Assessment of Surface and Groundwater Quality in Gussoro gold mining site, Niger State, North-central Nigeria

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Abstract

The water quality in Gussoro area of Niger State, North-central Nigeria was investigated in this study. Gussoro is located at the downstream of River Shiroro where the community carries out farming, artisanal mining and fishing activities. Field geological mapping of the area revealed that schist is the major lithological unit in the area. The schist was intruded by medium grained granite on the north-eastern part of the study area. The results of the laboratory analysis of both the surface and groundwater samples indicate that the pH of the water in some locations is slightly acidic. The concentrations of all the analyzed major cations (sodium, calcium, magnesium and potassium) as well as major anions (sulphate, chloride, bicarbonate, carbonate and nitrate) are below World Health Organization maximum permissible limits. However, in some locations, the concentrations of fluoride, iron, nickel, manganese and arsenic were higher than the recommended maximum permissible limits. Their enrichment in the surface and groundwater system in the area may be attributed to artisanal mining and farming activities in the area. The slightly acidic nature of the water in the area enhances chemical weathering as well as rock dissolution process, thereby enriching the water with these elements. Presently, there are no cases of dental fluorosis in the study area, despite the high concentration of fluoride in some locations. High concentration of fluoride in the water can be attributed to weathering of fluoride bearing mineral such as apatite and fluorite in granitic rock located at north-eastern part of the study area. Nickel, manganese, lead and arsenic are pathfinder elements to gold and are often discarded as gangue into the surrounding soils and surface water. This partly explains the concentrations of these metals are higher in surface water compared to groundwater. High concentration of iron in the water is due to the oxidation and weathering of pyrite that is associated with the gold mineralization in the area. Water types in the area from Durov and Piper diagrams revealed $Na+Ca/Cl+SO_4$ facies. Gibbs diagram also indicated that weathering is the major hydrogeochemical processes controlling the discharge of ions in water sources in the area. Water in areas with anomalous concentration of fluoride and heavy metals should be treated before use.

Keywords: Evaluation, water, mining sites, Gussoro, North-central Nigeria

Introduction

Access to potable water has remained a major challenge in developing countries. The inability of State owned Water Boards in Nigeria to provide adequate water supply for its urban population may be attributed to upsurge in population growth, expansion in towns, technical and managerial problems as well as ageing water treatment plants and distribution systems. This has led the urban dwellers to access groundwater through boreholes, hand dug wells and water vendors. Groundwater is widely used for domestic, drinking, industrial and irrigational purposes because it is free from pathogens and not easily contaminated like surface water (Amadi *et al.*, 2014).

In terms of socio-economic activities such as tourism, industry and commerce, water is an indispensable input. The suitability of groundwater for domestic, industrial and irrigational purposes depends on the composition of water. Potable and safe drinking water is a necessary requirement for the health and productive life of humans in any society. Polluted water is a major cause of epidemic and chronic diseases in human beings. Studies have revealed a correlation between cardiovascular deaths and water chemistry (El-Sayed *et al.*, 2012; Okiongbo and Douglas, 2013, Amadi *et al.*, 2015). Water as a solvent, has the capacity of dissolving and interacting with organic and inorganic components of bedrock in the course of its migration. The chemistry of the rocks as groundwater migrates influences its quality. They are compounded by the anthropogenic interference such as mining, seepage of uncontrolled solid wastes and sewages, agricultural wastes and urban runoffs. The focus of this work is to establish the level of surface and groundwater pollution in Gussoro area of Niger State, North-central Nigeria due to the mining and agricultural activities domiciled in the area.

Materials and Method

Study Area Description

Gussoro community is located downstream of Shiroro dam in Shiroro Local Government Area of Niger State and lies between latitude N 09°56' to N 10°00' and longitude E 06°42' to E 6°46' (Fig. 1). The area is accessible through Kuta-Shiroro road. The studied area is characterized by extensive ridges and valleys and is drained River Shiroro and its tributaries (Fig.2). The study area is characterized by two distinct seasons: the dry and rainy season. The mean annual rainfall in the area is 1200 mm while the minimum and maximum temperatures are 26 °C and 34 °C respectively (Nigerian Meteorological Agency, 2013). The vegetation of the study area is typical Guinea savannah which comprises of tall grasses sandwiched by tall trees. The trees become more populated along river channels (Ajibade, 1982).

