Hydrogeochemistry and Water Quality Index (WQI) Assessment for Surface and Ground Water Quality in Parts of North-Central, Nigeria

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Abstract

Geochemical characteristics of surface water and ground water in parts of Niger State, north-central Nigeria have been assessed in this study for the purpose of drinking. Five (5) surface water and twenty-five (25) groundwater samples were collected in pairs for analysis. Water pH, temperature, electrical conductivity, and total dissolved solids were measured in-situ using a handheld device (Hanna instruments; H198311). Analysis for major cations and selected heavy metals such as manganese (Mn^{2+}), total iron (∑Fe), copper (Cu^{2+}), zinc (Zn^{2+}) and lead (Pb^{2+}). The fast sequential Atomic Absorption Spectrometry (AAS) procedure was used to do this. Turbidimetric method was used to determine SO_4^{2-}. Chloride was analysed by argentometric method; titrimetric method was used to determine phosphate (PO_4^{2-}) and bicarbonate (HCO_3^-) and nitrate (NO_3^-) was determined by cadmium method. Results of the study revealed that both surface and ground water are fresh. Surface water is soft in nature while ground water is soft and very hard in nature. Calcium and chloride are dominant ions among cations and anions respectively. The chemical composition and quality of both the surface and ground water in the area are satisfactory in respect to the parameters analysed except for a few water samples with anomalous pH covers about 90% of the samples, Ca^{2+} (GW16), Cl (GW4), PO_4^{2-} (SW2, GW3, GW8), ∑Fe (GW17, SW5), Pb^{2+} (SW1, GW3, SW4, GW5) and Rock-water interaction and precipitation were found to be the dominant processes affecting the chemistry of both surface and ground water in the area. This was further found to be influenced by simple dissolution or mixing and reverse ion exchange processes. Ca, Mg-Na, K-SO_4 and Ca, Mg-SO_4 are the dominant water types in the area. The water quality index (WQI) indicates excellent category that is suitable for drinking.

Keyword: Hydrogeochemistry, water quality, surface water, groundwater

INTRODUCTION

Water of good drinking quality is of basic importance to human physiology. Man's continued existence depends very much on good drinking water availability. Different regions of the world are faced with different types of problems associated with the occurrence, use and control of water resources, which may endanger the sustainable development of these resources (Sanchez *et al*, 2007). The provision of good quality water can help in eradicating water borne diseases and in improving the general sanitation of Nigeria's towns and villages. Water pollution is a major challenge amongst all other types of pollution. Several factors such as geology, soil, effluents, sewage disposal, agricultural runoff and other environmental conditions are responsible for this. Water is the most fundamental requirement of human, plant, and animal life (VanLoon and Duffy, 2017) and it is commonly found from two major sources:

fresh surface water, and ground water. The natural chemistry of surface and groundwater is principally controlled by the rocks and sediments through which these waters flow. Background geochemistry is an important tool which can be applied to evaluate the hydrochemistry of water and plan the monitoring of water quality (Cocker, 1995; Hoko, 2005; Pazand *et al*. 2012). Minerals may influence the chemistry of surface and groundwater through weathering, precipitation, dissolution, and ion exchange reactions. The knowledge of hydrochemistry is important to assess the groundwater quality in any area in which the ground water is used for both irrigation and drinking needs (Srinivas *et al.*2013). The water quality assessment may give clear information about the subsurface geological environments in which the water presents (Raju *et al.*2011). The conventional techniques such as trilinear plots and statistical techniques are widely accepted methods to determine the quality and geochemical behaviour of water. Water Quality Index (WQI) also provides a single number that expresses the overall water quality at a certain location and time based on several water quality parameters. The objective of WQI is to turn complex water quality data into information that is understandable and usable by the public. The WQI which was first developed by Horton in the early 1970s is basically a mathematical means of calculating a single value from multiple test results. The index results represent the level of water quality in each water basin, such as lake, river, or stream. After Horton, several workers such as: Krishna Kumar *et.al.,*2015; Mallick., 2017; Chegbelen *et.al.,*2020 and host of others developed WQI based on rating of different water quality parameters. Basically, WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality. The water quality classification system used in the WQI denotes how suitable water is for drinking. A single WQI value makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters. The single-value output of this index, from several parameters, provides important information about water quality that is easily interpretable, even by lay people (Chowdhury *et al.,* 2012). The present study was carried out for analysis based on physicochemical parameters of surface water and ground water to establish hydrogeochemistry and the assessment of water quality index (WQI) for drinking purpose.

