Hydrogeochemical Evaluation of Surface and Groundwater Quality around Galadima Koko Mining sites, Niger State, North-central Nigeria

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Hydrogeochemical Evaluation of Surface and Groundwater Quality around Galadima Koko Mining Sites, Niger State, North-central Nigeria

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Abstract

Problem Statement: The impact of artisanal gold mining on surface and groundwater around Galadima koko area of Niger State, North-central Nigeria is disturbing. This is because the same surface water and hand-dug wells used for gold washing are also used for drinking and domestic purposes. This makes it imperative to ascertain the pollution status of surface water and groundwater from shallow hand-dug wells in the area. **Methodology:** Surface and groundwater samples were collected in the vicinity of the mining sites while control samples taken far away from the mining sites and taken to the laboratory for chemical and bacteriological analyses. Prior to the samples, physical parameters (pH, temperature, total dissolved solid, electrical conductivity and turbidity) were determined insitu using standard instruments and procedures. **Summary of Findings:** Geological mapping of the area revealed that gneiss, schist and granite as the major lithological unit in the area. The concentrations of all the major cations (sodium, calcium, magnesium and potassium) and anions (sulphate, chloride, bicarbonate, carbonate and nitrate) are below their respective maximum permissible limit postulated by Nigerian Standard for Drinking Water Quality. However, within the vicinity of the mining sites, the concentrations of iron, copper and manganese were slightly higher than their respective maximum permissible limits. Their concentration in the surface and groundwater in the area may be attributed to the impact of artisanal mining. The practice of washing the rocks containing gold directly on the nearby stream as well as using the mining buckets and pan to fetch water from the shallow hand-dug wells exposes the water system in the area to pollution. High concentration of iron, cooper and manganese in the water is due to the oxidation, dissolution and weathering of pyrite that is associated with the gold mineralization in the area. The microbial analysis indicates that both the surface and groundwater in the area is contaminated with human and animal faeces. The results of Piper, Duròv, Schoeller, Stiff and Gibbs diagrams suggest the water type in the area as alkaline-bicarbonate. **Conclusion:** The present study has ascertained that mining and poor sanitation in the study area have deteriorated the water system in the area. **Recommendation:** Due to the high concentration of bacteria in the water, boiling of water before use is suggested.

Keywords: Water Quality, Assessment, Galadima, Niger State, North-central Nigeria

Introduction

Availability of potable water is one of the important ingredients for sustainable development and civilization of any community. According to the World Health Organization (2015) report, about 1.1 billion people globally do not have access to potable water supply while 2.4 billion people do not have access to good sanitation. Water is an essential resource for life and good health. It is so vital that it improves many health conditions such as chronic exhaustion, dehydration, toxin removal, poor blood circulation, waste removal and good kidney function. There is an increasing awareness that water will be one of the most critical natural resources in future due to the fact that about 2 million children less than 5 five years die annually in developing countries as a result of water borne diseases (WHO, 2012). According to WaterAid (2016) report, lack of potable water killed more people in Nigeria (about 73, 000) than Boko Haram (slightly above 4,000).

This shocking revelation places importance on the need to regularly monitor the quality and source of our daily water supply. Water is an essential requirement of human and industrial development and the most delicate part of the environment and hence, monitoring of its quality is essential to guarantee a safe environment and healthy people. Water is a universal solvent and has the ability to dissolve and interact with organic and inorganic components of the aquifer material through which it migrates (Amadi *et al.* 2014). These materials constitute the amount of total dissolved solids present in the groundwater which enhances its conductivity. This implies that groundwater chemistry is a function of the mineral composition and the formation as it moves from recharge to discharge areas which varies spatially and temporally depending on the chemical nature of the water, mineralogy of the geological formations and residence time of the groundwater (Okunlola *et al.*, 2014; Olasehinde *et al.*, 2015; Dan-Hassan *et al.*, 2016).

Artisanal gold mining is the use of rudimentary methods to extract and process gold. It is a subsistent type of mining which is largely driven by poverty and plays a large role in boosting the economic base of the low income people living in rural communities. This type of gold mining operation impacts negatively on the environment as the gangue are disposed on the nearby soil and surface water without any precaution. The rock hosting the gold usually contain other trace elements and the process of crushing these rocks liberates these metals into the environment (air, soil or water) thereby posing a lot of environmental hazards (Amadi *et al.*, 2016a). Artisanal mining have caused a lot of negative impacts on several communities in Nigeria. It was estimated that about thirteen million people across thirty countries are directly involved in artisanal mining out of which a significant number of are women and children (Omanayin *et al.*, 2016; Abdullahi *et al.*, 2016).

Gold mining is an economically profitable venture and a major point source of surface and groundwater contamination. Recent studies around the world and Nigeria in particular have shown that gold is often associated with metals such as lead, copper, mercury, arsenic, manganese, nickel, iron and cobalt (Amadi *et al.* 2016b; Okunlola *et al.* 2016). These metals can either be liberated from the rocks hosting them in the process of extracting the gold. Sometimes mercury is used to extract and concentrate fine gold particles from crushed rocks leading to the pollution of soil and water sources by heavy metals. The present study is aimed at evaluating the pollution status of soil, surface and groundwater due to artisanal gold mining activities in the area. The absence of organized mining techniques for gold despite the great potentials, coupled with the high rate of unemployment and poverty, led to the invasion of the Nigerian gold fields by artisanal gold miners. Though mining has a lot of economic benefits to the miners and their host communities, its environmental and health effects in terms of land degradation, air pollution and heavy metal contamination of the soil, surface and groundwater could be devastating if not properly handled (Amadi *et al.*, 2017).

The main target of the artisanal gold miners was the primary and alluvial gold deposits with little or no consideration for the environment thereby expelling a lot of heavy metals associated with quartz as gangue and other sundry poisonous by-products into the environment and any available water source. These hazards could set in during the gold exploitation process itself either from the tailings generated which has a lot of heavy metals in them or from the dangerous trenches created during mining. The process of getting gold out of the crushed rocks brings it into contact with people and water whereby the heavy metals contained in the rocks as gangue are deposited. Galadimma Koko village host thousands of artisanal miners as a result of the discovery of a viable gold deposit few kilometres upstream of Shiroro River. The area is strategic to the miners because of the availability of electricity and a large water body for processing the milled gold dust. These unsafe activities are capable of contaminating the surface and groundwater system in the area, hence the need for the present study, which is targeted at evaluating the pollution status of surface and groundwater around Galadimma Koko mining sites in Shiroro Local Government area of Niger State, North-central Nigeria (Fig. 1).

