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Geochemical Investigation and Physical Impact Assessment of Artisanal Gold Mining, Kataeregi, North-Central Nigeria

Omanayin, Y. A.[1]*, Ogunbajo, M. I[1]., Waziri, N. M[1]., Ako, T. A[1]., Shuaibu, A. M[2]. and Alaku, I. O[1].

[1]Department of Geology, School of Physical Sciences, Federal University of Technology, Minna, Nigeria
[2]Department of Geological Sciences, Federal University Gusau, Zamfara, Nigeria
*Corresponding Author's Email Address: o.adinoyi@futminna.edu.ng

Phone No.: +2348038388110 and +2348053584236.

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Abstract

The geochemistry of mine products and stream sediments from Kataeregi area in North-central Nigeria was studied with the objective of environmental hazards assessment that is caused by artisanal gold mining activities through field work and laboratory analyses. The field work involves the observation of physical impact of mining on the environment and collection of representative samples along the streams, mined site and tailings within the location of study. The sediment samples were analyzed using X-ray fluorescence spectrometry. The result obtained from laboratory analysis was compared with the ideal average crustal concentration of the elements in upper continental crust. Field observation revealed that mining activity has impacted on the environment with land destruction, loss of vegetation and erosion of soils. Geological field mapping show the area is underlain with Migmatite-Gneiss complex, Mica Schist, Granite and Sandstone lithologies. Results from geochemical analysis revealed that sediments are enriched with elements such as Au (0.23ppm), Ag (2.59ppm), Hg (0.21ppm) and Mo (1.14ppm). The presence of Hg in sediments can get consumed directly or indirectly through food chain and passed on to human.

Keywords: *Artisanal gold mining; Sediment geochemistry; degradation of land; Contamination; North-central Nigeria.*

1.0 INTRODUCTION

The impact of the activities of artisanal and small-scale gold mining on the environment and health of the workers and inhabitants of an area can never be over emphasized. The artisanal and small-scale gold mining simply implies the mining of gold by individuals or at most small groups of people employing basic implements with or without valid permits from government. Series of scientific work have been documented revealing various impacts of Artisanal and

Small-scale Mining (ASM) ranging from environmental, fluvial and soil contamination, health challenges and mitigations (Kelly, 1988; Thornton, 1996; Appleton *et al*., 2001; Jung, 2001; Hilson, 2002; Lottermoser, 2007; Mallo, 2012).
The high and increasing gold price among other metals in the world market today has triggered the attentions of world populace, marginalized communities and developing countries into adopting this informal method of mining. Since the activity require modest investment and minimal technical skills to complement their source of livelihood. Gold as one of the most valuable precious metals, constitute more than half of all the minerals mined worldwide, with an estimate of about 6 to 9 million artisanal miners involved (Tieguhong *et al.*, 2009). Mining is an essential economic activity that has the potential of contributing to rapid socioeconomic development of a country blessed with the resource. It can also be source of doom to mankind if not properly executed, leading to environmental and health challenges to plants and animals. Particularly within the North-western Schist Belt and some other parts of Nigeria, gold mining and other associated sulphide minerals by artisans have been on the increase. This activity might have introduced toxic trace elements into the soils, stream sediments and even the water draining the area. This work therefore focuses on the geochemical investigation and physical impact assessment of Kataeregi artisanal gold mining, North-central Nigeria.

2.0 METHODOLOGY

The geological field work of the area with subsequent sampling exercise of stream sediment and mine tailings of the area were carried out. The study site assessed to determine the level of physical impact of mining on the host community. The various samples obtained from the field were subjected to various laboratory analyses to determine their elemental compositions.

2.1. Study Area and Field Work

The study area is located within Katcha Local Governmnet Area of Niger State, North-central Nigeria (Figure 1). The area is part of Bida Sheet 184 NE and is located between Latitudes 09º21'N to 09º25'N and Longitudes 006º17'E to 006º22'E on the scale of 1: 25,000 covering a total area of about 68km^2. The area is generally accessible through Minna → Kataeregi → Bida Federal road and Minna → Kataeregi railway line. It is approximately 39km south of Minna town and about 4km North of Kataeregi village. The nearest settlements within the study area are Maiwayo, Gadaeregi and the most populous, Kataeregi.