DESCRIPTION OF THE STUDY

This research covers some parts of Niger State, north- central Nigeria. The area is bounded by latitudes 8°1'N to 9°24'N and longitudes 6°15' to 6°45'E on a scale of 1:100,000. It has an area of about 3300 square kilometres, covering parts of Bida Sheet 184 SE and SW: Paiko Sheet 185 NW and SW and Baro 205 NE and NW (Figure 1). The area is generally classified as part of the tropical climate characterized by alternating wet and dry seasons. The seasonal rainfall regime gives rise to a longer wet season of about six to seven months beginning from April or May to October, with an average of rainfall of about 250mm and a dry season of about five to six months. In the month of November to March, the dry season is also marked by the influence of harmattan, a north easterly air stream. Its influence is most felt from December to February that leads to a low relative humidity. The day light temperatures vary from about 24°C at the middle of wet season to temperature of about 35°C at the peak of dry season (Shekwolo, 1990). The rock units observed in the study area includes sandstone and siltstone, basal conglomerate and grits, porphyritic granite, medium grained granite, granitic gneiss, biotite gneiss and amphibolites.

MATERIALS AND METHODS

Sampling and Analytical Methods

The study involved geological mapping, surface, and ground water sampling. A total of thirty (30) water samples were taken from surface and ground water sources in the study area in March 2018 when the concentration of the salts in water was high. The water samples were collected into clean low-density polyethylene bottles kept in an icebox in the field and were later transferred to a freezer until analysis to avoid microbial activity. The physical parameters including temperature, pH, total dissolved solids (TDS) and electrical conductivity (EC) were measured in the field using handheld device (Hanna instruments; H198311). Sample bottles were rinsed at the sampling site with the water to be sampled before collection. Two samples of 500 ml each were collected at every sampling point with one of the samples acidified with concentrated nitric acid to a pH less than 2. Concentrations of cations were determined from the acidified samples as the treatment was meant to keep the cations in solution and prevent reaction with the tightly sealed plastic sample containers while anions samples that are not acidified are chilled and preserved at a temperature of 4°C. Analysis of the collected water samples for their major cations, anions and some heavy metal components was carried out at the Soil Science Laboratory, Department of Soil Science, Ahmadu Bello University Zaria. The major ions analysed, and the methods used in analysing them are as follows: sodium (Na^+) and Potassium (K^+) were analysed by flame photometry, calcium (Ca^{2+}), magnesium, (Mg^{2+}), manganese (Mn^{2-}), copper (Cu^{2+}), total Iron (∑Fe), lead (Pb^{2+}) and Zinc (Zn^{2+}) were determined by fast sequential Atomic Absorption Spectrometry (AAS), (PG instrument London version, AA500). Turbidimetric method was used to determine sulphate (SO_4^{2-}) using H18200 multiparameter Bench Photometer, chloride ion (Cl^-) was analysed by the argentometric method which is silver nitrate titration using potassium chromate as indicator and phenolphthalein/methyl orange, titrimetric method was used to analyse bicarbonate (HCO_3^-), turbidimetric method was used to determine phosphate (PO_4^{2-}) using spectronics 20 photometer and (NO_3^-) was determined by Cadmium method. The analytical procedures are as suggested by the American Public Health Association (APHA 1995).

Mechanism controlling water geochemistry

Gibbs (1970) predicted the factors responsible for the geochemical characteristics of water. Three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas are shown constituting different segments in the Gibbs diagram, which can be interpreted using simple plots of the TDS versus weight ratio of Na^+/ (Na^+ +Ca^{2+}) or Cl^- / (Cl^- + HCO_3^-).

