HYDROGEOCHEMICAL INVESTIGATION OF SURFACE AND GROUNDWATER QUALITY AROUND ANGUWAN MAIGIRU MINING SITES, NIGER STATE, NORTHCENTRAL NIGERIA

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Abstract

An investigation of surface and groundwater quality was carried out in Anguwan Maigiru, Madaka District of Rafi Local Government of Niger State, North-Central Nigeria. This was aimed at evaluating the quality status of surface and groundwater in the study area. The geological mapping revealed that the area is dominantly underlain by schist and granite. The physical parameters of the collected water samples were determined on site using the appropriate techniques while the chemical analysis was done at Regional Water Quality Laboratory Minna and the National Geosciences Research Laboratory Kaduna. A wide range and standard deviation was observed in the following groundwater quality parameter: Total dissolved solid (54.00-1123.00), electrical conductivity (35.00-1696.00), pH (5.54-10.60), sodium (5.00-471.00), iron (0.10-95.60), zinc (0.03-6.14), copper (0.03-3.13), chromium (0.05-0.36), manganese (0.06-1.36) and lead (0.00-11.00) are signatures that the water sources in the area are deteriorated by enrichment of these parameters. The Piper and Stiff plots show that the water samples analyzed had Na-HCO_3-Cl as the most dominant water type with minor mixed Ca-Na-Cl and Ca-Cl types. Gibbs plot illustrates that majority of the groundwater samples fall within the rock source dominance which suggests that the weathering of rocks primarily controls the major ion chemistry of groundwater in this area. The result of water quality analyses indicates that the surface and groundwater in the area are polluted and unsuitable for drinking and domestic purposes. The study attributed the poor condition of the water sources in the area to long term environmental abuse in the area arising from artisanal and illegal mining. Shallow hand-dug wells should be discouraged and alternative source of groundwater should be provided for the inhabitants. Residents of the area should build their houses miles away from mine site to prevent contamination and inhalation of toxic metals and waste from mine site should be treated before disposal into nearby surface water or farmlands and regulatory agencies should ensure that global minimum mining standard is maintained in every mining site in Nigeria.

Keywords: Hydrogeochemical Assessment, Surface and Groundwater Quality, Anguwan Maigiru Mining Sites, Niger State, Northcentral Nigeria

1. Introduction

Globally, there is an increasing awareness that water will be one of the most critical natural resources in future. Considering the four basic needs of man water, food, shelter and good health, water is the pivot on which the other variables revolves. Potable and safe drinking water is a necessary requirement for the health and productive life of humans in any society. In terms of economic activities such as commerce, tourism and industry, water is an indispensable input. It is essential requirements for civilization and industrial development of any nation. Therefore, a continuous monitoring of its quality is very essential in order to quantify the level of pollution arising from geogenic and anthropogenic sources as well as to avoid water borne diseases traceable common with contaminated water. Polluted water is a major cause of epidemic and chronic diseases in human being (Okiongbo and Douglas, 2013; Amadi *et al.*, 2016).

2. Literature Review

Amadi, (2011) worked on the geochemical assessment of Aladimma dumpsite on the nearby soil and shallow groundwater. The concentrations of all the parameters analyzed were higher in soil than in groundwater and these may be attributed to the high affinity between organic matter content of soils and element. Ige and Olasehinde, (2011) carried out preliminary assessment of water quality in Ayede-Ekiti, Southwestern Nigeria., it was found that sodium and chloride are the most dominant ions of the total chemical budget. The hydrochemical characteristics of the water revealed that, the cationic concentrations is in the order of (Na^{+}+K^{+}) > Ca^{2+} > Mg^{2+} for both wells and surface waters, while the anionic concentrations is in the order of Cl^{-} > HCO_3^{-} > SO_4^{2-}. Amadi *et al.*, (2010) carried out research on coastal plain-sand aquifer of Owerri using factor analysis for characterization of groundwater chemistry. The study revealed five factors which correspond to five possible sources of pollution of groundwater in the area. Olatunji *et al.* (2005) carried out hydrochemical evaluation of groundwater resources in shallow coastal aquifers around Ikorodu area, southwestern Nigeria. Over 120 groundwater samples from hand dug wells and boreholes were sampled and analyzed for their physicochemical properties. The general hydrochemical character of the water revealed that the cationic concentration of the water to be Na>Ca>Mg while the anionic concentration of the water is Cl>SO_4>HCO_3. The dominant water type in the area is Na+K/Cl+SO_4 type. The water samples analysed showed that the groundwater of the area is affected more by the impact of Lagoon water.

Ali, (2004) carried out research on hydrochemical identification and salinity problem of ground-water in WadiYalamlam basin, western Saudi Arabia. He integrates hydrochemical, hydrogeological and recharge estimation analyses to identify the process/processes, that led to the aquifer salinity. The results of chemical analysis indicate that the groundwater salinity is highly variable and inconsistent along the course of the Wadi. This variability is probably due to the local hydrogeological conditions and to the intensive evaporation of effluent surface irrigation water that led to the precipitation of evaporites. Elueze *et al.*, (2001) researched on hydrochemical assessment of surface water in part of Southeastern Nigeria. The application of R-mode factor analysis suggests that the main component of the water characteristics is related to hydrological, lithological and environmental controls while the water facies for the area is sodium-bicarbonate. Hanaa *et al.* (2000) investigated possible relationships between chemical toxicity of high concentrations of heavy metals and incidence of clinic diseases in Great Cairo city of Egypt. They associated high concentrations of Pb and Cd with renal failure, high concentrations of Cu and Mn to liver cirrhosis. They reported the presence of these metals in the urine of patients suffering chronic health effects like cancer, birth defects, organ damage, disorders of the nervous system and nervousness as well as damage to immune system. Nkotagu, (1996) determined the groundwater geochemistry in a Tanzania. He concluded that the chemical character of the groundwater in this area is due to the dissolution of amphiboles, sodic feldspars, cation exchange and salt leaching while the nitrate content of the groundwater in Dodoma was attributed to the nitrification process of the sewage effluents.