Statement of the Problem

All over the world, artisanal gold mining have resulted to water pollution. The cases of water borne diseases recorded around Galadima Koko make it imperative to ascertain the quality status of the water sources in the area and this is the trust of the present work. Since most of the diseases identified in the area are water-related, it therefore becomes necessary to evaluate the impact of gold mining and other anthropogenic activities on the quality of surface and groundwater in the study area.

Justification of the Research

The quality of life of an individual is a function of the quality of water he or she drinks. According to World Health Organization, about 55% of the disease outbreaks are attributed to consumption of polluted water. It therefore becomes necessary to ascertain the potability of water consumed in Galadima Koko in Shiroro Local Government Area of Niger State, North-central Nigeria, which is the focus of the present study.

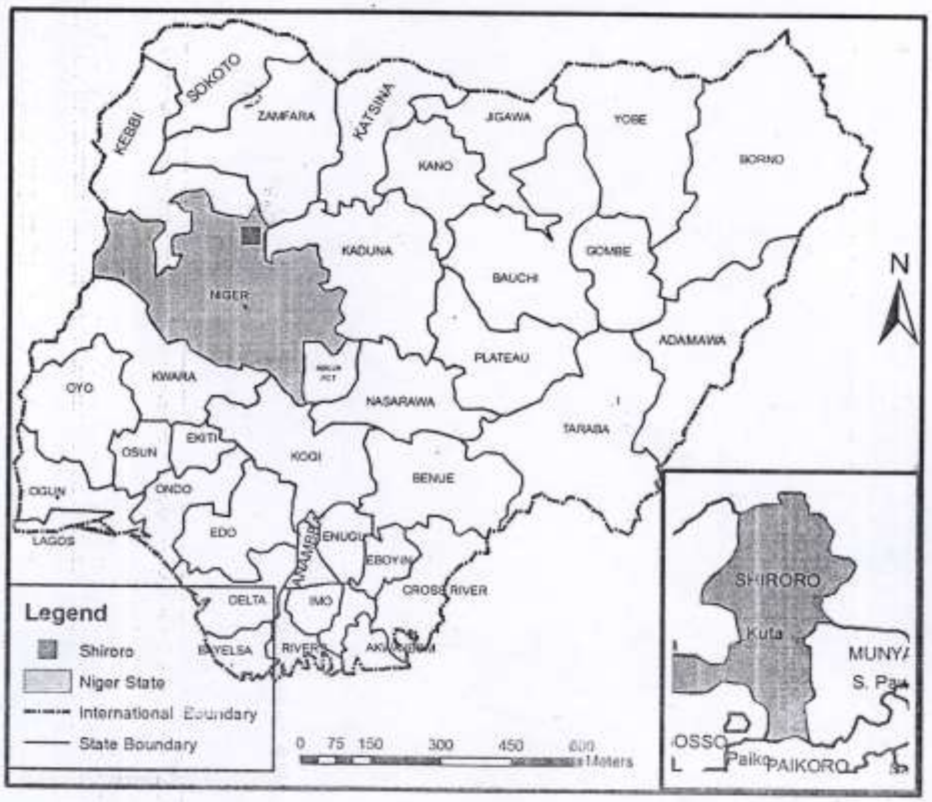

Fig. 1: Map of Nigeria showing Shiroro Local Government (Source: Niger State Ministry of Lands and Housing, 2014)

Materials and Methods

The Study Area Description

The study area lies between latitudes N10°00' to N10°30'and longitudes E06°46' to E06°49' on the scale of 1:25,000 (Fig. 2). The main settlement in the study area is Madaka and are situated north-eastern part of the area. The study area is accessible through Minna-Shiroro road and other minor road. Galadima Koko is mostly low-lying and downstream of Shiroro River. It is characterized by weathering activities that are shown on many of the outcrops in the study area. The land form of the area comprises undulating valleys and hills. The area is drained by River Shiroro and its tributaries. The major ecological challenge faced by the inhabitants is flooding during rainy season especially when Shiroro dam spill gate is open. The area of study is characterized by two seasons, the rainy season and dry seasons. The vegetation of the study area falls under the Guinea Savannah vegetation which is characterized by scattered trees, shrubs and patchy grasses (Nigerian Meteorological Agency, 2014).

Geology of the Study Area

The quality of groundwater is greatly influenced by the chemistry of the host rock in the course of its interaction and migration. The local geology of study area is composed of gneiss, schist and granite as revealed through field mapping. The schist is the most dominant rock types, followed by gneiss and granite respectively (Fig. 3). The schist hosts the gold in the area, and the occur along the fault zones characterized by pegmatites or quartzites.

Water Sampling and Laboratory Analysis

All samples were collected in sets of plastic and glass bottles for cation and anion analyses respectively. Both containers were washed with distilled water and few drops of HNO_3 were added to the plastic bottle for cation analysis in order to prevent loss of metals, bacterial and fungal growth. A total of 50 water samples comprising of 30 hand-dug wells, 10 boreholes and 10 surface water were collected in March, 2017 from the area and sent to the laboratory for analysis. The sampling was done during dry season in order to avoid dilution effect common during rainy season. The temperature, turbidity, conductivity and pH of water samples were measured insitu at the point of collection using a multimeter.

Results

The statistical summary of the physico-chemical and bacteriological analyses is contained in Table 1.