Geology and Hydrogeology of the Study Area

The geological mapping undertaken in the study area revealed that the local geology comprises of schist and granite of Pan African age (Ajibade, 1982; Dada, 2006; Obaje, 2009). The area is dominated by schist with granites intruding at the northeastern part of the area (Fig. 2). The granitic rock hosts the gold bearing quartzites in which the artisanal miners are prospecting (digging) for gold. Field observation on the schist and granitic outcrops revealed moderate weathering and presence of structural elements such as joints and faults. Hydrogeologically, the hand-dug wells in the area derived their water source from regolith aquifer while secondary porosity and permeability initiated via fractures account for the groundwater storage and yield (Ofodile, 2002).

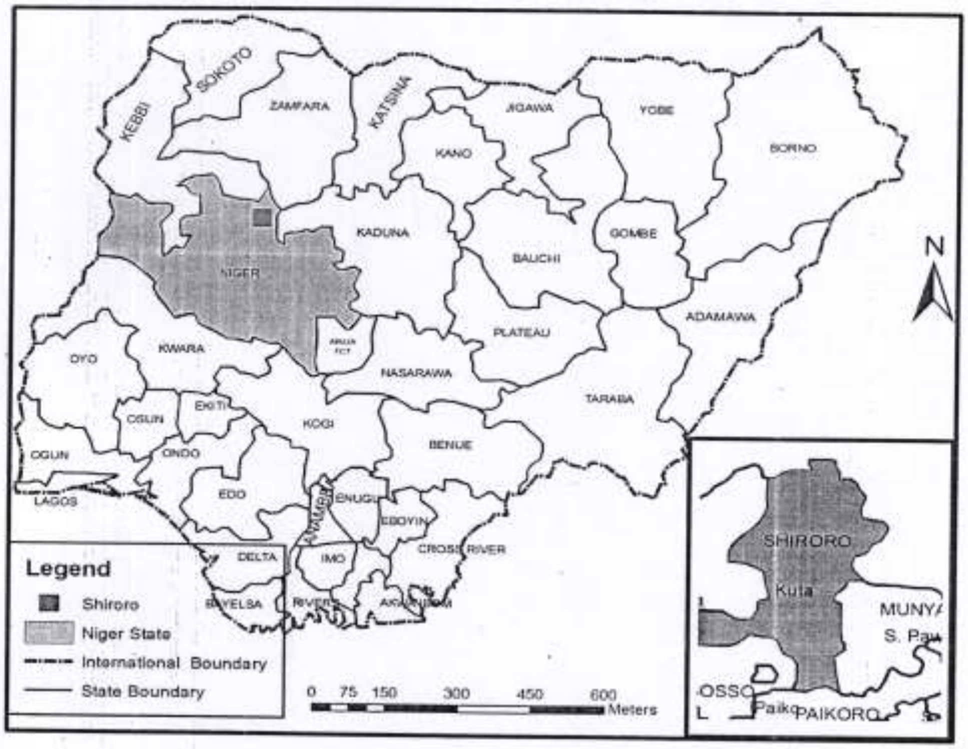

Fig. 1: Map of Nigeria showing the study area

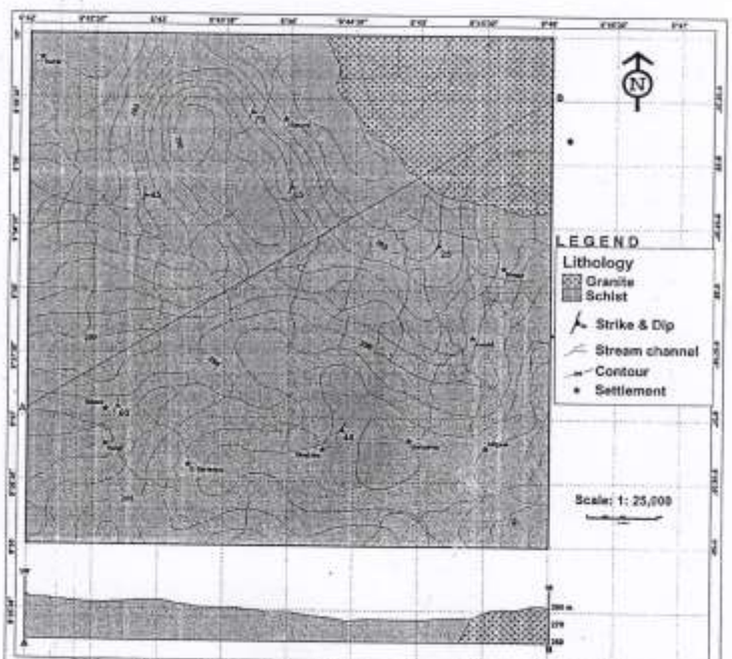

Fig. 2: Geological Map of the Study Area

Water Sampling

Plastic containers of 2-litre capacity were used in the collection of samples. At each sampling point, container was rinsed twice with the water to be collected. Little amount of the water sample was placed in a plastic beaker and the pH, electrical conductivity and temperature were determined insitu using a multimeter. Another set of plastic containers, of 1-litre capacity were properly prepared and the samples for heavy metal analysis and 2ml of concentrated nitric acid was added to it in order to prevent microbial activities and loss of metal by precipitation. The samples were properly labeled and stored in a cooler to maintain a temperature below 4 °C for further analysis of the samples.

Laboratory Analysis