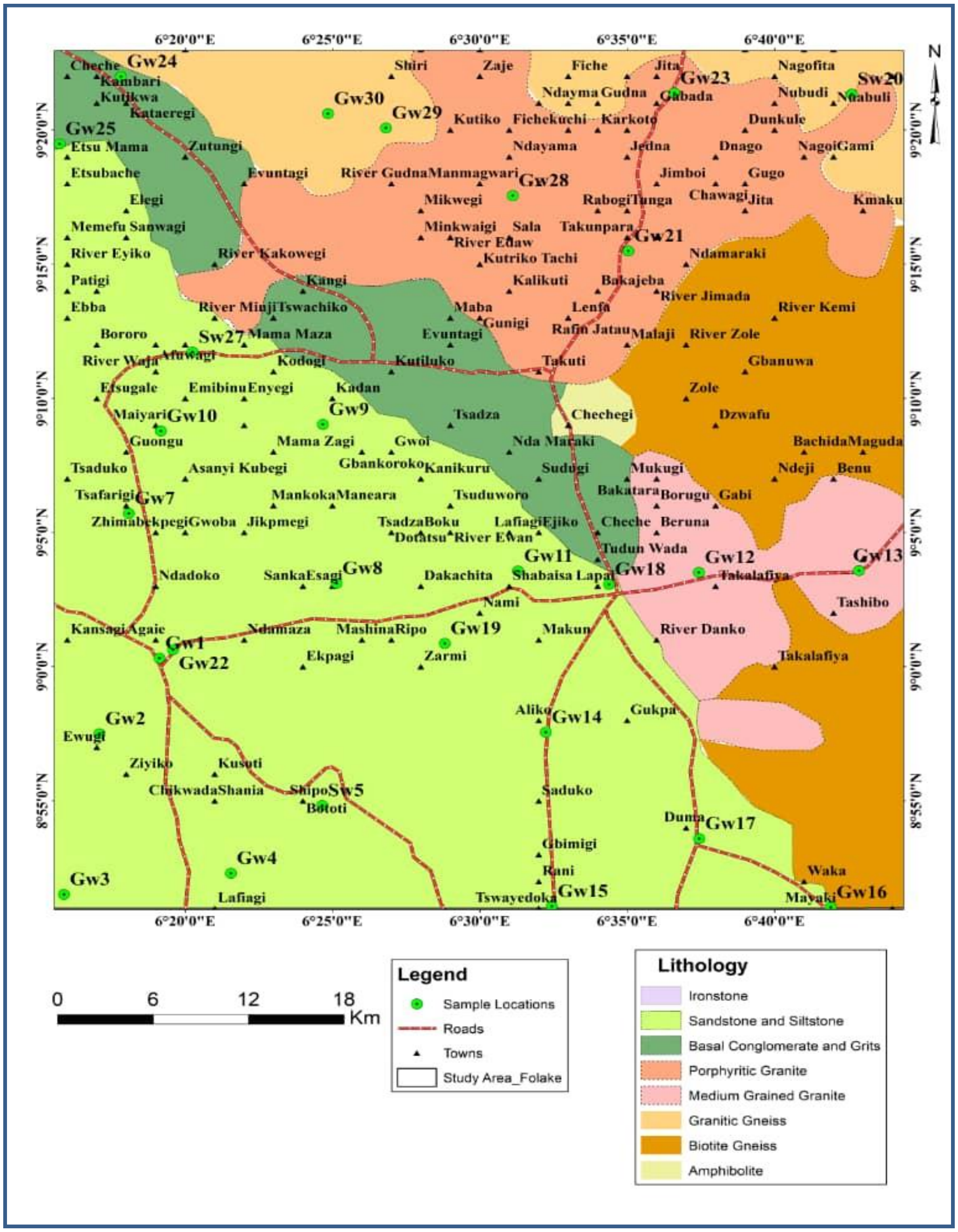

Figure 1: Location, accessibility, and generalized geology of the study area with sampling points

Computation of Water quality index

The water quality index (WQI) was calculated for evaluating influence of natural and anthropogenic activities based on several key parameters of surface and ground water chemistry.

The same has been adopted in this study, the weighted arithmetic index approach modified after Brown et al. (1972), to assess the quality of surface and ground water for drinking purposes. This method involves assigning weights (wi) to water quality parameters based on their health implications in potable water. The assigned weight ranges from 1 to 5. Parameters such as Pb, $NO_3^-$and pH which are believed to be of critical health importance and significant in the quality of water were assigned the maximum value of 5, 4 for EC, TDS and PO_4^{2-}, 3 for HCO_3^-, SO_4^{2-}, Cl^- and ∑Fe and weight 2 was assigned for Ca^{2+}, Mg^{2+}, Na^+, K^+ depending on their perceived significance relative to groundwater potability and health implications (Chegbelen, *et.al.*, 2020 Krishna Kumar, *et.al.*, 2015). This method also involves the computation of relative weights (*Wi*) (equation (1)) and quality rating scale (*qi*) (equations (2)) and determination of the sub index (SI) (equation (3)) and water quality index (WQI) (equation (4)). The computed WQIs were then classified according to Sahu and Sikdar (2008).