3. Methodology

3.1 Water Sampling and Laboratory Analysis

The water samples were collected in the month of November, 2015 and a total of 30 water samples comprising of (10 surface water, 12 boreholes, 4 hand dug well and 4 mine pits) were collected across the entire study area. The coordinate of each sampled location were obtained using the GPS (GARMIN-76) version (Fig. 3). The water samples were collected in pre-cleaned one litre plastic bottles. Two water samples were collected at each location for cation and anion analyses. Two drops of concentrated nitric acid (HNO_3) were added to one of the samples for the determination of major cations and heavy metals while the water samples in the second bottle were for the determination of the anions. The physical parameters measured in-situ on the field included temperature (T), pH, electrical conductivity (EC) and total dissolved solid (TDS) using appropriate techniques in accordance with the American Public Health Association standards (APHA, 2005). For the purposes of quality control, the water samples were duplicated and analyzed at the Department of Water Resources, Aquaculture and Fisheries Technology, Federal University of Technology Minna and National Geosciences Laboratory Kaduna while the control samples were analyzed at Federal Ministry of Water Resources Regional Laboratory, Minna.

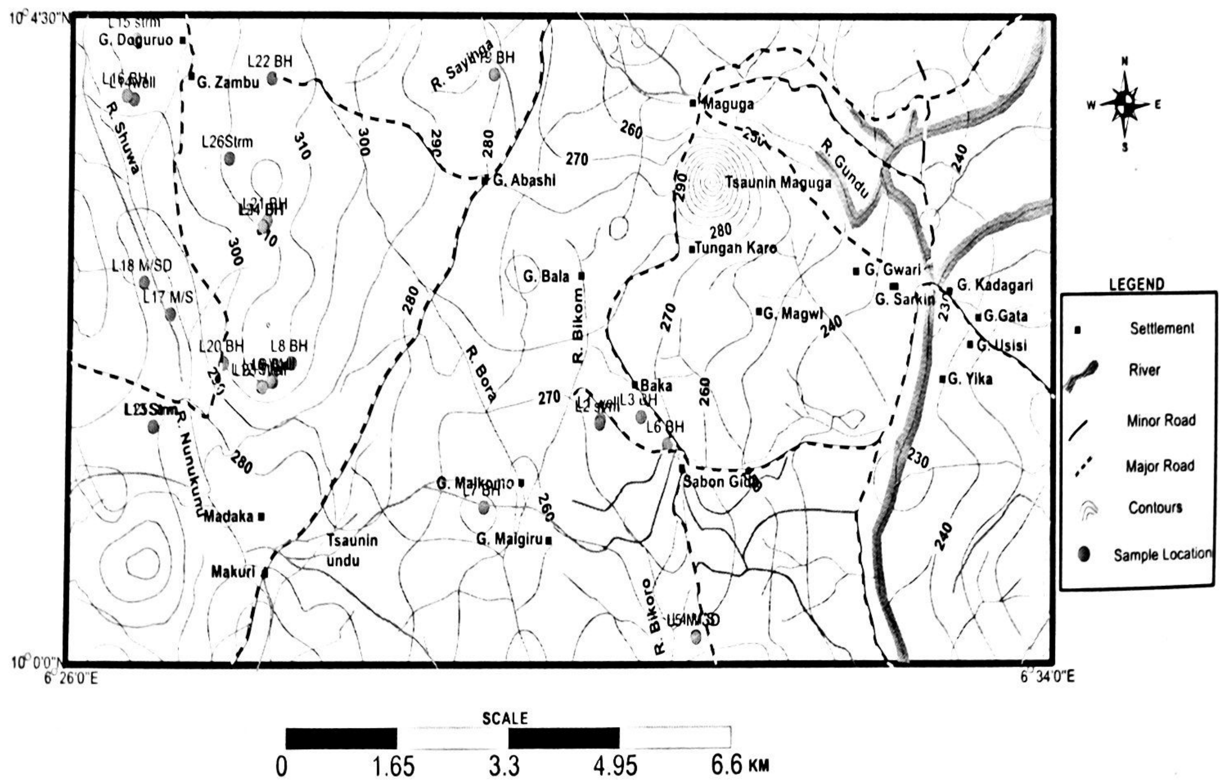

Fig. 3: Fact Map of the Study Area showing Sample Locations

4. Results and Discussion

4.1 Geological Mapping

Results of the geological mapping of the study area reveals schist and granite as the rock types that make up the local geology of the area (Fig. 2). The granite outcrops are common and well exposed in M adaka, Tsaunin-Undu, Baka and Sabon-Gida. They are light in colour and generally fine to medium grained containing feldspars, biotites and quartz as the major minerals. The schist strike NE–SW and dip 45°W along a stream channel in Angwan-Sarkin area. The schist is well foliated are largely deformed and weathered. They are potential sites for gold mineralization based on the structural configuration while the granite is characterized by dominant pegmatitic and quartz vein in granites (Ajibade *et al.*, 2008).