Table 1: Statistical Summary of Physico-chemical and Bacteriological Parameters

Parameters (mg/l)	SW			GW			NSDWQ 2007
	Min.	Max.	Mean	Min.	Max.	Mean	
TDS	62.3	633.0	146.63	75.0	800.0	195.23	500.00
Conductivity (µS/cm)	93.0	946.0	218.8	112.0	1193.0	301.1	1000.00
Dissolved Oxygen	6.44	7.01	6.90	6.35	7.17	6.41	10.00
Temperature (°C)	29.3	30.1	29.5	27.1	30.1	29.3	Ambient
pH	6.74	7.40	7.12	6.52	7.37	7.00	6.5-8.5
Turbidity (NTU)	5.00	603.0	81.94	0.00	52.0	7.97	5.00
Chloride	9.36	49.3	16.37	12.1	95.6	24.92	250.00
Total Hardness	51.0	248.0	79.0	33.0	261.0	109.8	500.00
Fluoride	0.00	0.48	0.16	0.00	1.28	0.42	1.50
Alkalinity	13.0	70.0	41.0	19.0	85.0	53.7	100.00
Phosphate	0.10	2.44	0.87	0.11	1.41	0.63	45.00
Carbonate	0.00	0.00	0.00	0.00	0.00	0.00	150.00
Sulphate	4.0	44.0	12.2	0.00	88.0	24.17	100.00
Copper	0.00	2.00	0.27	0.08	1.48	0.46	1.00
Bicarbonate	0.00	71.0	31.6	0.00	85.0	35.1	100.00
Nitrite	0.00	0.14	0.034	0.01	0.21	0.046	0.20

Nitrate	0.78	67.0	9.92	2.11	68.6	13.1	50.00
Sodium	8.00	32.0	13.3	6.00	58.0	17.33	250.00
Potassium	3.00	63.0	10.3	2.00	13.0	5.00	150.00
Calcium	4.27	67.7	19.82	1.80	59.4	26.19	200.00
Magnesium	1.60	12.9	6.43	0.54	32.6	13.57	200.00
Iron	0.03	0.83	0.23	0.01	0.65	0.18	0.30
Zinc	0.05	0.58	0.11	0.00	3.47	0.71	3.00
Manganese	0.01	0.028	0.0098	0.011	0.03	0.0112	0.20
Chromium	0.01	0.05	0.017	0.02	0.07	0.0256	0.05
Arsenic	0.00	0.01	0.001	0.00	0.01	0.0017	0.01
Nickel	0.00	0.01	0.004	0.00	0.03	0.0056	0.02
B.Coliform (cfu/100ml)	12.0	120.0	45.2	0.00	200.0	37.11	0.00
T.Coliform (cfu/100ml)	64.0	580.0	289.1	0.00	430.0	94.33	10.00
Faecal Strep.(cfu/100ml)	24.0	168.0	52.60	0.00	280.0	96.85	0.00

SW-Surface Water; GW-Groundwater; TDS-Total Dissolved Solids; T.Coliform-Total Coliform
NSDWQ-Nigerian Standard for Drinking Water Quality; B.Coliform-Bacteria Coliform

The geology map and sample location map of the study area are shown in figures 2 and 3 respectively.