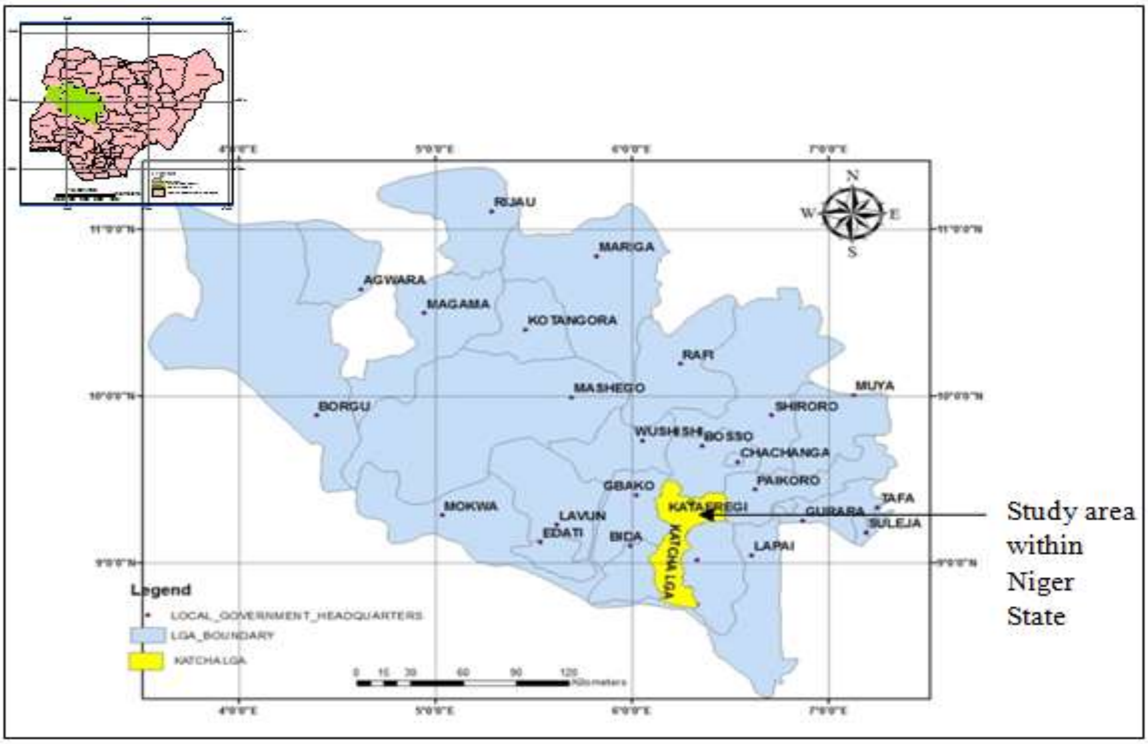

Figure 1. Location map of Kataeregi, Niger State, Nigeria.

The field work involved a systematic geological mapping and sample collection within the boundary of the study area. The method used during the field exercise was traverse, locating the different rock types which were described on hand specimen with regards to their colour, texture and mineralogy. The points where these rocks outcrop the earth surface were noted on the base map. The strike and dip values and directions were measured using a Silva compass clinometer. The samples were randomly collected from the mine site, mine pond and along the streams draining the study area with the aid of hand trowel. The stream sediment samples were taken between a depth of 0 and 20cm at the confluence of the stream while some were taken at the centre of drainage systems. These sample collected were properly described based on their colour, texture and carefully put on a polythene bags and labelled appropriately.

The points sampled along the stream channels, mine site and the mine ponds in the field were accurately represented on the base map with the help of a Garmin Global Positioning System (GPS) aided by geographic co-ordinates (Figure 2). A total of twenty six samples were collected for geochemical studies; five from mine site, five from mine tailing and sixteen along the streams draining the study area. During the field work, observation of the entire mining site was done in order to consciously evaluate the physical impact the mining activity might have caused on the land. This observation was particularly made based on the agricultural land use since the inhabitant of the area commonly engaged on farming (cereals and yam) and cattle rearing.