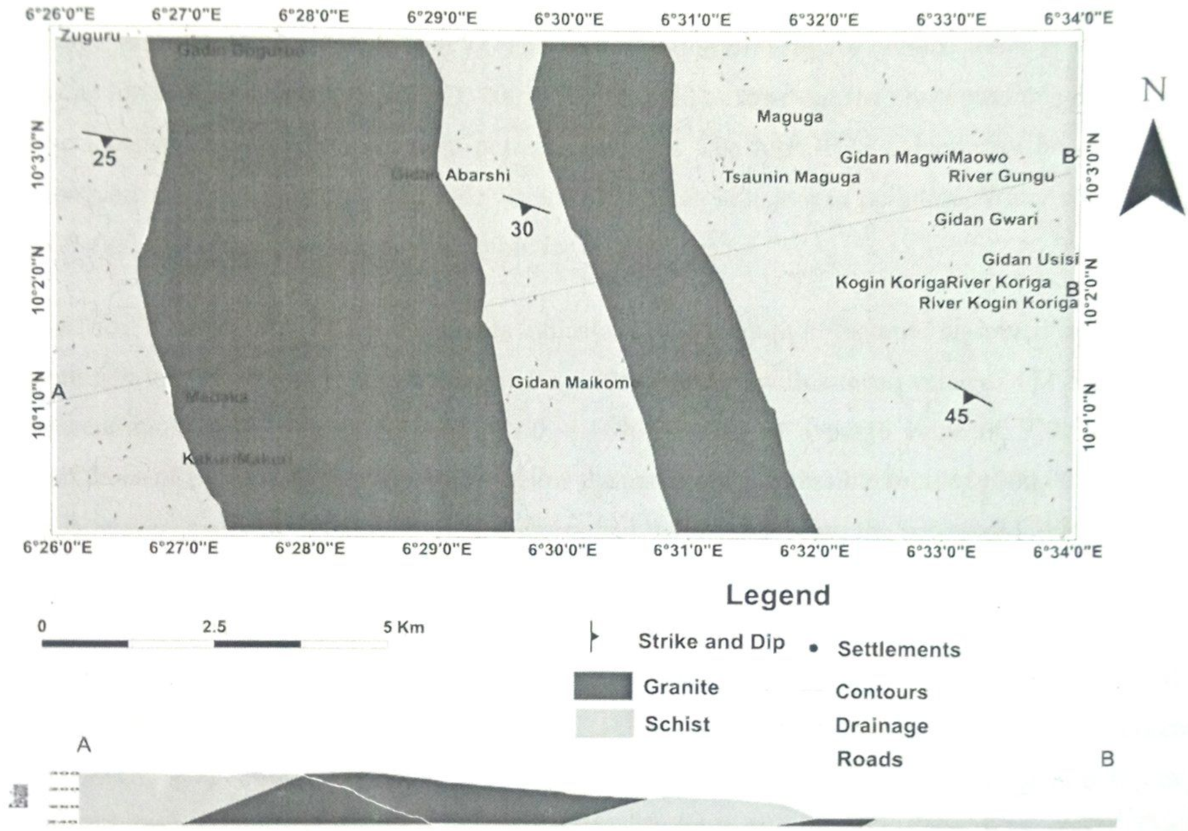

Fig. 2: Geological and Cross Sectional Map of the Study Area

4.2 Physical Parameters

The results of the laboratory analysis of the surface and groundwater are contained in Tables 1 and 2 respectively and discussed accordingly. Water pH is an indicator of the water quality and extent of pollution. The pH of the surface water ranged from 5.69 to 7.54 with a mean value of 6.67 (Table 1) while groundwater pH varied from 5.54 to 10.60 with an average value of 6.54 (Table 2). The mean pH values for both surface and groundwater fall within the permissible limit of 6.5 to 8.5 postulated by World Health organization (WHO, 2010) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007).

Slightly low pH enhances ionic exchange and mobility of metals in different media. It is a measure of the degree of hotness or coldness of a medium and it effects the various reactions that take place in the water body. The temperature values of the surface water ranged from 22.20 to 30.20 °C and a mean value of 26.02 °C while temperature of the groundwater varied from 25.50 to 32.90 °C with an average temperature of 29.45 °C. Water temperature is a crucial aspect of aquatic habitat, as aquatic organisms are adapted to live within a certain temperature range. As the upper and lower temperature limits are approached, the organism becomes more susceptible to diseases.

Total dissolved solid (TDS) is a good water quality indicator used to describe the amount of dissolved solutes in water. The concentration of TDS in surface water varied from 40.00 – 153.00 mg/l and a mean value of 94.75 mg/l (Table 1) while the concentration of TDS in groundwater ranged between 44.00 – 1123 mg/l with an average value of 347.41 mg/l (Table 2). The concentration of TDS for surface water is falls within the acceptable limit of 500.00mg/l (NSDWQ, 2007; WHO, 2010). However, the concentrations of groundwater in some locations exceed the maximum permissible limit. The high TDS values may be a reflection of anthropogenic interference with the surface water body and an indicator of pollution. Water containing more than 500 mg/l of TDS is considered undesirable for domestic use.

The electrical conductivity (EC) is a valuable indicator of the amount of material dissolved in water and the concentration in surface water ranged from 56.00 – 205.00 µs/cm with a mean value of 131.50 µs/cm while the concentration of EC varied between 35.00 – 1696.00 with an average value of 579.64 µs/cm. The concentrations of EC in surface water are far below the maximum permissible limit of 1000.00 µs/cm (WHO, 2010). However, many of the groundwater samples had values exceeding the permissible limit which is an indication that the groundwater contained more solutes than surface water. The observed wide range and deviation in TDS and EC values in groundwater may be attributed to weathering and bedrock dissolution as well as application of agro-chemicals on farm lands and mining. Turbidity value in surface water ranged from 11.80 – 714.00 NTU with a mean value of 158.84 NTU while the concentration of turbidity in groundwater varied between 1.52 – 460.00 NTU with an average value of 46.30 NTU. The values of turbidity in both surface and groundwater exceed the maximum allowable limit of 5.00 NTU (NSDWQ, 2007). The high turbidity in the water in the area is a major confirmation that the water sources in the area contained a lot of suspended substances materials. Turbidity in water reduces the transparency and visibility of the water (Okunlola *et al.* 2016).

