V, Sr, Ge, Zr, Co, Ba, Eu, Re, Bi, Rb, Sb and Te elements in both rock and sediment samples. The average concentration of these trace elements in rocks and sediments were compared with relevant published average crustal abundances of the elements in upper continental crust.

Relevant physical parameters in water samples 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. The chemical parameters analyzed for include SO_4, NO_3, HCO_3, Cl, Ca, Mg, Na, K, Cu, Fe, As and Pb in the laboratory. Sulphate ion (SO_4^{2-}) was determined by Spectrophotometric turbidimetry. This method is based on the principle of formation of barium sulphate in the presence of an acetic acid medium with barium chloride. The absorbance of the colloidal solution was measured against a standard on UV visible spectrometer at a wavelength of 420nm. Nitrate ion (NO_3^-) was determined by colorimetry with an UV visible spectrometer (brucine method). Bicarbonate (HCO_3^-) was determined by titration using 0.1M HCl; chloride (Cl^-) was determined by standard 0.1M $AgNO_3$ titration. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) 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 (Fe^{2+}) was determined by colorimetry with an UV-visible spectrometer at 520nm. Arsenic (As^{3+}) 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 (Pb^{2+}) was determined using atomic absorption spectrometry. All samples were analyzed 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

Geochemistry of Rock Chip and Sediment Samples

The summary result of geochemical analyses of the rock chip and sediment samples is presented in Table 1. The Mean concentrations of twelve elements in the samples were compared with relevant standard like Taylor and McLennan (1985; 1995) average concentration of elements in upper continental crust. Their element enrichment factors (EF) of the samples were calculated using the published crustal concentrations of these elements by Taylor and McLennan (1985; 1995) as baseline values (Table 1). It is essential in other to assess the level of enrichment or depletion of these elements in rocks and sediments in relative to their crustal concentrations.

Considering the rock samples; samples YR2, YR3, YR4, YR5, YR6 and YR7 are selected from the Granite and Migmatite-Gneiss Complex while samples YR1, YR8, YR9, and YR10 are from the Schist rocks found within the study area. From the geochemical result of the rock analysis and its elements enrichment

factors (EF) as presented in Table 1, the concentrations of Au, Ag and Hg in Schist rocks ranges from 0.010ppm to 0.386ppm, 0.41ppm to 4.56ppm and 0.071ppm to 0.30ppm represent average concentrations of 0.16ppm, 2.53ppm and 0.19ppm respectively. While in the Granite and Migmatite-Gneiss complex together, the concentrations of Ag and Hg ranges from 0.87ppm to 2.01ppm and 0.025ppm to 0.5ppm represent average concentrations of 0.99ppm and 0.21ppm respectively. These values are higher when compared with average upper crustal abundance by Taylor & McLennan (1985; 1995) with enrichment factors of 40, 42.2 and 6.33 for Au, Ag and Hg in the Schist rocks while in the Granite and Migmatite-Gneiss complex combined, is 16.5 and 7.0 for Ag and Hg respectively. Other elements such as Cu, Zn, As, Pb, Mo, Cr, Ni, V and Sr are depleted in the area. The result was further subjected to linear plots of some of the element shown in Figures 4, 5 and 6 below.

Table 1: Summary of the geochemical analyses of rock and sediment samples with their enrichment factors (All measurements in ppm)