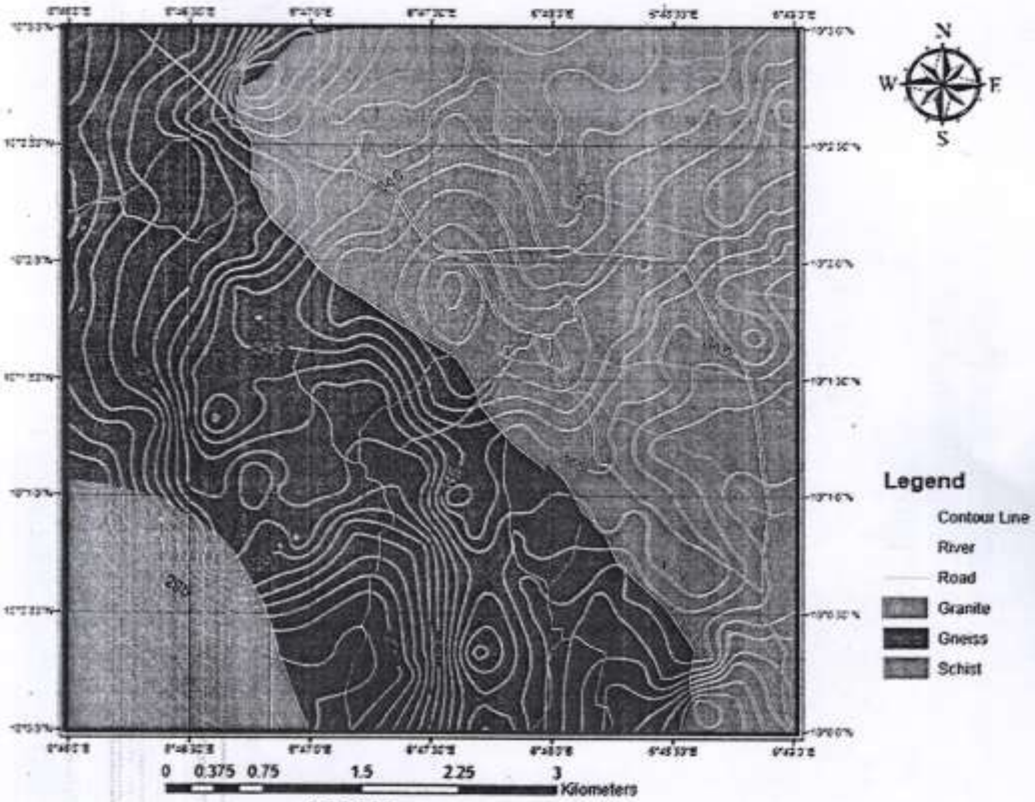

Fig. 2: Fact map of the Study Area

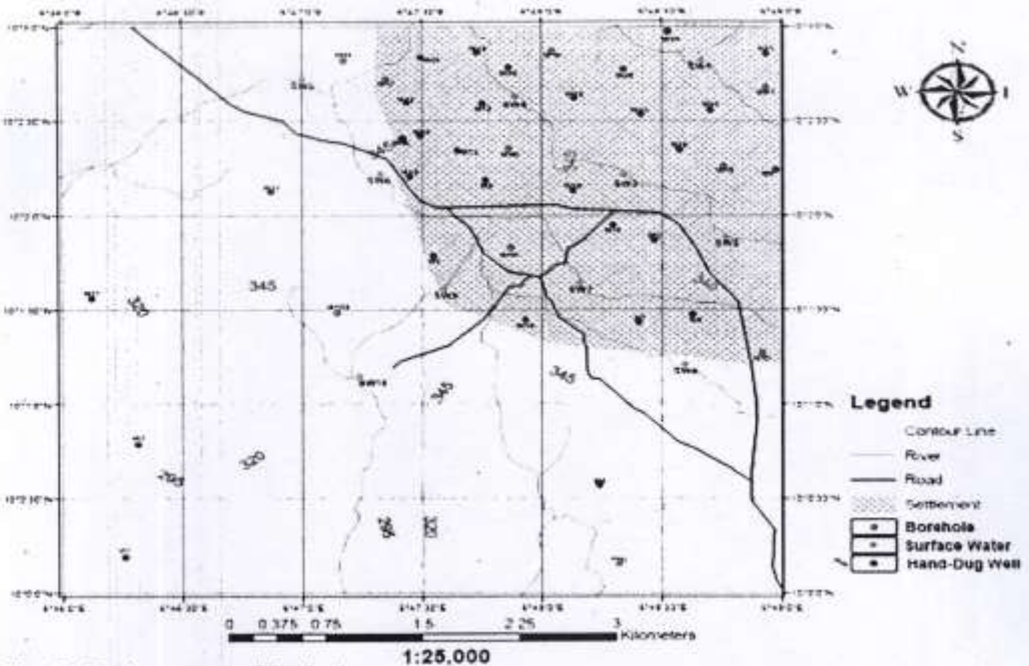

Fig. 3: Geology map of Study Area

The Piper diagram (Fig. 4), Durov Diagram (Fig. 5), Schoeler Plot (Fig. 6), Stiff Plot (Fig. 7) and Gibbs Plot (Fig. 8) were used to explain the water regime of the area in terms of water type, sources and facies.