$$Wi = \frac{wi}{\sum wi} \text{-----------------------Eq1}$$

$$qi = \frac{ci}{si} x100 \text{-------------------Eq2}$$

where ci and si are chemical parameter concentration

$$SI = qiWi \text{---------------------- Eq3}$$

$$WQI = \sum SI \text{------------------- Eq4}$$

Data Processing

The base map of the study area was downloaded using Shuttle Radar topographic model and digitized using Arc GIS 10.5 software. Gamin GPS was used to find the location of each sampling site and the coordinates were imported to GIS platform for preparation of the base map. The geochemical results are plotted on Piper trilinear diagram using AquaChem 4.0 software and Gibbs diagram was plotted to assess the quality controlling mechanism and dominated hydrogeochemical facies of the study area. Statistical analysis was performed using SPSS software package (SPSS, V 2.0). The physico-chemical parameters of the analytical results of groundwater were compared with standard guideline values recommended by the World Health Organisation (WHO, 2017).

RESULTS AND DISCUSSION

The rock units observed in the study area includes sandstone and siltstone, basal conglomerate and grits, porphyritic granite, medium grained granite, granitic gneiss, biotite gneiss and amphibolites (Fig.1). The statistical parameters like minimum, maximum and mean concentration of physico-chemical parameters, major ion concentrations compared with the standards are tabulated in Table 1. The values show that both surface water and groundwater from the study area is slightly acidic and slightly alkaline with the pH values below the recommended WHO standards of 6.50–8.50. The temperature variation ranges from 30.1 to 31° C with a mean value of 30.5°C for surface water and groundwater has temperature of 30 to 38.7°C with a mean of 32°C. The values of temperature for all water samples were above the permissible limit of WHO (2011) for drinking water. The electrical conductivity (EC) of surface water varied between 26 and 92 μS/cm while ground water varied widely between 24 and 1015 μS/cm. The factors responsible for large variation in EC are attributed to geochemical processes such as ionic exchange, reverse exchange, evaporation, rock-water interaction, and anthropogenic activities (Ramesh and Elango, 2012).

The TDS values range from 12.0 mg/l to 46.0 mg/l for surface water and 12.0 mg/l to 480.0 mg/l for ground water and these are within the freshwater range (Todd, 1980). The total hardness (as $CaCO_3$) for surface water ranges from 0.16 to 24.57mg/l with an average value of 7.01 mg/l indicating soft category while the ground water ranges from 8.91 to 410.82 mg/l with an average of 115.04 mg/l indicating soft and very hard category. The ranges of ionic concentrations in mg/l for surface and ground water in the study area are Table 1.

The highest concentrations of Ca^{2+} was found in samples number (GW1, GW8, GW13 and GW17) among the cations which could be derived from rainwater or as leaches from fertilizers in the study area. This can also be due to the dominance of silicate weathering which is derived from calcium rich minerals like feldspars. The concentrations of most of the parameters were found to be well within the permissible limits set by the WHO (2017) except for pH, K^+, PO_4^{2+}, ∑Fe, Cl^- and Pb^{2+} in few samples. Abundance of cations was in the order of Ca^{2+}>Na^+ > K^+>Mg^{2+} for both surface water and ground water while anions abundance was found to be in the order of Cl^- > SO_4^{2-}> HCO_3^-. Four hydrochemical facies have been distinguished and these are Ca^{2+} + Mg^{2+}, Na^+ + K^+ – SO_4^{2-} water type, Ca^{2+} + Mg^{2+} – SO_4^{2-} water type, Na^+ + K^+ – SO_4^{2-} - Cl^- water type, Ca^{2+} + Mg^{2+} - HCO_3^- + SO_4^{2-} water type (Figure 2).The first category is characterized by alkaline earth water with increased alkalis and prevailing sulphate ions (43.3%), demonstrating the dominance of alkaline earths over alkali (viz. Ca + Mg > Na + K) (Ravikumar and Somashekar, 2017). This according to Ravikumar and Somashekar, 2017 indicates permanent hardness, or reverse ion exchange (Karunanidhi, 2020).