Table 1: Table Statistical Summary of Surface water samples in the study area

Parameters (mg/L)	Minimum	Maximum	Mean	Standard Deviation
pH	5.69	7.54	6.67	0.69
Turbidity	11.80	714.00	158.84	239.74
Hardness	23.00	85.00	48.50	22.11
TDS	40.00	153.00	94.75	41.56
EC	56.00	206.00	131.50	58.76

BOD	3.00	9.00	6.25	1.90
COD	7.40	13.80	10.42	1.54
DO	3.00	12.50	7.05	3.58
Temperature	22.20	30.20	26.02	2.46
Alkalinity	11.00	36.00	21.75	8.29
E.coli	0.00	48.00	20.87	18.86
F.cocci	0.00	53.00	27.37	19.36
Chloride	8.00	62.00	20.65	17.46
Sulphate	0.00	63.50	42.08	20.86
Nitrate	0.30	23.89	10.12	10.30
Carbonate	10.80	50.00	21.88	16.28
Bicarbonate	2.00	29.00	12.43	9.65
Phospahe	0.61	0.11	0.72	0.48
Nitrite	0.04	0.03	0.07	0.05
Fluorite	0.00	0.35	0.10	0.15
Sodium	8.00	108	53.01	40.80
Potassium	3.00	39.60	12.02	12.53
Calcium	6.46	30.70	14.91	9.38
Magnesium	2.32	13.60	7.65	4.81
Iron	0.18	7.23	2.65	2.36
Copper	0.01	1.36	0.45	0.47
Arsenic	0.00	0.02	0.01	0.01
Nickel	0.00	0.03	0.02	0.01
Cobalt	0.00	0.04	0.01	0.01
Cadmium	0.00	0.01	0.00	0.00
Mercury	0.00	0.01	0.00	0.00
Lead	0.00	0.41	0.08	0.14
Manganese	0.21	0.92	0.52	0.27
Zinc	0.03	6.14	1.73	1.97

Table 2: Statistical Summary of Groundwater samples in the study area

Parameters (mg/L)	Minimum	Maximum	Mean	Standard Deviation
pH	5.54	10.60	6.54	1.15
Turbidity	1.52	460.00	46.301	112.82
Hardness	27.00	400.00	136.12	118.33
TDS	44.00	1123	347.41	344.80
EC	35.00	1696	550.82	579.64
BOD	3.00	8.00	5.59	1.46
COD	7.50	14.00	10.84	1.96
DO	2.28	7.77	5.19	1.50
Temperature	25.50	32.90	29.45	2.39
Alkalinity	8.00	58.00	35.18	16.00
E.coli	0.00	97.00	10.65	25.85

F.cocci	0.00	102.00	11.53	26.18
Chloride	7.80	367.00	82.79	108.38
Sulphate	0.00	179.00	62.89	45.26
Nitrate	0.15	178.20	25.55	44.86
Carbonate	25.40	80.00	35.65	13.23
Bicarbonate	0.50	43.00	18.79	14.88
Phospahe	0.11	0.81	0.33	0.21
Nitrite	0.01	0.16	0.07	0.05
Fluorite	0.00	1.16	0.54	0.46
Sodium	5.00	471.00	86.47	105.87
Potassium	2.00	61.50	15.55	19.90
Calcium	5.23	129.40	37.28	33.84
Magnesium	2.00	75.80	20.40	19.30
Iron	0.10	95.60	6.80	22.94
Copper	0.03	3.13	0.51	0.78
Arsenic	0.00	0.02	0.00	0.00
Nickel	0.00	0.14	0.02	0.04
Cobalt	0.00	0.01	0.00	0.00
Cadmium	0.00	0.01	0.00	0.00
Mercury	0.00	0.01	0.00	0.00
Lead	0.00	11.00	0.65	2.67
Manganese	0.06	1.36	0.24	0.31
Zinc	0.03	6.14	1.86	1.97

4.3 Bacteriological Parameters

The bacteriological analyses results in Tables 1 and 2 for surface and groundwater respectively show high bacteria count. The concentration of E.coli in surface water ranged from 0.00 – 48.00 cfu/ml with an average value of 20.87 cfu/ml while the concentration of E.coli in groundwater varied between 0.00 – 97.00 cfu/ml with a mean value of 10.65 cfu/ml. These values are higher than the recommended value of 0.00 cfu/ml (NSDWQ, 2007). Similarly, the concentration of faecalcocci ranged from 0.00 – 53.00 cfu/ml with a mean value of 27.37 cfu/ml while the concentration in groundwater varied between 0.00 – 102.00 cfu/ml with an average value of 11.53 cfu/ml as against the postulated value of 0.00 cfu/ml (WHO, 2010). They presence in water is an indication of faecal contamination arising from animal and human faeces being in contact with water. The mean value of E.coli and faecalcocci are higher in surface water compared to groundwater due to direct defecation on the river by the villagers. Studies have revealed that water pollution through faecal contamination is responsible for most water borne diseases such as meningitis, cholera and diarrhea as well as morbidity and mortality among children (Olasehinde *et al.* 2015). It also causes acute renal failure and haemolytic anaemia in adults (WHO, 2010).

4.4 Chemical Parameters

The concentration of chloride ranged between 8.00 – 62.00 mg/l with a mean value of 20.65 mg/l for surface water and 7.80 – 367.00 mg/l with an average value of 82.79 mg/l for groundwater. The value of chloride in the surface water fall below the maximum permissible limit of 250 mg/l (NSDWQ, 2007 and WHO, 2010) while the groundwater values in most locations exceeds the permissible value. High chloride values may not constitute health hazard to human beings, but it does produce salty taste, corrode metal pipes and harm non-halophytic plants. The sulphate level in the surface water ranged between 0.00 – 63.50 mg/l with an average value of 42.08 mg/l (Table 1) and 0.00 – 179.00 mg/l with a mean value of 82.89 mg/l for the groundwater (Table 2).