Elements	Rock samples Schist			Granite -Gneiss			Sediment samples			Taylor and McLennan Average crustal abundance (Bn)	Enrichment Factor (EF=Cn/Bn) in Schist	Enrichment Factor (EF=Cn/Bn) in Granite - Gneiss	Enrichment Factor (EF=Cn/Bn) in Sediments
	Min	Max	Mean (Cn)	Min	Max	Mean (Cn)	Min	Max	Mean (Cn)				
Cu	0.019	0.089	0.05	0.014	0.060	0.04	0.005	0.18	0.07	30ppm	0.002	0.001	0.002
Zn	0.021	0.052	0.04	0.020	0.079	0.05	0.001	0.1	0.03	60ppm	0.001	0.001	0.001
Ag	0.41	4.56	2.53	0.87	2.01	0.99	1.1	4.95	2.59	0.06ppm	42.2	16.5	43.2
Au	0.010	0.386	0.16	0.00	0.001	0.001	0.001	0.399	0.23	0.004ppm	40.0	0.25	57.5
As	0.005	0.050	0.03	0.016	0.024	0.02	0.002	1.09	0.11	1.7ppm	0.02	0.012	0.06
Pb	0.004	0.028	0.02	0.011	0.029	0.02	0.01	0.68	0.30	15ppm	0.001	0.001	0.02
Mo	nd	Nd	Nd	0.00	0.20	0.20	0.19	1.5	1.14	1.0ppm	nd	0.20	1.14
Hg	0.071	0.300	0.19	0.026	0.500	0.21	0.06	0.52	0.21	0.03ppm	6.33	7.0	7.0
Cr	0.006	0.098	0.04	0.010	0.358	0.10	0.01	0.398	0.07	70ppm	0.001	0.001	0.001
Ni	0.008	0.27	0.08	0.008	0.110	0.04	0.002	0.11	0.03	44ppm	0.002	0.001	0.001
V	0.048	0.18	0.13	0.048	0.120	0.10	0.006	0.18	0.12	95ppm	0.001	0.001	0.001
Sr	0.094	0.241	0.19	0.140	0.460	0.31	0.11	0.241	0.20	290ppm	0.001	0.001	0.001

nd = not detected, EF = Enrichment Factor, Cn = Average concentration of an element measured in a sample, Bn = Relative average concentration of the elements in crustal value given by Taylor & McLennan (1985; 1995), Granite-Gneiss (Migmatite-Gneiss Complex: YR2, YR6 and YR7; Granite: YR3, YR4 and Yr5).

The plot of V against Cu shows positive correlation in all the samples YR1, YR2, YR3, YR4, YR5, YR6, YR7, YR8, YR9 and YR10 with highest concentration of V and Cu in sample YR9 (0.18ppm and 0.089ppm respectively) (Figure 4). Considering the plot of V against Cr, relative correlation was observed in samples YR8, YR9 and Y10 only. V has it highest concentration in sample YR9 (0.18ppm) and Cr in sample YR7 (0.358ppm) (Figure 5).
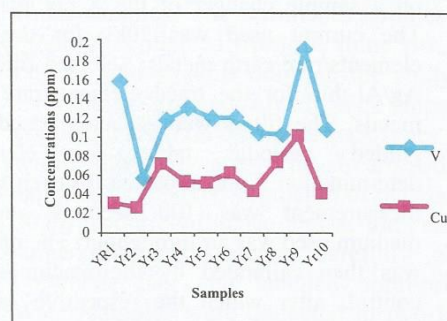

Figure 4: Correlation plot of V against Cu concentrations in the rock samples.
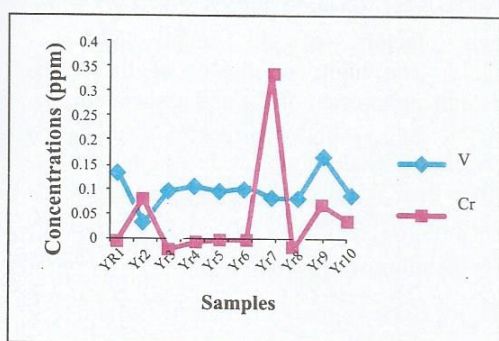
Figure 5: Correlation plot of V against Cr concentrations in the rock samples

Figure 6: Correlation plot of Ag against Au concentrations in the rock samples

Plot of Ag against Au shows positive correlation only in samples YR8, YR9 and YR10 (Figure 6). Au has its highest concentration in sample YR10 (0.386ppm) and lowest in sample YR6. However, the plots of V against Ag, V against Sr, Cu against Ag, As against Au, Pb against Au, Zn against Pb, As against Ag, Zn against Au and Hg against Au do not show any correlation, indicating a contrasting mineralization.