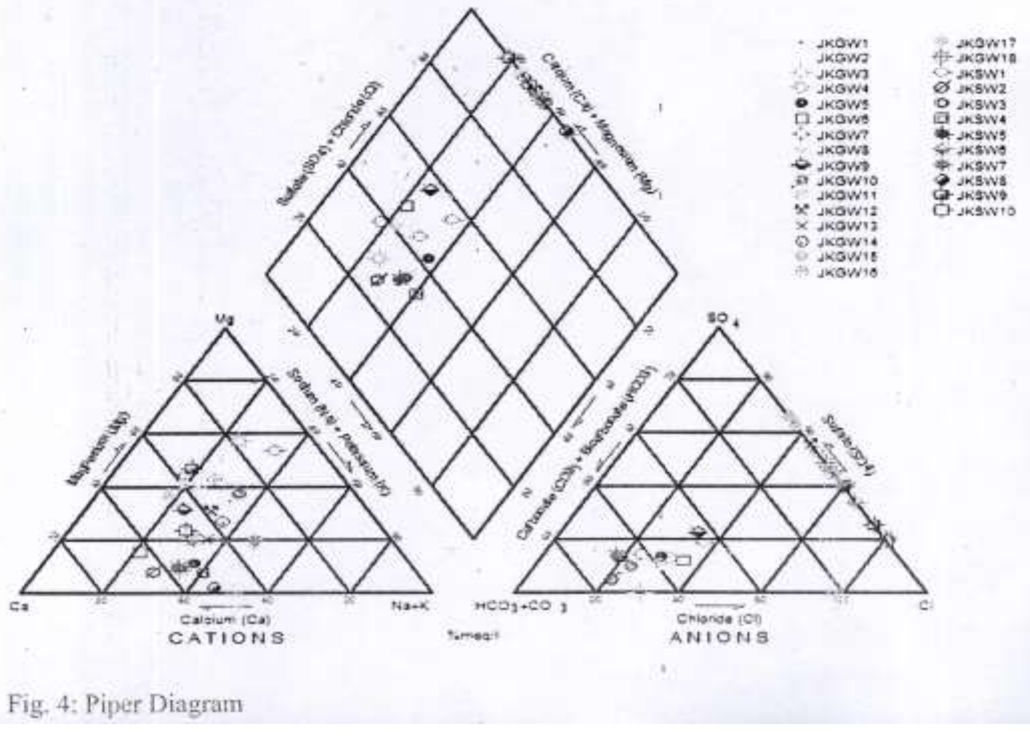

Fig. 4: Piper Diagram

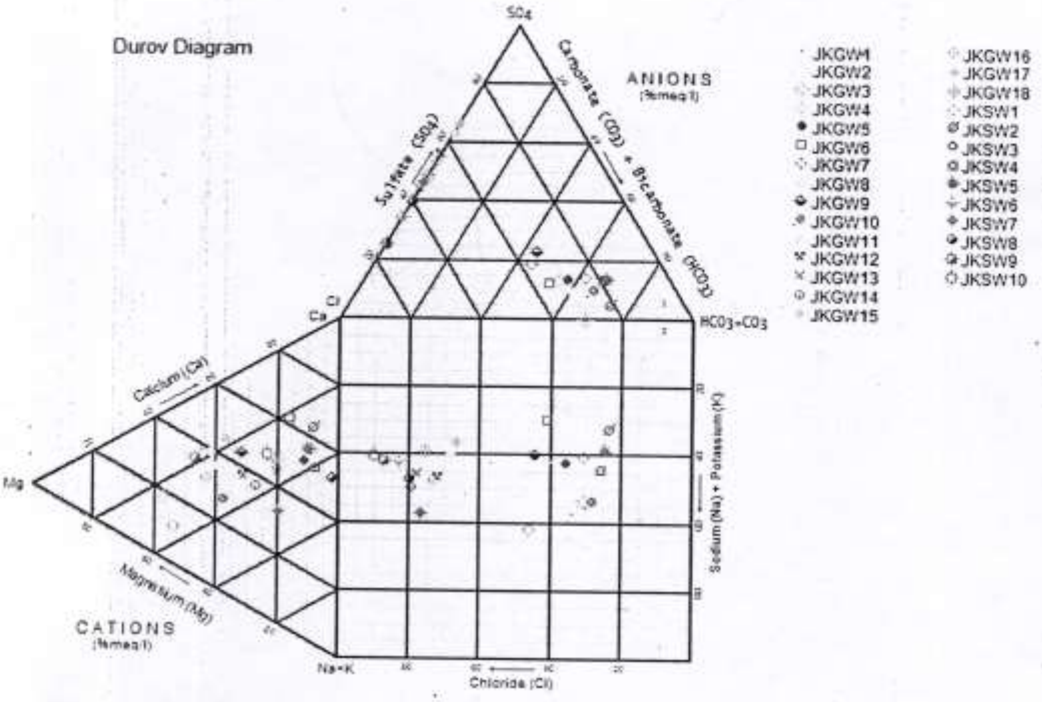

Fig. 5: Durov Diagram

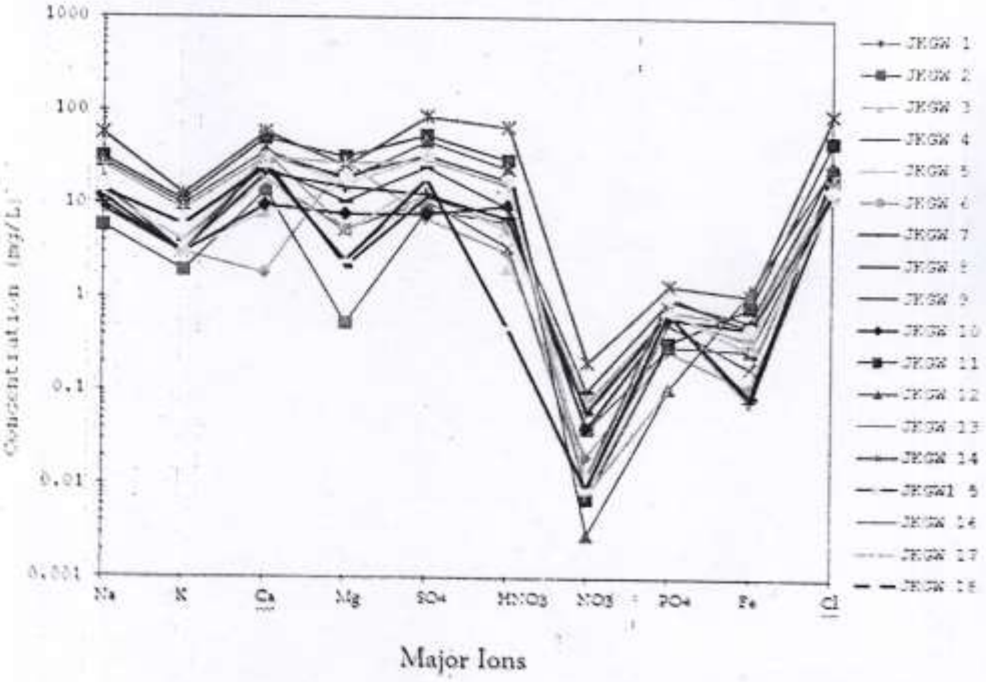

Fig. 6: Schoeler Plot

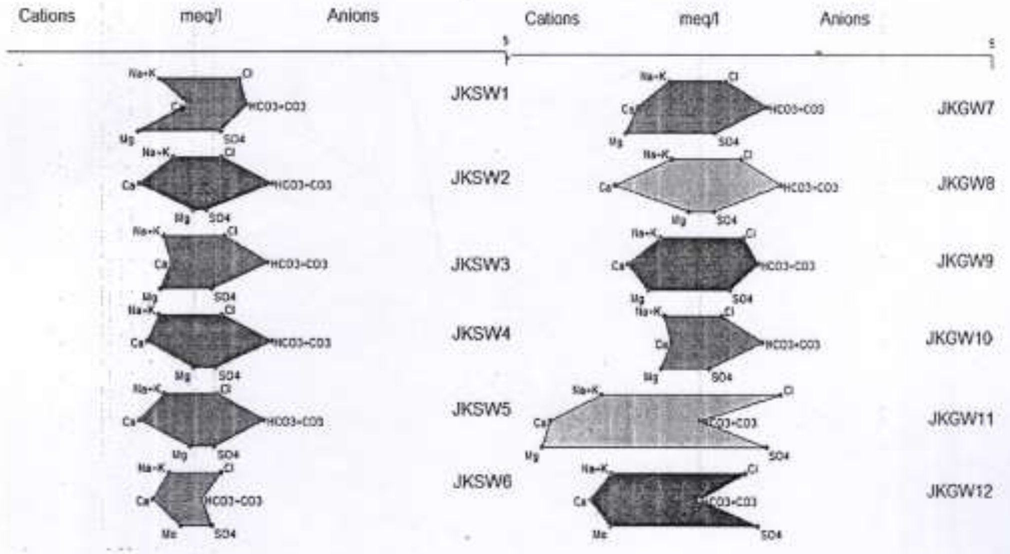

Fig. 7: Stiff Plot

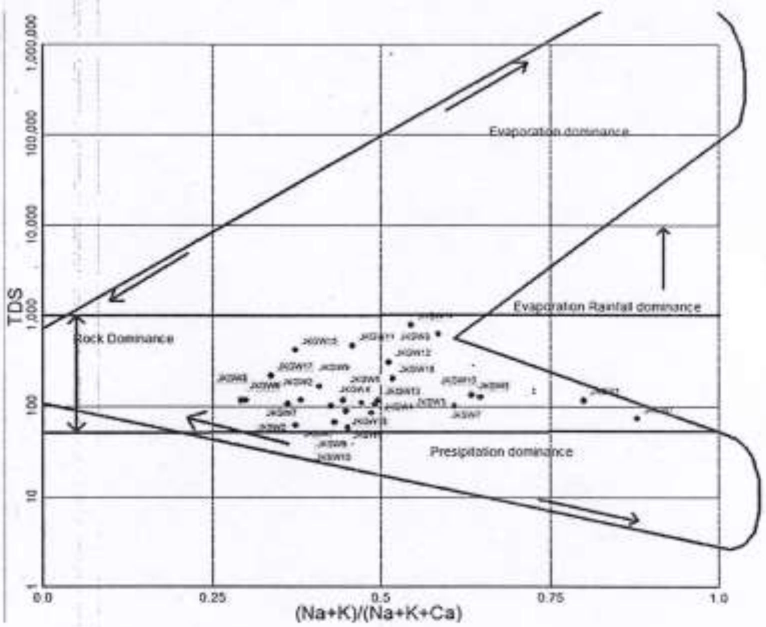

Fig 8: Gibbs Plot

Discussion

Physical Parameters

Total dissolved solid (TDS) is the amount of dissolved solute in water and its concentration in surface water ranged from 62.3 mg/l to 633.0 mg/l with a mean concentration of 146.6 mg/l while the concentration in groundwater varied from 75.0 mg/l to 800.0 mg/l with an average value of 195.2 mg/l. The concentration of TDS in 8 locations (surface water) and 14 locations (groundwater) were higher than the recommended maximum permissible limit of