Table 1: Statistical summary of major physicochemical parameters used for the study

Parameters	**Surface**				**Ground water**			**WHO (2017, 2011)**		**NSDWQ (2007)**
Parameters	Min	Max	Mean	Stand Dev	Min Max	Mean	Stand Dev	Most desirable	Not permissible	Allowable limit
pH	5.400	7.290	5.978	0.749	5.100 7.470	5.724	0.501	6.50 to 8.50	<6.5	6.5 to 8.5
Temp (°C)	30.100	31.000	30.540	0.329	30.000 38.700	31.996	1.743	15 to 22		Ambient
TDS (mg/l)	12.000	46.000	28.200	12.657	12.000 480.000	172.720	159.734	<500	>1500	500
EC (µS/cm)	26.000	92.000	48.200	25.840	24.000 1015.000	353.240	330.782	<500	>1500	1000
TH (mg/l)	0.16	24.57	7.01	3.822	8.91 410.82	115.04	6.25			
Ca^{2+} (mg/l)	2.3	66.7	34.76	30.608	4.300 200.000	58.696	49.831	<75	>200	
Mg^{2+} (mg/l)	0.025	0.184	0.074	0.068	0.020 0.441	0.194	0.130	<50	>150	0.200
K^{+} (mg/l)	0.100	6.400	3.880	2.586	0.420 80.100	16.703	23.058	<10	>10	
Na^{+} (mg/l)	1.690	4.700	3.158	1.287	1.230 76.700	16.859	19.167	<200	>200	200
Cl^{-} (mg/l)	0.500	0.800	0.660	0.114	0.300 1200.000	60.640	241.055	<200	>600	250.000
HCO_3^{-}(mg/l)	1.000	3.000	1.880	0.756	0.000 5.200	2.032	1.317	<300	>600	
NO_3^{-}(mg/l)	0.007	0.021	0.015	0.008	0.004 0.035	0.017	0.009	<45	>45	50.000

SO_4^{2-}(mg/l)	1.646	38.556	10.015	15.995	0.235 11.520	3.508	2.764	<400	>400	100.000
PO_4^{3-}(mg/l)	0.001	4.730	0.947	2.115	0.000 4.500	0.792	1.474	<0.3	>0.3	
∑Fe(mg/l)	0.372	11.570	3.438	4.585	0.009 11.570	0.671	2.275	0.100	1.000	0.300
Mn^{2+}(mg/l)	0.023	0.634	0.147	0.272	0.001 0.698	0.050	0.136	0.050	5.000	0.200
Cu^{2+}(mg/l)	0.001	0.008	0.003	0.003	0.001 0.020	0.005	0.004	2.000		1.000
Zn^{2+}(mg/l)	0.010	0.015	0.012	0.002	0.002 0.235	0.032	0.044	5.000	15.000	3.000
Pb^{2+}(mg/l)	0.019	0.085	0.056	0.029	0.001 0.088	0.030	0.024	0.010		0.010