The American Public Health Association method for analysis of drinking water and waste water were used for the study. The physical parameters (temperature, pH and electrical conductivity) were determined insitu using multimeter while the elemental analysis was done using the Perkin Elmer Atomic Absorption Spectrophotometer (Buck Scientific Model 200@/210) with double beam and background corrector, Acetylene flame (Perkin Elmer: HGA 500) and a hollow cathode lamp were used for the analysis.

Results and Discussion

The results of the laboratory analyses of surface and groundwater from Gussoro are contained in Table 1. The rate of biochemical reactions in water largely depends on temperature. The temperature of the groundwater ranged from 24.30 °C to 32.00 °C with a mean temperature of 29.23 °C while in surface water, the temperature varied from 24.00 °C to 24.10 °C with an average value of 27.84 °C (Table 1). The temperature values falls within the ambient temperatures postulated by the Nigerian Standard for Drinking Water Quality (NSDWQ). The pH is an important water quality parameter which regulates the dissolution of mineral ions in water as well as the solubility and toxicity of metals in aquatic system. The pH for the groundwater varied from 5.86 to 6.96 with an average value of 6.17 while that of surface water ranged from 5.55 to 6.98 with a mean of value of 6.27 (Table 1). The pH of both surface and groundwater in some locations falls below the minimum acceptable pH value of 6.5 for a safe drinking water (WHO, 2012). This suggests that water in the area is slightly acidic and such condition favours dissolution of minerals, solubility and mobility of metals in water (Amadi *et al.*, 2013). The concentrations of total dissolved solids (TDS) and electrical conductivity in surface and groundwater were by far less than that of the recommended values of 500 mg/l and 1000 µs/cm (NSDWQ, 2007). The higher the amount of solids dissolved in water, the more conductive it becomes (Olasehinde *et al.*, 2016; Maspalma *et al.*, 2016; Vasanthavigar *et al.*, 2015).