500.0 mg/l by the Nigerian Standard for Drinking Water Quality. Surface run off, chemical weathering, bedrock dissolution and other rock-water interaction phenomenon are the potential ways through which solute dissolve in water. The electrical conductivity for the surface water ranged between 93.0 µs/cm to 946.0 µs/cm with a mean value of 218.8 while the electrical conductivity of the groundwater varied between 112.0 µs/cm to 1193 µs/cm with an average value of 301.1 µs/cm. Except for the groundwater samples in locations 14 and 18 whose values are above the maximum permissible limit of 1000.0 µs/cm (NSDWQ, 2007), the concentration of other locations in both surface and groundwater were below the allowable limit for a safe drinking water. Both TDS and conductivity are good indicators of pollution level in water sources. The temperature is the measure of the degree of coldness or hotness of a medium and it has an essential role to play on the chemical reaction taking place in water.

The surface water temperature ranged between 29.3 °C and 30.1 °C with a mean temperature of 29.5 °C while the groundwater temperature varied between 27.1 °C and 30.1 °C with a mean temperature of 29.3 °C. The higher the water temperature, the faster solutes dissolves in water and the observed temperature values falls within the recommended ambient temperature. The pH of the surface water is in the order of 6.74 to 7.40 with a mean value of 7.12 while the groundwater varied from 6.52 to 7.37 with an average value of 7.00. The pH for both surface and groundwater are within the acceptable limit of 6.5 – 8.5 (NSDWQ, 2007; WHO, 2012). Low pH encourages the dissolution, solubility and mobility of metals in water (Amadi *et al.* 2015).

Turbidity values of the surface water varied from 5.0 NTU to 603.0 NTU with a mean concentration of 81.9 NTU while the groundwater has concentration ranging from 0.0 NTU to 52.0 NTU with an average value of 7.9 NTU. From the analysis, the turbidity concentration values in all the sampled surface water are above the maximum permissible limit of 5.0 NTU (NSDWQ. 2007). The amount of suspended materials in water makes it turbid, and such water are cloudy (not clear) in appearance, thereby reducing the visibility and transparency of the water. Since groundwater is covered by overlying formation and as a result turbidity values is generally low when compared to surface water which is exposed and receives all sort of materials via human activities and run off. The turbidity values in locations 11, 12, 14 and 15 of the groundwater are above the permissible limit of 5.0 NTU while the concentrations in the remaining locations falls within the acceptable value.

Chemical Parameters

The results of the chemical analyses of surface and groundwater from the study area are contained in Table 1. The dissolved oxygen has concentrations for the surface water in the range of 6.44 mg/l to 7.01 mg/l with a mean value of 6.90 mg/l while the groundwater has dissolved oxygen concentration value in the range of 6.35 mg/l to 7.17 mg/l with an average of 6.4 mg/l. The dissolve oxygen measured the oxygen available for aquatic organisms and it is very essential for well-being of aquatic lives. The concentration of total hardness for the surface water ranged between 51.0 mg/l and 248.0 mg/l with a mean value of 79.0 mg/l while the concentration for groundwater is in the range of 33.0 mg/l and 261.0 mg/l with an average value of 109.8 mg/l. Groundwater is in constant interaction with the host rock through which it moves and such rock-water interaction accounts for the higher values of total hardness in groundwater than in surface water. The presences of calcium and magnesium ions in water are responsible for hardness of water. Total alkalinity concentration in the surface water ranged between 13.0 mg/l and70.0 mg/l with a mean concentration of 41.0 mg/l while its concentration in the groundwater varied between 19.0 mg/l to 85.0 mg/l with an average concentration of 53.7 mg/l. Shallow water aquifers in basement complex have high alkalinity and this serve as a pointer to the fact that the groundwater has higher alkalinity concentration than the surface water (Olasehinde *et al.*, 2016).

Sodium concentration level in the surface water ranged from 8.0 mg/l to 32.0 mg/l with an average value of 13.3 mg/l and the groundwater has concentration value in the order of of 6.0 mg/l to 58.0 mg/l with a mean value of 17.33 mg/l. The sodium content in surface and groundwater are below the maximum permissible value of 250 mg/l (NSDWQ, 2007).

High concentration of sodium in drinking water can cause hypertension in humans (Nwankwoala *et al.*, 2015). Potassium concentration in the surface water ranges between 3.0 mg/l to 63.0 mg/l with a mean concentration of 10.3 mg/l while the groundwater concentration varies from 2.0 mg/l to 13.0 mg/l with an average value of 5.00 mg/l. The concentration of calcium in surface water range between 4.27 mg/l and 67.70 mg/l with an average concentration of 19.82 mg/l while the concentration in groundwater varied from 1.80 mg/l and 59.4 mg/l with a mean value of 26.19 mg/l. The concentration of calcium in surface and the groundwater fall within the maximum permissible limit of 200.0 mg/l (NSDWQ, 2007) for potable water. Calcium is an essential element for the development of teeth and bones in the animals (Tukur and Amadi, 2014; Okiongbo and Douglas, 2013; El-Sayed *et al.*, 2012).