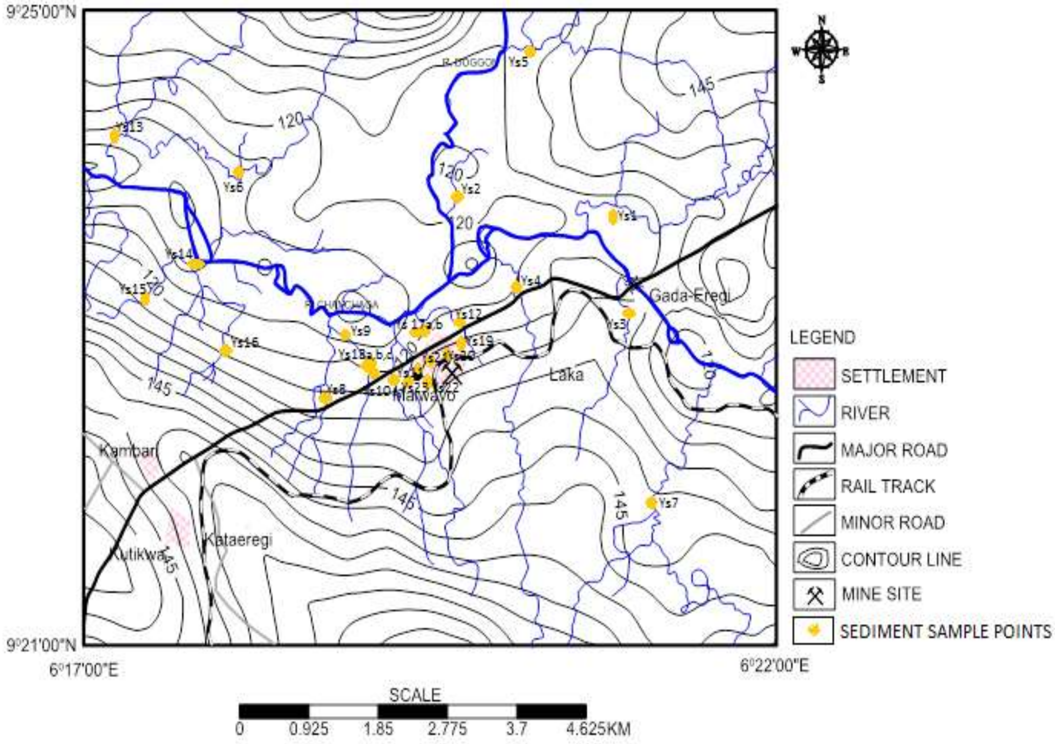

Figure 2. Sample location map of Kataeregi area.

2.2. Laboratory Work

The preparation and chemical analysis of the collected samples were carried out on twenty six (26) samples at the National Geosciences Research Laboratory (NGRL), Kaduna. The bulk samples were sun-dried for about 24 hours in order to remove moisture, 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 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.

The pressed powdered samples were analyzed for trace elements using Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer of model "Minipal 4" software. The prepared pellet from each of the twenty six 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 research compared the mean concentration of each element in the samples with the average concentration of elements in upper continental crust adopted after Taylor and McLennan, (1985; 1995) and Wedepohl, (1995).

3.0 RESULTS AND DISCUSSION

3.1. Lithology and Field Relation

The major rock types encountered during geological field work were the migmatite-gneiss complex occupying about thirty percent (30%) of the total area, schist (about 20%), granite (35%) and sandstone (about 15%). The north and south-eastern parts of the study area is underlain by both granite and migmatite-gneiss complex. The Migmatite-gneiss complex appears to be the oldest lithology in the area and mesocratic in colour. In term of texture, they are medium to coarse grained. Mineral constituent of the rock in hand specimen consist of quartz, feldspar and mica. The Migmatites are highly jointed and moderately weathered. The granite occurs as intrusive to both the Migmatite-gneiss complex and schist. Central portion of the study area is dominated by mica schist that serves as host to auriferous quartz veins in the area. They are generally low-lying outcrops except those along the stream, grey to darkish in colour with characteristic medium to coarse grained texture. They are slightly weathered (Plate I).