The positive correlation of Ag and Au and the high concentration of Au recorded in samples YR8, YR9 and YR10 is observable in Figure 6. It is an indication that the Au mineralization falls within the schist lithologies as these samples were collected from the schist in the central portion of the study area coinciding with where the artisans works. Ag and Hg were also observed to occur in Schist, Granite and Migmatite-Gneiss complex that constitute the major lithologies of the area. Ag has highest concentration within the schistose rocks while Hg is highest within the Granite-Gneiss (Granite and Migmatite-gneiss complex together).

In sediment samples, the concentration of Cu ranges from 0.005ppm to 0.18ppm and Zn from 0.001ppm to 0.083ppm with mean concentrations of 0.07ppm and 0.03ppm respectively. These values are low compared with Taylor and McLennan (1985; 1995) (Table 1). Ag, Au and As concentrations ranges from 1.10ppm to 4.95ppm, 0.001ppm to 1.790ppm and 0.002ppm to 0.066ppm with mean concentrations 2.59ppm, 0.23ppm and 0.11ppm respectively. The concentrations of Ag and Au as compared with their published crustal concentrations are higher while As is low. Also, Pb concentration ranges from 0.010ppm to 0.68ppm, Mo from 0.190ppm to 1.50ppm and Hg from 0.060ppm to 0.52ppm
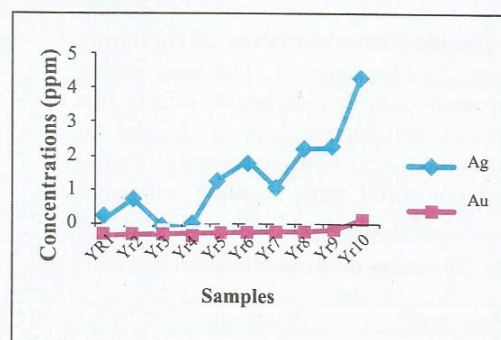
with mean concentrations of 0.30ppm, 1.14ppm and 0.21ppm respectively. When these values were compared with standard in Table 1, Pb is low while Mo and Hg are higher than the average crustal abundance (Taylor and McLennan, 1985; 1995). Cr, Ni, V and Sr have concentrations ranging from 0.01ppm to 0.39ppm, 0.002ppm to 0.11ppm, 0.006ppm to 0.23ppm and 0.11ppm to 0.28ppm represent average concentrations of 0.07ppm, 0.03ppm, 0.12ppm and 0.20ppm respectively. These concentrations are low compared with the referenced published crustal concentrations (Table 1). The element enrichment factor (EF) was calculated using the equations below:

$$EF = Cn/Bn$$

Where: Cn = Concentration of an element measured in sediment sample. Bn = Element equivalent in the baseline or background concentration used.

The assessment of these elements was done in accordance to the work of Sutherland (2000). Interpreting enrichment factor (EF) as follows;

EF < 2 – Depletion to minimal enrichment
EF 2 < 5 – Moderate enrichment
EF 5 < 20 – Significantly enrichment
EF 20 < 40 - Very high enrichment
EF > 40 - Extremely high enrichment

In the sediment, result shows that elements such as Cu, Zn, As, Pb, Cr, Ni, V and Sr were generally depleted relative to their background value, with mean ratios of less than 1 with exception of Mo and Hg, greater than 1. This indicates that artisanal mining activity has not contaminated the environment with these elements. Mo shows minimal enrichment with enrichment factor of 1.14 (<2) which is typical of a granitic environment while Hg shows significant enrichment as compared with the background value, with enrichment factor of 7.0 (>5). This generally tallies closely to high Hg concentration in the upper crust. Hence, it indicates an influence from the geology of the area and also from the activity of artisanal

miners resulting from the usage of Hg during processing (gold amalgam). The emission of Hg can result into serious health effects like nervous and reproductive disorder. Ag and Au concentrations are both extremely highly enriched compared with baseline values of Taylor & McLennan (1985; 1995) with enrichment factors of 43.2 and 57.5 respectively. The high enrichment of these elements indicate present of Au and associated trace metal, Ag, which is evident by the presence of artisanal mining activity in the area. Other than Au, Ag can also be explore and exploit for in the area.