The concentrations of the major cations (calcium, magnesium, sodium and potassium) as well as the major anions (sulpahte, chloride, bicarbonate, carbonate and nitrate) were found to be lower than their respective permissible limits in both surface and groundwater (Table 1) which suggest no mineral enrichment in the water sources from the area. Similarly, the values of total hardness, total alkalinity, phosphate, zinc and copper in all locations in both surface and groundwater (Table 1) were below their respective permissible limit, implies no pollution from these parameters. However, the concentrations fluoride, iron, manganese, lead, nickel and arsenic in many locations were found to be higher than their respective recommended maximum permissible limit for a safe drinking water (WHO, 2012; NSDWQ, 2007).

Table 1: Statistical Summary of Results of Laboratory Analyses of Surface and Groundwater Samples

	GW			SW			
Parameters (mg/l)	Min	Max	Mean	Min	Max	Mean	WHO, 2012
TDS	53.76	158.72	98.22	19.86	43.50	31.18	500
Conductivity(μS/cm)	84.00	248.00	153.47	36.00	68.00	54.20	1000
Temperature (°C)	24.30	32.00	29.23	24.00	34.10	27.84	Ambient
pH	5.86	6.96	6.17	5.55	6.98	6.27	6.50-8.50
T. Hardness	20.00	132.00	65.73	28.00	60.00	42.40	150
Magnesium	2.30	28.20	13.35	4.23	12.30	7.92	200
Chloride	4.47	20.85	14.21	15.89	35.75	22.47	250
T. Alkalinity	16.00	72.00	40.00	8.00	28.00	18.80	-
Bicarbonate	5.67	34.53	18.33	1.52	12.89	8.54	100
Sulphate	12.40	56.15	28.38	5.25	23.18	12.14	100
Nitrate	0.10	0.64	0.23	0.11	0.81	0.35	50
Carbonate	1.81	8.62	3.82	1.14	2.70	1.96	100
Phosphate	0.10	0.86	0.31	0.09	0.36	0.20	-
Fluoride	0.05	4.90	2.21	0.42	3.61	1.53	1.50
Sodium	15.60	79.00	44.46	12.20	18.50	13.96	200
Potassium	1.23	21.70	6.52	1.75	13.70	6.01	200
Calcium	6.61	50.26	24.22	9.30	22.18	15.30	200
Zinc	0.01	0.83	0.26	0.08	0.19	0.12	3.00
Copper	0.10	0.26	0.20	0.15	0.26	0.19	1.00
Iron	0.31	4.77	1.36	0.24	4.29	1.24	0.30
Chromium	0.00	0.07	0.02	0.00	0.03	0.01	0.05
Manganese	0.00	0.71	0.17	0.02	0.81	0.20	0.20
Lead	0.00	0.04	0.01	0.00	0.03	0.01	0.01
Nickel	0.43	1.32	0.83	0.49	1.79	1.12	0.02
Arsenic	0.00	0.05	0.02	0.00	0.06	0.03	0.01

NSDWQ = Nigeria Standard for Drinking Water Quality; TDS = Total Dissolved Solid
GW = Groundwater; SW = Surface Water; T.Hardness = Total Hardness; T.Alkalinity = Total Alkalinity

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 (Okunlola *et al.*, 2016; 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 (Nur and Ayuni, 2004; Okiongbo and Douglas, 2013; 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. The concentration map of fluoride in the area is shown in fig 3.