The extreme south-western part is occupied by the sedimentary rock (a typical of Bida sandstone). Principal joint direction as determined from the rose diagram shows a NW-SE direction. Most of the joints were filled with feldsparthic and quartz veins.

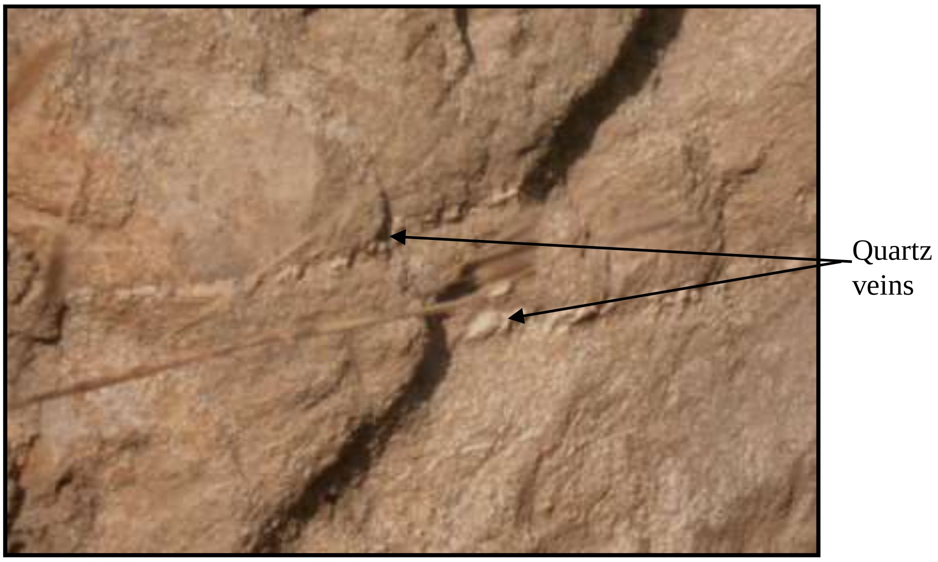

Plate I. Schist rock with quartz veins from Kataeregi area.

3.2. Physical Impact of Mining on the Environment

The observable physical impact of gold mining activity on the land and environment in general ranges from land degradation, loss of vegetation, dust pollution, soil erosion and general reduction in agricultural practices which are shown in Plates II, III, IV and V respectively.

3.2.1. Land destruction

The activity of artisanal gold mining in Kataeregi and it environ have led to the destruction of natural landscape (Plate II). Heaps of rock waste and tailings were generated from trenches and series of pits created. This could be hidden place for reptiles and death trap to both human and animals (Ako *et al.*, 2014). According to Salati *et al.*, (2011) the destruction of over 1000 hectares of arable land and flooding of abandoned pits due to artisanal mining in Azara barite deposits in Nasarawa State have become a death traps.

Plate II. Land destruction due to mining activity.

3.2.2. Dust pollution

The use of machines in the crushing, grinding and milling of crystalline rocks hosting gold deposits during processing can pollutes the air and affect human by inhaling the dust and in plant either by settling on the leave or through intake from the soil. This could lead to serious health challenges such as respiratory tract infections (Plate III).

Plate III. Dust pollution arising from crushing and milling of host rock.

3.2.3. Loss of vegetation

Mining activity is usually preceded by clearing of the site which results in deforestation. Large amount of vegetation are destroyed during mining and extraction of gold from its host rock, exposing and washing away of the top fertile soil (Plate IV).

Plate IV. Loss of vegetation in the processing portion of the area.

Plate V. Development of erosion channel arising from mining activity.

3.2.4. Soil Erosion

The waste generated from the activity of artisanal gold mining in the area leaving large heaps of excavated soils from trenches and tailings generated during processing creates an artificial barrier for surface run-off. This has led to the modification in the stream channels by disrupting the initial channel and creating new ones (Plate V). According to Ogezi (2005), the activities of tin and columbite mining in Jos Plateau have caused a change in the natural geology of the area promoting geological hazards like erosion and flooding.