Table 2: Summary of the geochemical result of water and its corresponding standards

Parameters (mg/l)	Minimum	Maximum	Mean	NSDWQ, 2007	WHO, 2011
Temp (°C)	26.5	29.6	27.95	Ambient	Variable
pH	6.93	7.57	7.07	$6.50 - 8.50$	$7.0 - 8.5$
TDS	30.00	533	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	0.3
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

Geochemistry of the Water Samples

The summary of the geochemical analysis of water samples from Kataeregi area and its corresponding standards is presented in Table 2 below. The ambient temperature ranges from 26.5°C to 29.6°C with mean value of 27.95°C indicates suitability for human consumption (Table 2). 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 content varies from 6.93 to 7.57 with average value of 7.07 which is approximately neutral and recommended for drinking and domestic use since increase in the value. 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) (Table 2). 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).

Major ion chemistry

The calcium (Ca^{2+}) from 20.03 to 121.04, magnesium (Mg^{2+}) from 1.44 to 31.70, sodium (Na^+) from 8.0 to 51.0 and potassium (K^+) from 1.0 to 16.01 concentrations (on the basis of mg/l) represent on an average of 41.25, 20.83, 12.58 and 6.58 respectively and in the order of abundance is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. The values of calcium and magnesium (alkaline earth metals) are lower when compared with the WHO, 2011 and NSDWQ maximum permissible limit of 200mg/l for both calcium and magnesium (Figure 7). The values of Sodium and Potassium (alkali ions) with potassium lower than sodium are generally low when compared with recommended values 200mg/l and 150mg/l (NSDWQ, 2007) for sodium and potassium respectively (Figure 7).

Magnesium and calcium ions is usually known to contribute to water hardness, their low concentration indicates softness of the surface water in the area (Amadi *et al.*, 2014). Though, slight elevation in the values recorded

in some parts can be attributed to the mining activities in the area.

The values of bicarbonate (HCO_3^-) varies from 17.0 to 90.0, sulphate (SO_4^{2-}) from 0.0 to 190.0, chloride (Cl^-) from 12.0 to 26.10, nitrate (NO_3^-) from 2.30 to 8.62 and phosphate (PO_4^{3-}) from 0.89 to 3.67 concentrations (on the basis of mg/l) represent on an average to 32.01, 31.14, 17.65, 4.86, 2.04 and in the order of abundance is $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > PO_4^{3-}$. When these values are compared with NDSWQ, 2007 maximum permissible limit is in the order of 100mg/l, 100mg/l, 250mg/l and 50mg/l respectively (Figure 8).

These revealed that they fall within the required limit and also indicate minimal chemical weathering effect and low level of agricultural practices due to dominance of mining activities in the area. Considering the sulphate (SO_4^{2-}) concentration, the high level was recorded in the mining portion of the study area (Table 2) indicates input from the oxidative weathering of pyrites associated with the Kataeregi gold mining in the region.
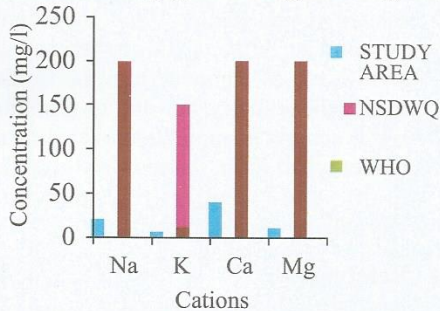

Figure 7: Correlation of the mean concentration of cations versus NSDWQ and WHO Standards
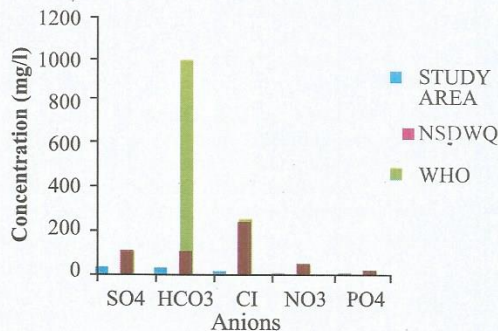