Magnesium concentration in surface water is in the range of 1.6 mg/l to 12.9 mg/l with a mean value of 6.43 mg/l while the concentration in groundwater varied from 0.54 mg/l to 32.6 mg/l and an average value of 13.57 mg/l. These values far below the maximum permissible limit of 200.0 mg/l (NSDWQ, 2007). Magnesium is easily absorbed in water than magnesium in diet. Studies have revealed that intake of magnesium from water in sufficient quantity prevents nervous disturbance and arterial hypertension (Vasanthavigar *et al.*, 2010; Nur. and Ayuni, 2014). The concentration of sulphate in surface water ranged from 4.0 mg/l to 44.0 mg/l with a mean value of 12.2 mg/l while the concentration in the groundwater varied from 0.00 mg/l to 88.0 mg/l with an average value of 24.17 mg/l. The sulphate concentration in both surface and groundwater are within the maximum permissible limit of 100.0 mg/l (NSDWQ, 2007). High sulphate concentration may result from chemical weathering and dissolution of bedrocks and may also be due to anthropogenic influences resulting from urban pollution such as mining activities and fertilizer application in farming system (Dan-Hassan *et al.*, 2012; Aboud and Nandini, 2009). The concentration of nitrate in surface water ranged from 0.78 mg/l to 67.0 mg/l with a mean value of 9.92 mg/l while the concentration in groundwater varied from 2.11 mg/l to 68.6 mg/l with an average value of 13.1 mg/l. Four locations in the surface water and two locations in groundwater have values higher than the recommended maximum permissible limit of 50.0 mg/l (WHO, 2012; NSDWQ, 2007). High nitrate concentration in water for drinking purposes may causes methaemoglobinaemia in infant (blue-baby syndrome), metabolic disorder and poisoning of livestock. Nitrate concentration in groundwater can be attributed to man activities like leachate from waste dumpsite, application of fertilizer in farming and poor sanitation (Ali, 2004; Olatunji *et al.*, 2005; Elueze *et al.*, 2011). The nitrite concentration in surface water ranged from 0.00 mg/l to 0.14 mg/l with a mean value of 0.034 mg/l while the concentration of nitrite in groundwater varied from 0.01 mg/l to 0.21 mg/l with an average value of 0.046 mg/l. These values falls within the permissible limit 0.2 mg/l (NSDWQ, 2007). The phosphate concentration in surface water ranged from 0.10 mg/l to 2.44 mg/l and with a mean concentration of 0.87 mg/l while the concentration of phosphate in the groundwater varied from 0.11 mg/l to 1.41 mg/l and with a mean of 0.63 mg/l. High concentration of sulphate, nitrate, nitrite and phosphate in water are indicators of anthropogenic pollution (Ige and Olasehinde, 2011; Amadi *et al.*, 2013).

The concentration of fluoride ranged from 0.00 mg/l to 0.48 mg/l with a mean concentration of 0.16 mg/l while fluoride concentration in groundwater varied from 0.00 mg/l and 1.28 mg/l with an average value of 0.42 mg/l. These values are below the recommended maximum permissible limit of 1.50 mg/l (NSDWQ, 2007). Fluoride content in water is both beneficial and detrimental to the body depending on the concentration. Fluoride content below 1.50 mg/l helps in the formation of strong bones and tooth while concentrations exceeding 1.50 mg/l cause fluorosis and skeletal paralysis (Nwankwoala *et al.*, 2017). High fluoride content in groundwater can be attributed to either natural means via chemical weathering and rock dissolution processes or anthropogenic interference through the application of fluoride rich fertilizer (Nwankwoala *et al.*, 2016). This study revealed that the highest concentration of fluoride in groundwater in the area occurs in the portion underlain by granite while fluoride concentration within the schist lithology was found to be averagely low. The fluoride-bearing minerals in granitic and metamorphic rocks are apatite, selecite, topaz, fluorite, flouroapatite and cryolite (Abimbola *et al.*, 2002). The high fluoride content in water in the area may be due to natural release of fluoride rich mineral in the granite dominated portion via chemical weathering and bedrock dissolution processes.

Chloride concentration in surface water ranged from 9.36 mg/l to 49.3 mg/l with a mean concentration of 16.37 mg/l while in groundwater, the concentration ranged between 12.1 mg/l and 95.6 mg/l with an average value of 24.92 mg/l as against the maximum permissible limit of 250 mg/l (NSDWQ, 2007 and WHO, 2012). High chloride content in water causes hypertension in humans, corrosion in metallic pipes and is harmful to plants that are non-halophytic. Bicarbonate concentration in surface water ranged from 0.00 mg/l to 71.0 mg/l with a mean value of 31.6 mg/l while the concentration of bicarbonate in groundwater varied from 0.00 mg/l to 85.0 mg/l with a mean concentration value of 35.1 mg/l. High concentration of bicarbonate in water does not pose any health challenge. Carbonate was not detected in surface and groundwater. The paucity of carbonate in the area may be a function of the geology of the area.

Heavy Metals

The results of the laboratory analyses of the heavy metals in surface and groundwater are shown in Table 1. These are chemical elements that are naturally metallic and they relatively have high density and are very toxic at considerably low concentration. They are unique because of their characteristic distinguishing properties that include density, solubility, valency and redox potential. The concentration of iron in surface water ranged between 0.03 mg/l to 0.83 mg/l with a mean concentration of 0.23 mg/l while iron concentration in groundwater varied from 0.01 mg/l to 0.65 mg/l with an average value of 0.18 mg/l. The mean concentration of both surface and groundwater are below the maximum permissible limit of 0.30 mg/l (NSDWQ, 2007). Surface water samples from locations 2 to 8 and groundwater samples from locations 9 to 14 have values higher than the permissible limit. The concentration of iron in water has some merit and demerit. Lack of iron in water (< 0.3 mg/l) causes goitre while in higher concentration it makes the water turbid, coloured, tasty and causes hemochromatosis. The concentration of zinc in surface water ranged from 0.05 mg/l to 0.58 mg/l with a mean concentration value of 0.11 mg/l while zinc concentration in groundwater varied from 0.00 mg/l to 3.47 mg/l with an average value of 0.71 mg/l. In aquatic system, high zinc concentration could pose adverse effect to the aquatic ecosystem as it cause toxicity in fisheries and livestock.

The concentration of copper in surface water ranged between 0.00 mg/l to 2.00 mg/l with a mean concentration value of 0.27 mg/l while copper concentration in groundwater varied from 0.08 mg/l to 1.48 mg/l with an average value of 0.46 mg/l. The concentration of copper in surface water at locations 2, 5 and 7 as well as groundwater in locations 3, 6, 9 and 12 were above the permissible limit of 1.00 mg/l (NSDWQ, 2007). Copper is an important element to human life, but when its concentration is high, it may results to some diseases like anaemia, kidney and liver damages, irritation in the intestine and stomach.