3.3. Trace Element Geochemistry

The summary of geochemical result of 26 stream sediments and mine tailings is presented in Table 1. The mean concentration of twelve elements in the sediment samples was further compared with relevant standards like Taylor and McLennan (1985; 1995) and Wedepohl, (1995) average concentration of elements in upper continental crust (Table 2). Tables 3, 4 and 5 show the determination of Element enrichment factor (EF), Classes of index of geoaccumulation (Igeo) by Muller, 1969 and the Summary of index of geoaccumulation, Igeo for trace elements in sediments from the study area in accordance to Sutherland, 2000 respectively. The average concentration of these elements in sediment is also represented using pie chart (Figure 3).

Table 1: Summary of the geochemical analysis of sediment samples from Kataeregi area.

Elements (ppm)	Sediment Samples		
	Minimum	Maximum	Mean
V	0.006	0.18	0.12
Cr	0.01	0.398	0.07
Ni	0.002	0.11	0.03
Cu	0.005	0.18	0.07
Zn	0.001	0.1	0.03
Ge	0.032	0.071	0.05
Zr	0.67	0.81	0.74
Co	0.001	0.004	0.00
Ba	0.068	0.65	0.29
Mo	0.19	1.50	1.14
Eu	0.13	1.20	0.29
Re	0.05	0.14	0.12
Ag	1.10	4.95	2.59
Rb	0.04	0.11	0.07
Au	0.001	0.399	0.23
As	0.002	1.09	0.11
Sr	0.11	0.241	0.20
Hg	0.06	0.52	0.21
Pb	0.01	0.68	0.30

Table 2: Summary of the mean concentration of elements in sediments from Kataeregi area along with published average crustal concentrations.

Elements	Average concentration of 26 samples (ppm)	Crustal Abundance of Chemical Elements			
		Taylor and McLennan, (1985; 1995) Average Crustal Abundance	Status	Wedepohl, (1995) Average Crustal Abundance	Status
Cu	0.07	30ppm	Low	14.3ppm	Low
Zn	0.03	60ppm	Low	52ppm	Low
Ag	2.59	0.006ppm	High	0.07ppm	High
Au	0.23	0.004ppm	High	0.004ppm	High
As	0.11	1.7ppm	Low	2.0ppm	Low
Pb	0.30	15ppm	Low	17ppm	Low
Mo	1.14	1.0ppm	High	1.5ppm	Low
Hg	0.21	0.03ppm	High	0.08ppm	High
Cr	0.07	70ppm	Low	35ppm	Low
Ni	0.03	44ppm	Low	18.6ppm	Low
V	0.12	95ppm	Low	98ppm	Low
Sr	0.20	290ppm	Low	333ppm	Low

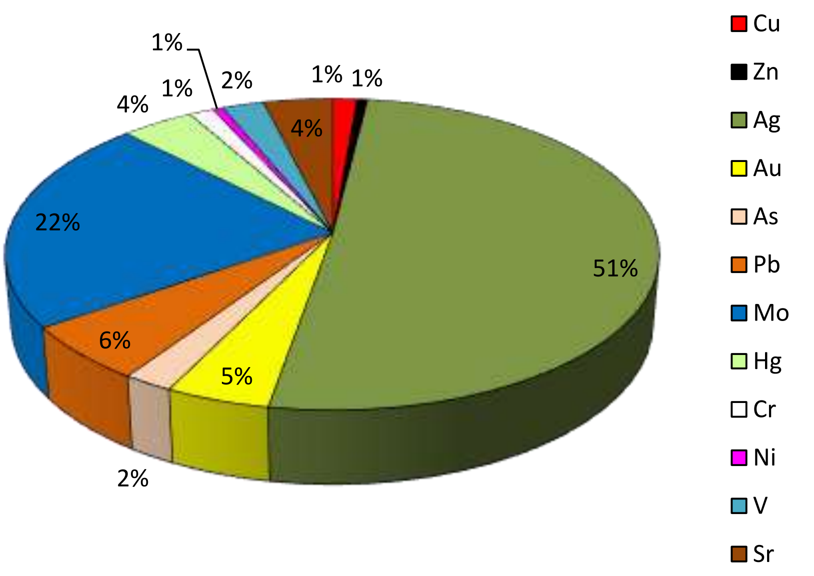

Figure 3. Pie Chart showing average concentration of elements in the sediment samples.