The sulphide concentration in surface is within the acceptable limits of 100.00 mg/l (NSDWQ, 2007) while the groundwater samples have values higher than the acceptable limit. High sulphate and chloride concentration in water may be naturally induced as a result of bedrock dissolution and chemical weathering or due to anthropogenic influence coming from fertilizer application and mining activities (Dan-Hassan *et al.* 2012). The concentration of total hardness in surface water varied from 23.00 – 85.00 mg/l with a mean value of 48.50 mg/l while in groundwater the value of total hardness varied from 27.00 – 400.00 mg/l with an average value of 136.12 mg/l. The more dissolved and suspended material in water the more the hardness of the water. Groundwater is always in constant contact with the host rock through which it migrates and this explains why its concentration is higher than the surface water. The alkalinity content in surface water is in the order of 11.00 – 36.00 mg/l and a mean value of 21.75 mg/l while in groundwater, the concentration ranged from 8.00 – 58.00 mg/l with an average value of 35.18 mg/l (Tables 1 and 2). Water from shallow aquifers in basement complex is characterized by high alkalinity and this explains why the groundwater concentration is higher compared to surface water.

Biochemical Oxygen Demand (BOD) values ranged from 3.00 – 9.00 mg/l with a mean value of 6.25 mg/l for surface water and 3.00 – 8.00 mg/l with an average value of 5.59 mg/l for groundwater samples. Biochemical Oxygen Demand determines the relative oxygen necessary for biological oxidation of waste waters, effluents and polluted waters. It is the only test available to determine the amount of oxygen required by bacterial while stabilizing decomposable organic matter. It measures the biodegradable organic carbon and under certain conditions, the oxidizable nitrogen present in a water sample. The study of BOD gives an idea of the oxidizable matter actually present in a water sample and this allows pollution load evaluation to be established. The chemical oxygen demand provides a measure of the oxygen equivalent of the portion of organic matter in a sample that is susceptible to oxidation by strong chemical oxidant. It determines the quantity of oxygen required for the oxidation of the inorganic and organic matter in a water sample under controlled condition of oxidizing, temperature and time.

Chemical oxygen demand (COD) test measures the total organic carbon, with the exception of certain aromatics such as benzene, which are not completely oxidized in the reaction. The concentration of COD in the surface water varied from 7.4 – 13.80 mg/l with an average value of 10.42 mg/l (Table 1) and 7.50 – 14.00

with a mean value of 10.84 mg/l (Table 2). The concentration of dissolved oxygen (DO) in surface water ranged between 3.00 – 12.50 mg/l with an average value of 7.05 mg/l while the concentration in groundwater varied from 2.28 – 7.77 mg/l with a mean value of 5.19 mg/l. The DO, BOD and COD measure the water oxygen available for aquatic organisms and their concentration is very important for the survival of aquatic lives.

The concentration of sodium in surface water varied from 8.00 – 108.00 mg/l with a mean value of 53.01 mg/l (Table 1) and 5.00 – 471.00 mg/l with an average value of 86.47 mg/l (Table 2). The mean concentration of sodium in both surface and groundwater are below the maximum permissible value of 250.00 mg/l (NSDQW, 2007) though few locations of the groundwater samples have higher values. Studies have shown a direct relationship between hypertension and high sodium level in drinking water. Calcium content in the surface water ranged between 6.46 – 30.70 mg/l with a mean value of 14.91 mg/l while calcium concentration in the groundwater varied from 5.23 – 129.40 mg/l with an average value of 37.28 mg/l. This values fall within the allowable limits of 200.00 mg/l for a potable water. Calcium is needed by the body for good tooth and bone development. Magnesium concentration in both surface water (2.32 – 13.60) and groundwater (2.00 – 75.80) are far within the allowable limits of 100.00 mg/l (NSDWQ, 2007).

Magnesium in water is better absorbed than dietary magnesium. Epidemiological data in man and experimental data in rats have demonstrated that the intake of water containing sufficient amount of magnesium may prevent arterial hypertension and nervous disturbances. The concentration of potassium in surface water varied from 3.00 – 39.60 mg/l with a mean value of 12.02 mg/l (Table 1) and between 2.00 – 61.50 mg/l with an average value of 15.55 mg/l for the groundwater samples (Table 2).

The concentration of nitrate in surface water ranged between 0.03 – 23.89 mg/l and a mean value of 10.12 mg/l and between 0.15 – 178.20 mg/l with an average value of 25.55 mg/l for the groundwater samples. Nitrate values in the surface water are within the permissible limit of 50.00 mg/l while in groundwater, some locations were higher than the maximum permissible limit of 50.00 mg/l by (WHO, 2010; NSDWQ, 2007). High nitrate level in drinking water causes infant methaemoglobinaemia (blue-baby syndrome), gastric cancer, metabolic disorder and livestock poisoning. The sources of nitrate in the groundwater can be attributed to anthropogenic activities such as on-site sanitation, waste dumpsites and fertilizer application (Dan-Hassan *et al.*, 2012). The mean concentration of phosphate, carbonate and bicarbonate in surface water are 12.02 mg/l, 21.88 mg/l and 12.43 mg/l respectively while in groundwater, their respective mean values are 0.33 mg/l, 35.65 mg/l and 18.79 mg/l. These concentrations are below their permissible limit. The observed concentrations in the major cations and anions are signatures of rock-water interactions.