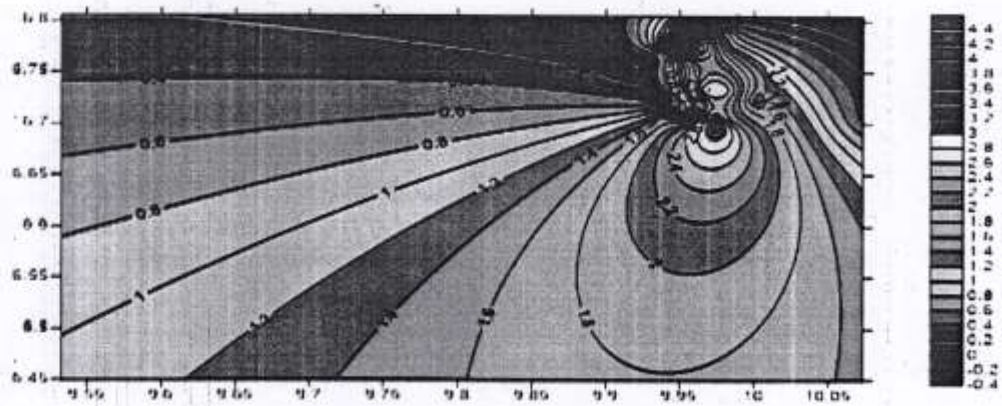

Fig. 3: Concentration map of Fluoride in the area

The observed enrichment of the water systems in the area by nickel, iron, manganese, lead and arsenic can be attributed to chemical weathering and subsequent decomposition, dissociation and dissolution arising from rock-water interaction as well as urban run-offs. High manganese content causes neurological and gastrointestinal disorder while high concentration of arsenic, nickel and lead are responsible for cancer, interference with vitamin D metabolism, affect mental development in infants, toxic to the kidney, central and peripheral nervous systems (WHO, 2012). The artisanal mining taking place in the area necessitated the precipitation and release of these metals from their host rock into the surface and groundwater systems. Also agro-chemical used in farming contains these metals and when applied on the farms, can infiltrate into the shallow groundwater system or into the surface water via surface run off (Amadi, *et al.*, 2017). High iron content in water does not constitute any health problem except impairment of the colour, odour and taste (Olasehinde *et al.*, 2014; Okunlola *et al.*, 2014). The concentrations maps of arsenic and iron in study area are shown in figures 4 and 5 respectively.