From Table 1 the concentration of Cu ranges from 0.005 to 0.18ppm and Zn from 0.001 to 0.083ppm with mean concentrations of 0.07ppm and 0.03ppm respectively. These values are low compared with Taylor and McLennan (1985; 1995) and Wedepohl (1995) (Table 2). According to Zarie *et al*. (2011), Cu is needed by plant, animal and human but in high concentration it can cause damage to the major organs like liver and Kidney. Zn is also needed as essential micronutrient that contributes to metabolic processes. It excess causes kidney failure in human and stunted growth with leave colouration in plants (Cakmark and Marsher, 1993).

Ag and As concentrations ranges from 1.10ppm to 4.95ppm and 0.002ppm to 0.066ppm with mean concentrations 2.59ppm, 0.23ppm and 0.11ppm respectively. The concentration of Ag as compared with the published crustal concentration is higher while As is low. Au is a precious metal people sort for and highly valued. It can be dangerous if not well processed due to potential toxic elements such as As, Cu, Pb, Zn and Hg usually associated with it. Ag can easily get into living organisms either through inhaling or ingestion. It has fatal effect on skin due to its bleaching potential. Arsenic can get into human body through inhalation of contaminated dust and food chain as a result of accumulation in plants (Data *et al*., 2000). It is carcinogenic and can cause heart failure in human. The high concentration of Au is recorded in areas where gold mining and processing take place.

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 standards in Table 2, Pb and Mo are low in all. Hg was high compared with all the reference standards used. According to World Health Organization (WHO, 1996); Osher *et al*., (2006) and Ling *et al*., (2006) Pb can be transported in water, food and soil into human. It can result into brain, kidney problems, and morphological changes in plants. Mo on the other hand is an important rare earth element needed in small quantity in both plant and animal. It shows minimal enrichment in area where gold mining and processing take place. It could be an indication of complex sulphide mineralization within the schist of the area (Adepoju and Adekoya, 2011). Hg may be released into the environment due to mining activities, contaminating the air, soil, water and plants within the neighbourhood. Its elevated concentration has effect on nervous and reproductive systems (Frumkin *et al.*, 2001) while on plants causes metabolic problem (Messer *et al*., 2005). Significant elevation was not observed in the mining area, the high sediment content may be attributed to gold processing by artisans using mercury (gold amalgam).

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 all the referenced published crustal and sediment concentrations (Table 2). All these elements are naturally present in background values in the crust, an elevation in their level in soil, sediments and water could be due human activities like mining, and acid rain transportation (Gimemo-Garcia *et al*., 1996). High concentration of Ni is carcinogenic in human and leave chlorosis in plant (Zornoza *et al*., 1999 and Rahaman *et al*., 2005). Sr in high concentration is a indication of the presence of important proportion of aragonite suggesting sedimentary origin (Fernandez-Bastero *et al*., 1998). However, the general low concentrations of these elements especially Ni, in comparison with average crustal reference material may suggest that ultramafic and mafic rocks are few in the study area (Adepoju and Adekoya, 2011).

3.4. Enrichment Factors (EF)

The calculation of enrichment factors of the twelve elements was carried out on the chemical results of sediment samples from the studied area (Table 3). It is essential in other to assess the level of enrichment or depletion of these elements in sediments in relative to their crustal abundances. In this study, the published average crustal concentrations of these elements by Wedepohl, (1995) were used as baseline values and the enrichment factor (EF) was calculated using the equations below:

EF = Cn/Bn

Where: Cn = Concentration of an element measured in sediment sample.

Bn = the 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.

Table 3: Summary of enrichment factor (EF) for the sediment samples from Kataeregi.