Figure 8: Correlation of the mean concentration of anions versus NSDWQ and WHO Standards

Trace elements in the water samples

The following trace elements were analyzed for (Cu^{2+}, Fe^{2+}, Pb^{2+}, As^{3+}). Copper (Cu^{2+}) 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 each. Also, the concentrations of iron (Fe^{2+}) varies from 0.0mg/l to 3.54mg/l and lead (Pb^{2+}) from 0.222mg/l to 0.940mg/l represent on an average of 1.56mg/l and 0.60mg/l which is by far higher when compared with WHO and NSDWQ maximum permissible limits (0.30mg/l and 0.01mg/l) respectively (Figure 9). 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. This however indicates the presence of pollutants of iron and lead in water from the area. There was no change in the concentration of arsenic in 0.00mg/l.
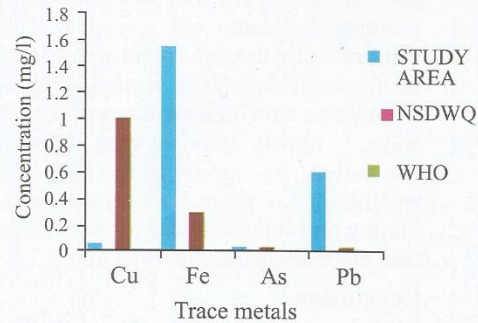

Figure 9: Correlation of mean concentration of trace elements versus NSDWQ and WHO Standards

Hydrogeochemical facies and water types

The variation in the hydrogeochemical 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 Langguth plot.
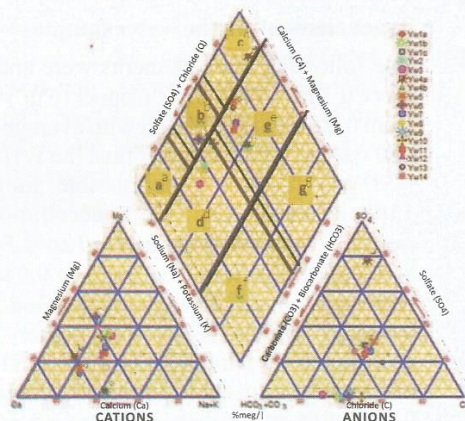
Figure 10: Water classification plot from Kataeregi area (after Langguth, 1966).

The result show that major ion composition plotted on a Langguth (1966) 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 10). This indicates the mine pond and stream water in the 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.

Conclusion

The result from the geological field work shows that the area is dominated by four major rock types. They are the migmatite-gneiss complex, schist, granite and loose sandstone. The geochemical analyses of some selected rock samples based on the constituting lithology of the area revealed that Au mineralization is hosted by the auriferous quartz veins cross-cutting the schist rock. Ag and Hg are present in both Granite, Migmatite-gneiss complex and the Schist. Relative high concentration Ag was recorded in the Schist while highest concentration of Hg was recorded in the Migmatite-gneiss complex. Based on the analysis, there are no correlations between Au, Zn, Pb and Cu.

Trace element geochemistry of the sediment samples in the area when compared with relevant published crustal abundances shows the area is highly mineralized with Au and Ag and moderately enriched with Hg. Pb and Cu was depleted in the study area indicating no mineralization of these elements. The activity of artisanal mining in the area has impacted on the environment with Hg. This toxic element can be consumed directly or indirectly by human and cause severe health challenges like skin colouration, cancer, respiratory and kidney problems. To plants, it can results in stunted growth, leave chlorosis and low yield to mention but few.

The hydrogeochemical study of water from the area indicates earth-alkaline fresh water with high alkaline content, and the water is mostly sulphate type and considered suitable for human use. 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. The high concentration of Pb in water from the area is related to the geology and by extension to human activity. Though, there was no significant enrichment from the result of the rock geochemistry but due to it solubility in water can get accumulated over time and can render water unfit, causes slow growth rate in plant and respiratory, nervous and reproductive disorder in man.

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