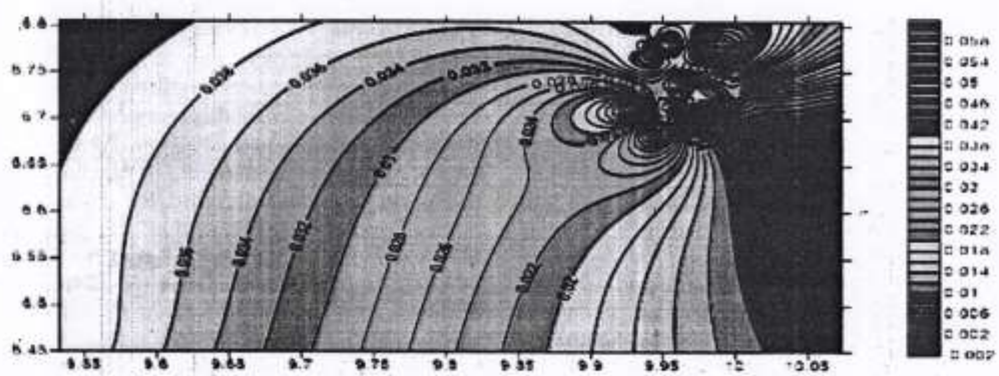

Fig. 4: Concentration map of Arsenic in the study area

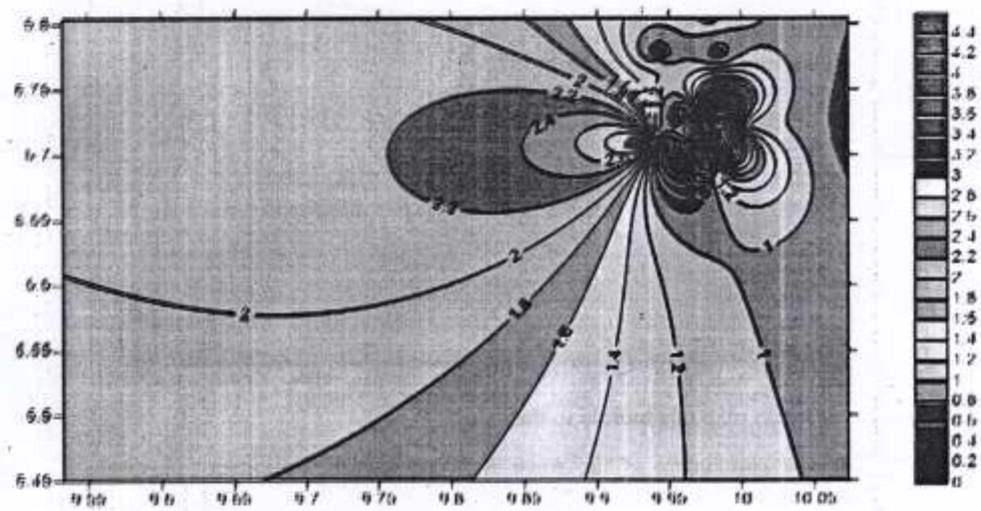

Fig. 5: Concentration map of Iron in the study area

Piper and Durov Diagrams

This method was devised by Piper (Fig. 6) and Durov (Fig. 7) to outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. The trilinear diagram illustrates the relative concentration of cations (left diagram) and anions (right diagram) in each sample. 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. On the Piper diagram, 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 to represent the total ion. The degree of mixing between freshwater and saltwater can also be shown on the Piper diagram. The Piper diagram (Fig. 3) can also be used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water in the area is Na/Ca- SO_4/ HCO_3 water type.

Gibbs Plots

Gibbs (1970) suggested that a simple plot of TDS versus the weight ratio of $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ and TDS versus the weight ratio of $Cl^-/(Cl^- + HCO^-_3)$ could provide information on the relative importance of the major natural mechanisms controlling surface and groundwater chemistry such as precipitation, rock weathering and evaporation. 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 are characterized by chemistry influencing rock-water interaction. This 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.