4.5 Heavy Metals

They are metallic chemical elements that have a relatively high density and are toxic or poisonous at low concentrations. Like all other chemical elements have distinguishing physical and chemical characteristics, properties such as density, valency, redox potentials and solubility makes them unique. From an environmental standpoint, heavy metals are recognized in terms of their toxicity and health effects (Nikoladis *et al.*, 2008). In spite of some of these elements having physiological functions in plants and animal, they have been shown to be harmful beyond certain concentrations (USEPA, 1997). The concentration of iron varied from 0.08 – 7.23 mg/l with a mean concentration of 2.65 mg/l in surface water (Table 1) while the concentration in groundwater varied between 0.10 – 95.60 mg/l with an average value of 6.80 mg/l (Table 2) as against the acceptable value of 0.30 mg/l (NSDWQ, 2007). The implication of the high iron content is that the water from the well will have taste, colour and other aesthetic problems such as hemochromatosis.

The concentration of lead in surface water ranged between 0.00 – 0.41 mg/l with a mean value of 0.08 mg/l while lead concentration in groundwater varied from 0.00- 11.00 mg/l with a mean value of 0.65 mg/l as against the permissible value of 0.01 mg/l (NSDWQ, 2007). Lead is potentially hazardous to most form of life and is considered toxic to organisms. Lead is bio-accumulated by benthic foraminifera, freshwater plants, invertebrates and fish. The chronic effect of lead on man includes neurological disorders, especially in the foetus and in children, synthesis of hemoglobin, gastrointestinal tract, kidney diseases and impaired performance in IQ test. Lead is however used in batteries, petrol additives, alloys, cable sheathing, pigments, rolled and extruded products (WHO, 2010). The concentration of copper in the surface water ranged from 0.01 – 1.36 mg/l with an average value of 0.45 mg/l while the concentration in 0.03 – 3.13 mg/l with an average value of 0.51 mg/l as against the maximum permissible limit of 1.00mg/l (NSDWQ, 2007). Copper is an essential substance to human life, but in high concentration, it can cause anemia, liver and kidney damage, stomach and intestinal irritation. Copper normally occurs in drinking water from copper pipes, weathering of products made from copper as well as from mining and additives used to control weed (Vasanthavigar *et al.*, 2010).

Zinc concentration in surface water ranged from 0.04 – 5.30 mg/l and an average value of 1.82 mg/l (Table 1) while the concentration in groundwater varied from 0.03 – 6.14 mg/l and an average value of 1.73 mg/l (Table 2). High zinc concentration could be a problem in aquatic ecosystem. Zinc is unusual in that it has low toxicity to man, but relatively high toxicity in fish or livestock watering. The maximum concentration of cadmium, cobalt and mercury in groundwater were 0.01 mg/l as against their maximum permissible limit of 0.003 mg/l, 0.001 mg/l and 0.001 mg/l respectively (NSDWQ, 2007). Also, the maximum concentration of cadmium, cobalt and mercury in surface water are 0.01 mg/l, 0.04 mg/l and 0.01 mg/l respectively. They observed high concentration of these metals can be linked with the mining and farming activities going on in the area. Several renal dysfunction and damage to the bone structure, a syndrome known as itai-itai disease, have been associated with long-term exposure to cadmium through water (USEPA, 1997). Cobalt has also been used as a treatment for anemia, as it causes red blood cell production (Mohanty *et al.* 2001). Acute toxicity of cobalt may be observed as effects on the lungs, including asthma, pneumonia, and wheezing (Adams *et al.*, 2008). High concentration of mercury in drinking water causes severe respiratory irritation, digestive disturbances and damage to developing fetus, brain and kidney (Singh *et al.* 2008).

The concentration of nickel in surface water ranged between 0.00 – 0.03 mg/l mg/l with an average value of 0.02 mg/l (Table 1) while the concentration in groundwater varied from 0.00 – 0.14 mg/l with a mean value of 0.02 mg/l (Table 2) as against the maximum allowable value of 0.02 mg/l (WHO, 2010). Nickel is a very abundant element in the environment, and is found primarily combined with oxides and sulphides. The most common adverse health effect of nickel in humans is an allergic reaction. People can become sensitive to nickel when things containing it are in direct contact with the skin, when they eat nickel in food, drink it in water, or breathe dust containing it (Aktar *et al.,* 2010). Once a person is sensitized to nickel, further contact with it will produce a reaction. The most common reaction is a skin rash at the site of contact. Less frequently, allergic people have asthma attacks following exposure to nickel (Lohani *et al.* 2008). Lung effects, including chronic bronchitis and reduced lung function, have been observed in workers who breathed large amounts of nickel (Edet and Okereke, 1997; Kraft *et al.,* 2006).

The concentration of arsenic ranged between 0.00 – 0.02 mg/l for both surface and groundwater. Arsenic is the most common cause of acute heavy metal poisoning in adults and can be released into the environment through mining as a pathfinder element to gold. When arsenic enters the environment, it does not evaporate, rather it can be absorbed in the soil through pesticides application on farm lands, infiltrate into groundwater system or surface water via run off (Karbassi *et al.*, 2008; Amadi *et al.* 2013). The concentration of manganese ranged from 0.21 – 0.92 mg/l with an average value of 0.52 mg/l for surface water (Table 1) and between 0.06 – 1.36 mg/l with a mean value of 1.73 mg/l (Table 2). Some locations in both surface and groundwater have values higher than the WHO and NSDWQ acceptable limit of 0.2 mg/l. Manganese is essential for plants and animals, and are used in products such as batteries, glass and fireworks (Aboud and Nandini, 2009). Manganese compounds are used in fertilizer, fungicides and as livestock feeding supplements (Huang and Lin, 2003). Fluoride concentration in surface water ranged from 0.00 – 0.35 mg/l with a mean value of 0.10 mg/l while in groundwater, the fluoride content varied between 0.00 – 1.16 mg/l with an average value of 0.54 mg/l. These values fall below the permissible limit of 1.5 mg/l (NSDWQ, 2007). The high fluoride content in water causes dental and skeletal fluorosis (Amadi *et al.*, 2014, Aminu and Amadi, 2014).