The concentration of manganese in surface water ranged between 0.01 mg/l to 0.028 mg/l with a mean value of 0.0098 mg/l while the manganese concentration in groundwater varied from 0.011 mg/l to 0.03 mg/l with an average value of 0.0112 mg/l. All the samples from both the surface water and the groundwater are below the maximum permissible limit of 0.20 mg/l (WHO, 2012; NSDWQ, 2007). High concentration of manganese in water causes neurological disorder in animals. The concentration of chromium in the surface water ranged from 0.01 mg/l to 0.05 mg/l with a mean value of 0.017 mg/l while the chromium concentration in groundwater ranged from 0.02 mg/l to 0.07 mg/l with an average value of 0.0256 mg/l. The concentrations of chromium in surface water are within the permissible limit of 0.05 mg/l while the locations 3 and 8 have concentrations slightly above the maximum acceptable limit. High chromium content in water causes cancer humans.

The concentration of arsenic in surface water ranged from 0.00 mg/l to 0.01 mg/l with a mean value of 0.001 mg/l while the concentration in groundwater varied from 0.00 mg/l to 0.01 mg/l with an average value of 0.0017 mg/l. Arsenic is a pathfinder element to gold. Gold mining releases it to the environment and is the major cause of acute poisoning and cancer in human organs. When it enters the environment bedrock dissolution processes, it remains until it is absorbed in soil and infiltrate into groundwater or surface water through runoff. The concentration of nickel in surface water ranged from 0.00 mg/l to 0.01 mg/l with a mean concentration value of 0.004 mg/l while the concentration in groundwater varied from 0.00 mg/l to 0.03 mg/l with an average value of 0.0056 mg/l. The concentration value is within the acceptable limit of 0.02 mg/l (WHO, 2012; NSDWQ, 2007)) except the groundwater samples in location 10 at 0.03 mg/l that is slightly above the permissible limit. High concentration of nickel results to allergic reactions and possible carcinogen.

Bacteriological Parameters

The results of the bacteriological parameters are contained in Table 1 for both the surface and groundwater. The concentration total coliform for the surface water ranged from 64.0 cfu/100ml to 580 cfu/100ml with a mean value of 289.1 cfu/100ml while the concentration total coliform in groundwater varied from 0.00 cfu/100ml to 430 cfu/100ml with an average value of 94.33 cfu/100ml. These values are higher than maximum recommended value of 10.00 cfu/100ml (NSDWQ, 2007). The presence of total coliform in water is an indication that the water in the area is polluted with human faeces. The concentration of bacteria coliform for the surface water ranged between 12.0 cfu/100ml and 120 cfu/100ml with a mean concentration of 45.2 cfu/100ml while the concentration of bacteria coliform for the groundwater varied between 0.00 cfu/100ml and 200 cfu/100ml with a mean concentration of 37.11 cfu/100ml. The mean concentration of bacteria coliform in surface and groundwater falls above the recommended value of 0.00 cfu/100ml (NSDWQ, 2007 and WHO, 2012). This is also an indication of faecal contamination of the surface and groundwater system in the area (Amadi *et al*., 2017). The concentration of faecal streptococci concentration for the surface water ranged from 24.0 cfu/100ml to 168 cfu/100ml with a mean concentration of 52.6 cfu/100ml while the concentration value for the groundwater ranges between 0.00 cfu/100ml to 280 cfu/100ml as against the acceptable value of 0.0 cfu/100ml. The presence of total coliform, bacterial coliform and faecal streptococci in water is an indication of faecal contamination. This is responsible for water borne diseases such cholera, diarrhea, yellow fever, acute renal failure and haemolytic anaemia.

Hydrochemical Facies Classification Piper and Durov Diagrams

The Piper (Fig. 5) and Durov (Fig. 6) diagrams represent fundamental principles in a graphic form used effectively in interpreting hydrochemical data with respect to water sources and types. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO^-_3 and SO_4^{2-}) are represented on a trilinear diagram by grouping the K^+ with Na^+ and the CO_3^{2-} with HCO^-_3, thus reducing the number of parameters for plotting to 6. In both diagrams, the relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field, where the water source and type are identified. The diagrams are used to classify the hydrochemical facies of the water samples according to their dominant ions.

Schoeler and Stiff Plots

Unlike the Piper and Durov diagrams where grouping the K^+ with Na^+ and the CO_3^{2-} with HCO^-_3 are done before plotting take place, the concentration of each parameter is used in Schoeler and Stiff Plots. They are graphical representation of major ions concentration in the water. The Schoeler plots (Fig. 7) reveals the ions with very high, high, averge, low and very low concentrations in the water. In case of Stiff Plot (Fig. 8), similar shape implies possible similar water source and type.

Gibbs Plots

Gibbs plot is a plot of TDS versus the weight ratio of $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ for cations and TDS versus the weight ratio of $Cl^-/(Cl^- + HCO^-_3)$ for anions. This plot provides useful information on the major natural mechanisms controlling surface and groundwater chemistry. The processes include but not limited to precipitation, evaporation, weathering and bedrock dissolution. Figure 8 shows the Gibbs scatter diagram plotted using surface and groundwater data from the area. In these diagrams, samples falling in the centre of the curve suggests that chemical weathering of rock-forming minerals is the main causative factor in the evolution of the chemical composition of both surface and groundwater in the study area.

Conclusion

The hydrogeochemical investigation of surface and groundwater quality around Galadimma Koko area, north central Nigeria was studied in the present research work. The study was aimed at evaluating the quality status of surface and groundwater in the vicinity of a mining site. Results of the field geological mapping of the study area reveal three rock types in the order of schist, gneiss and granite. The physical parameters were determined insitu while the chemical and bacteriological parameters were determined in the laboratory. Results of the water analysis were interpreted and compared with the Nigeria Standards for Drinking Water Quality (NSDWQ) and World Health Organization (WHO). The cations and anions analyzed for both surface and groundwater samples were within the WHO permissible limits and their source in the water is traced to natural geological process of rock weathering, bedrock dissolution and surface run-off. The concentration level of some of the analysed heavy metals in surface and groundwater slightly exceeds the NSDWQ and WHO permissible limits in few locations and these include Cu, Fe, Mn and Ni. The slight contamination may be attributed to anthropogenic via mining activities and geogenic through weathering and rock-water interaction. Bacteriologically, both surface and groundwater were heavily contaminated with total coliform, bacteria coliform and faecal streptococci which are an indication of faecal contamination. It is a confirmation that the water systems in the area is in contact with animal faeces.

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