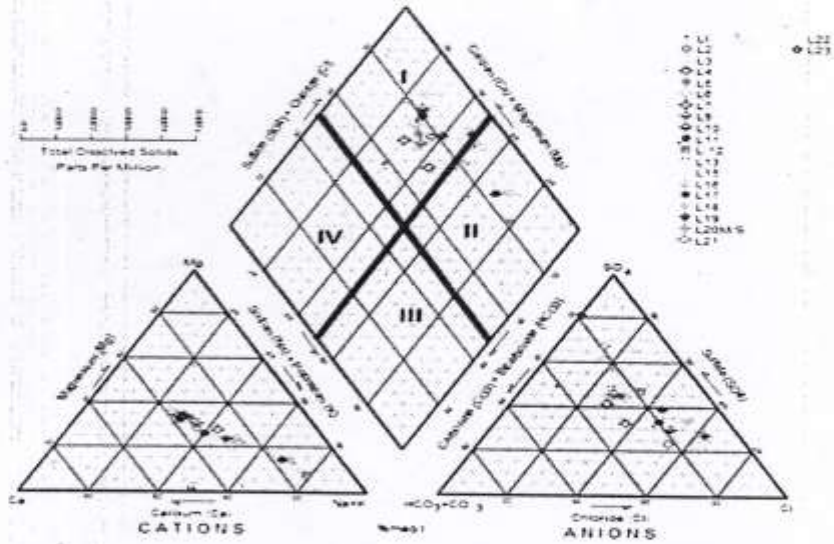

Fig. 6: Piper diagram for the Study Area

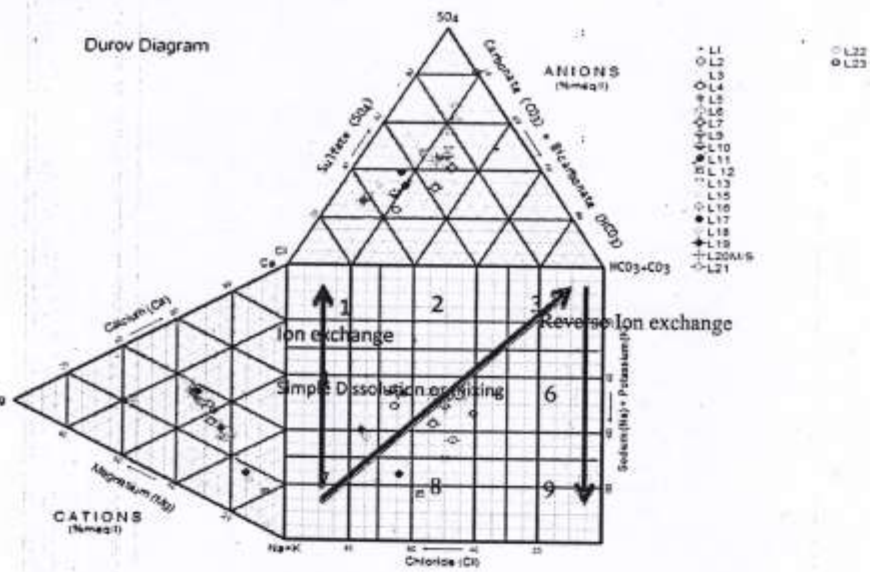

Fig. 7: Durov Diagram for the Study Area

Fig. 7: Durov Diagram for the Study Area

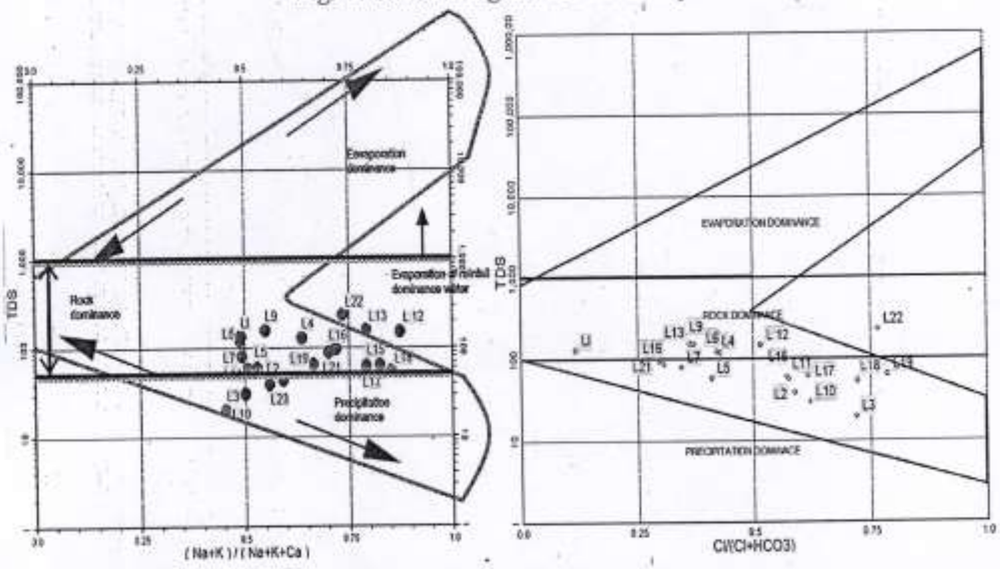

Fig. 8: Gibbs plot of (Na + K)/ (Na+ K + Ca) versus TDS and Cl/ (Cl + HCO_3) versus TDS

Conclusion

Surface and groundwater quality in Gussoro area of Niger State was investigated in this study. The area is dominated by schist with granites intruding in the northeastern part of the area. The study has established that the high fluoride and other heavy metals (nickel, manganese, iron arsenic and lead) in both surface and groundwater in area are due to chemical weathering and subsequent decomposition, dissociation and dissolution arising from rock-water interaction. All the analyzed parameters fall below World Health Organization maximum permissible limits except fluoride, iron, nickel, manganese, lead and arsenic. Their enrichment in the surface and groundwater system in the area may be attributed to mining and farming activities domiciled in the area. The water type in the area is Na+Ca/Cl+SO_4 indicating a marine source. Gibbs diagram suggests chemical weathering as the major hydrogeochemical processes controlling the discharge of ions in waters in the area. The locations in the areas with anomalous concentration of fluoride and heavy metals should be treated before use.

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