4.6 Hydrogeochemical Facies

The evolution of hydrochemical parameters of groundwater can be understood by plotting the major cations and anions in pictorial form as demonstrated in Piper diagram (Fig. 3) and Durov diagram (Fig. 4). They are used to determine the water type and their possible source. For the purpose of plotting, Na and K ions are combined together as well as HCO_3 and CO_3 ions. The diagrams show that the dominant water type in the area is Na-HCO_3-Cl followed by Ca-Na-Cl and Ca-Cl types. From the plot, it was observed that the concentration of alkali metals (Na and K) exceed the alkaline earth (Ca and Mg).

Futhermore, Gibbs plot (Fig. 5) was employed in this study to elucidate the concept and role of rock water interaction in water quality studies. The results revealed that majority of the water samples fall within the rock source dominance which suggests that weathering of rocks primarily controls the chemistry of groundwater in the area while precipitation is the main source of groundwater recharge. The wet and dry climatic conditions of the area encourage chemical weathering of rock which enhances ionic dissolution of soluble mineral component of the rocks thereby altering the chemistry of water in the study area.

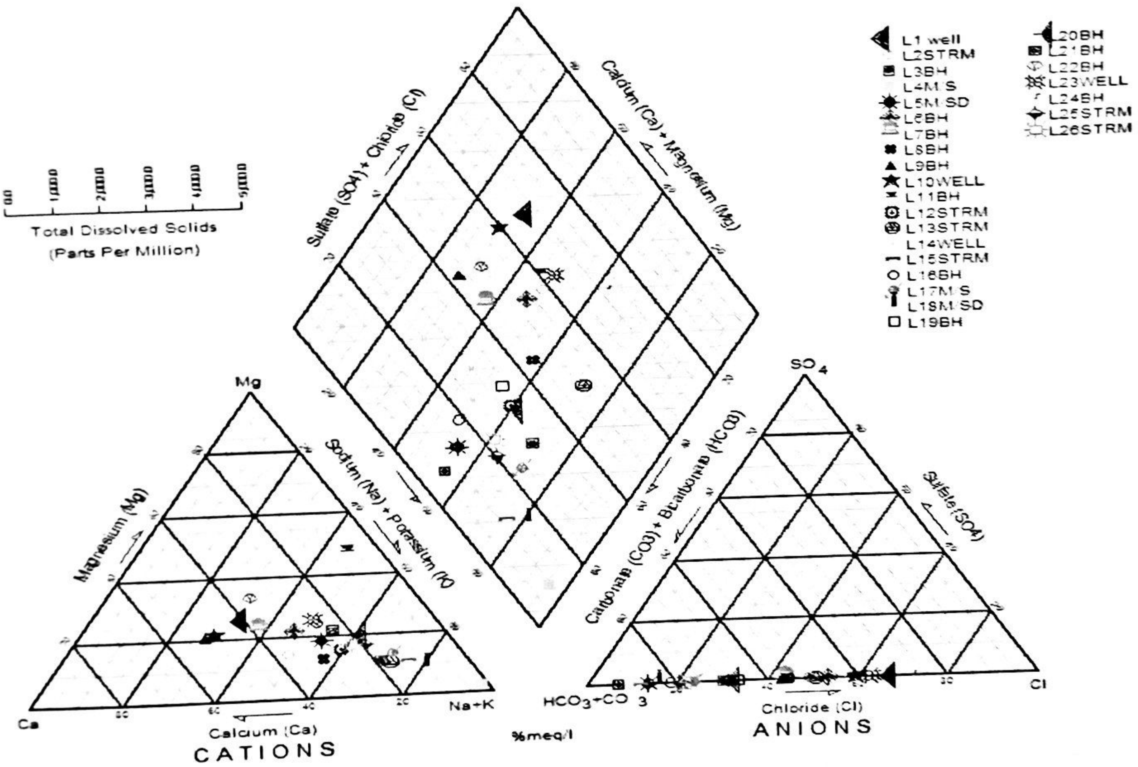

Fig. 3: Piper's Trilinear Diagram for the Study Area

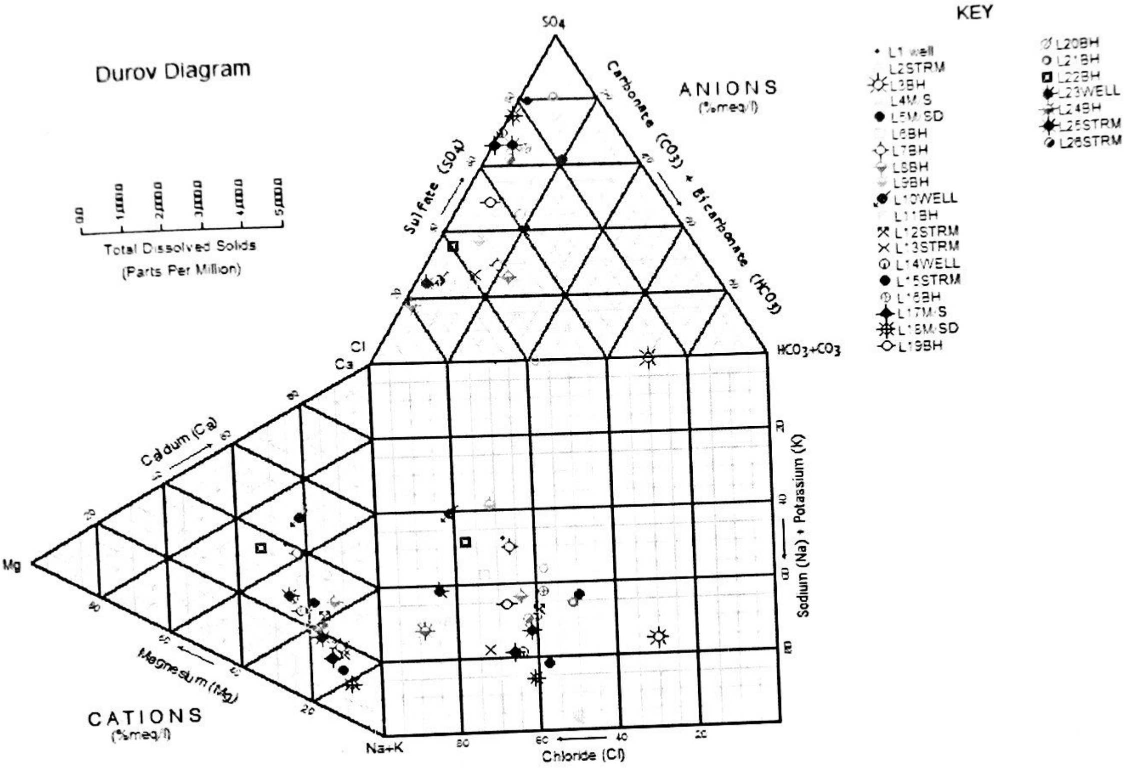

Fig. 4: Durov diagram for the Study Area

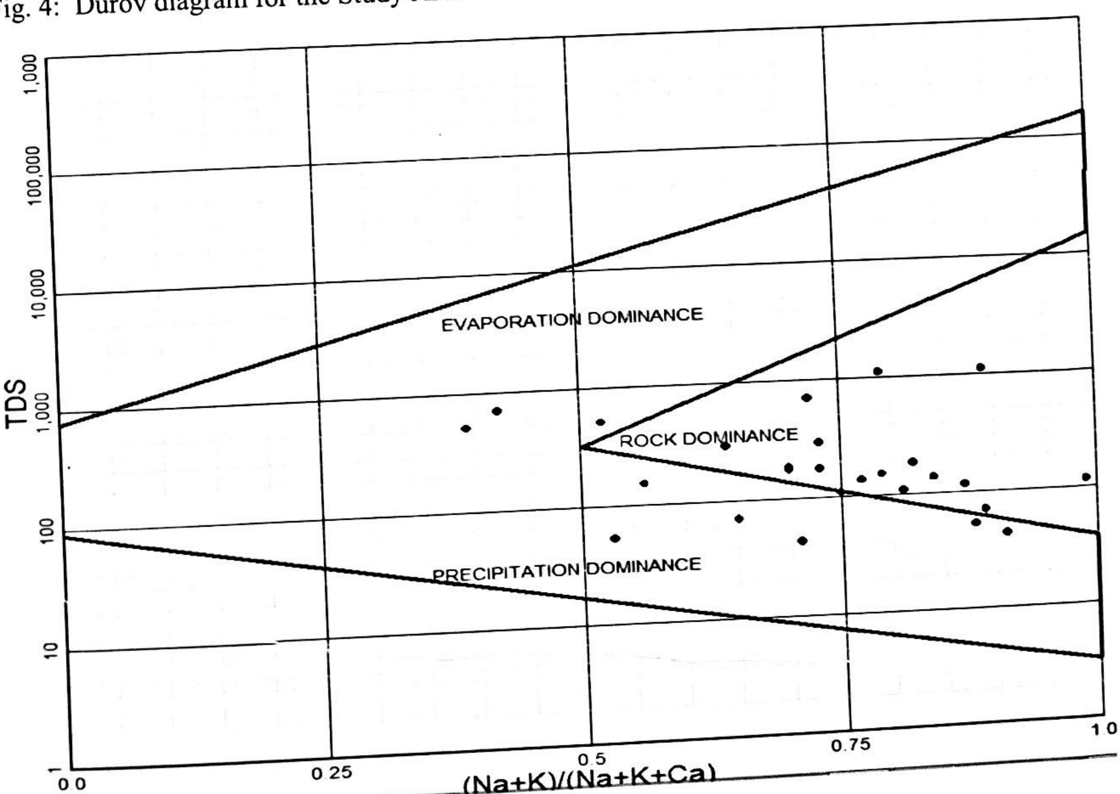

Fig. 5: Gibbs plot for the Study Area

5. Conclusion