Elements	Average concentration of 26 samples (ppm)	Wedepohl, (1995) Average Crustal Abundance	Enrichment Factor (EF= Cn/Bn)	Status
Cu	0.07	14.3ppm	0.005	Depleted
Zn	0.03	52ppm	0.001	Depleted
Ag	2.59	0.07ppm	37.0	Very High Enriched
Au	0.23	0.004ppm	57.5	Extremely High Enriched
As	0.11	2.0ppm	0.06	Depleted
Pb	0.30	17ppm	0.02	Depleted
Mo	1.14	1.5ppm	0.76	Depleted
Hg	0.21	0.08ppm	2.6	Moderately Enriched
Cr	0.07	35ppm	0.002	Depleted
Ni	0.03	18.6ppm	0.002	Depleted
V	0.12	98ppm	0.001	Depleted
Sr	0.20	333ppm	0.001	Depleted

From Table 3 above, the result shows that elements such as Cu, Zn, As, Pb, Mo, Cr, Ni, V and Sr were generally depleted relative to their background value, with mean ratios of less than 1 with exception of Hg, greater than 1. This indicates that artisanal mining activity has not contaminated the environment with these elements. Hg shows moderate enrichment as compared with the background value, with enrichment ratio of 2.6 (>2). 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 concentration ranges from very high enriched to extremely high enriched compared with baseline values of Wedepohl (1995) with enrichment ratios of 37 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.

3.5. Index of Geoaccumulation (Igeo)

This is one of the methods that can be used to estimate the level of enrichment of the concentration of an element above the background value. According to Muller (1969), index of geoaccumulation (Igeo) can be used to assess the severity of pollution using seven enrichment classes as presented in Table 4 below. The formula below was used to calculate the index of geoaccumulation (Igeo):

Igeo = Log2 (Cn/1.5Bn)

Where: Cn = Concentration of the element measured in the sediment sample

Bn = the equivalent concentration in referenced background value (Taylor and McLennan, 1985; 1995 Average Crustal Abundance), and a constant of 1.5 was introduced to help minimize effect of variation of the background values (Abrahim and Parker, 2008).

Table 4: Classes of the index of geoaccumulation, Igeo adopted after (Muller, 1969).

Igeo value	Igeo class	Pollution intensity
> 5	6	Extremely polluted
4 – 5	5	Strongly to extremely polluted
3 – 4	4	Strongly polluted
2 – 3	3	Moderately to strongly polluted
1 – 2	2	Moderately polluted
0 – 1	1	Unpolluted to moderately polluted
0	0	Unpolluted

Table 5: Summary of index of geoaccumulation, Igeo for trace elements in sediments from the study area.

Element	Average concentration of 26 samples (ppm)	Taylor and McLennan, (1985; 1995) Average Crustal Abundance	Average index of geoaccumulation (Igeo)	Status
Cu	0.07	30ppm	-9.3	Unpolluted
Zn	0.03	60ppm	-11.6	Unpolluted
As	0.11	1.7ppm	-4.5	Unpolluted
Pb	0.30	15ppm	-6.2	Unpolluted
Mo	1.14	1.0ppm	-0.4	Unpolluted
Hg	0.21	0.03ppm	2.2	Moderately to strongly polluted
Cr	0.07	70ppm	-10.6	Unpolluted
Ni	0.03	44ppm	-11.1	Unpolluted
V	0.12	95ppm	-10.2	Unpolluted
Sr	0.20	290ppm	-11.1	Unpolluted

Table 5 presents the result obtained from the calculation of index of geoaccumulation (Igeo). It shows that Kataeregi area may have problems relating to Hg contaminations. The mean Igeo value of 2.2 for Hg falls within class 3 of the Muller scale, thus indicating that the sediment is moderately to strongly polluted with Hg. However, other elements such as Cu, Zn, As, Pb, Mo, Cr, Ni, V and Sr have mean Igeo value of less than 1. This corresponds to unpolluted condition, showing that the area has no problem with respect to these elements.

4.0 CONCLUSION

The results of geochemical analysis of the stream sediment and mine tailing samples from Kataeregi area when compared with relevant published crustal concentrations (Table 3) shows that 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 (Tables 3 and 5). 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 result in stunted growth, leave chlorosis and low yield to mention but a few. It is advised that Ag should also be explored and exploited for in the area. This will complement the exploitation of gold and generate more income to the investors and the government through revenue generation. However, the activities of artisanal gold mining in Kataeregi and its environs has led to degradation in the natural environment. Therefore, regulations should be put in place so as to check mate these effect during and after the mining activity.

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