The hydrogeochemical evaluation of surface and groundwater quality around Anguwan Maigiru area of Madaka district, Northcentral Nigeria was studied in this work. Results of the field geological mapping of the study area revealed two rock types in the area which are schist and granite, with minor units such as pegmatite as well as quartz veins which are known to host gold mineralization. Results of the water analysis were interpreted by comparing it with the Nigeria Standards for Drinking Water Quality and World Health Organization water quality guideline. The water is poor bacteriologically due to presence of pathogens. The concentration of major cations and anions analysed 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. However, the concentration of some trace elements such as Fe, Zn, Cr, Mn and Pb were slightly higher the recommended maximum permissible limits of WHO and NSDWQ which is an evidence of pollution. The results of the laboratory analysis of the rock samples (Schist and granite) indicate that the rocks were highly enriched with these heavy metals. Their presence in groundwater may be attributed to natural process of rock weathering and bedrock dissolution. The excavation of rock boulder as well as the crushing and milling by artisanal gold miners creates a pathway for water pollution via anthropogenic interference. The Piper and Durov diagrams confirmed that the dominant water type in the area is $Na\text{-}HCO_3\text{-}Cl$ while Gibbs plot established the weathering is the main process controlling the water chemistry in the area. Good hygiene and standard mining procedures are recommended for the area.

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