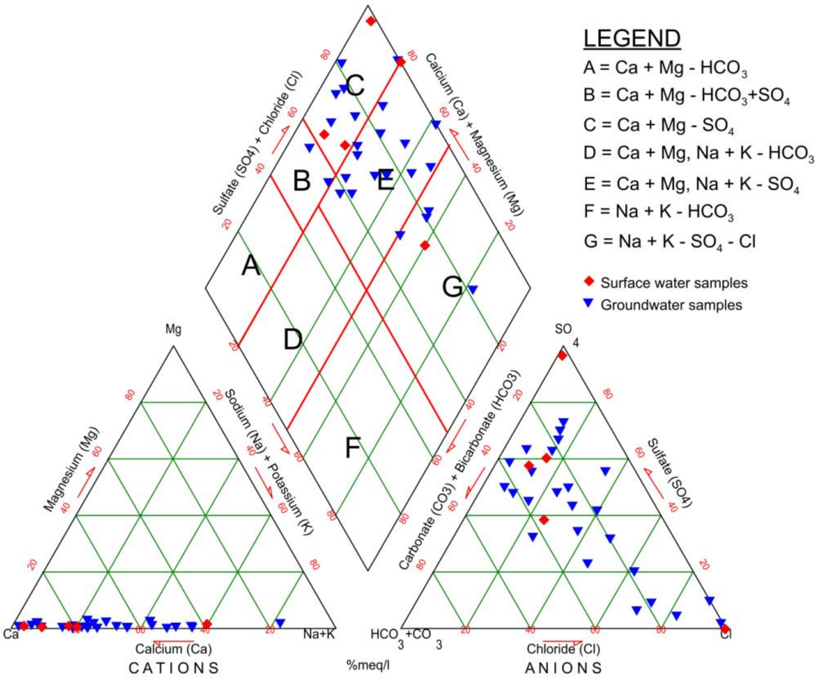

Figure 2: Piper tri-linear plot showing major hydrochemical facies in the surface water and groundwater samples (Langguth, 1966)

The second category is Ca^{2+} + Mg^{2+} – SO_4^{2-} water type which is characterized by normal earth alkaline water with prevailing sulphate (33.3 %); The third category is Na^+ + K^+ – SO_4^{2-} -Cl^- water type which is characterized by the alkaline earth water with increased alkalis and prevailing sulphate or chloride ions (16.7%) strong acidic anions over weak acidic anions (i.e., SO_4^{2-} - Cl^- > HCO_3^- and (6.7%) belong to Ca^{2+} + Mg^{2+} - HCO_3^- + SO_4^{2-} water type signifying the dominance of alkaline earths over weak acidic anions. Presence of alkaline earth cation facies represents the prevalence of natural weathering over human interventions with few exceptions that may have anthropogenic sources such as leaching of fertilizers from agricultural fields (Srivastava and Ramanathan, 2018). Fourteen (14) of the 30 samples (3 surface and 11ground water) plotted on the dissolution line in the Durov diagram (Fig. 3) with no dominant cation or anion represent 46.7 % of the total samples. This is characteristic of fresh recent recharge water that exhibits simple dissolution Lloyd and Heathcote (1985). Nine (9) or 30 % samples of the total samples indicating reverse ion exchange. This is one of the parts of hydrochemical processes affecting water chemistry in the study area. Three (3) samples representing 10 % have SO_4 dominant or anion discriminate and Na dominant. This is the water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.

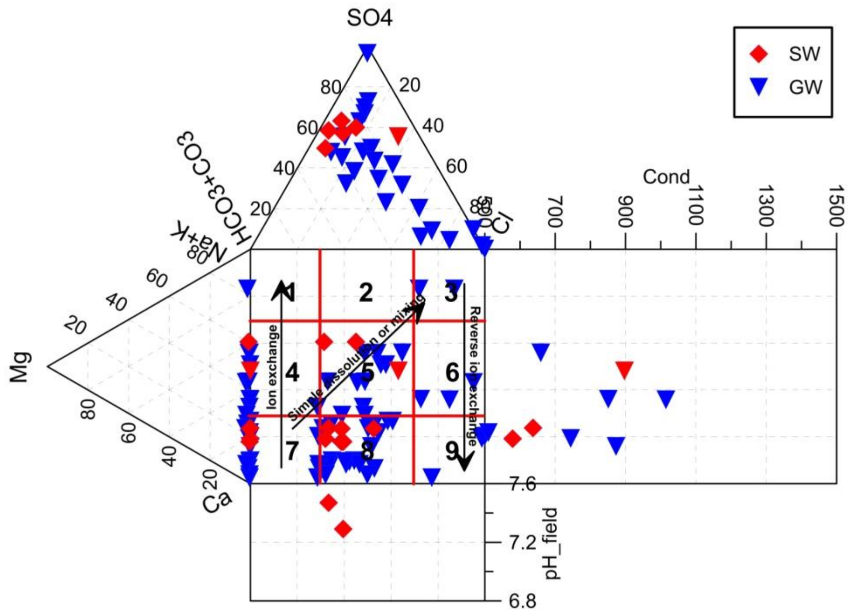

Fig. 3: Classification of surface water and groundwater in the study area after Durov Diagram

Mechanism controlling water geochemistry in the study area

Gibbs diagram of the surface and ground water samples are shown in Fig. 4. The Gibbs diagram show that 53.3% of the samples for surface and groundwater are grouped in the rock dominance field with just 23.3% samples trending towards precipitation domain.

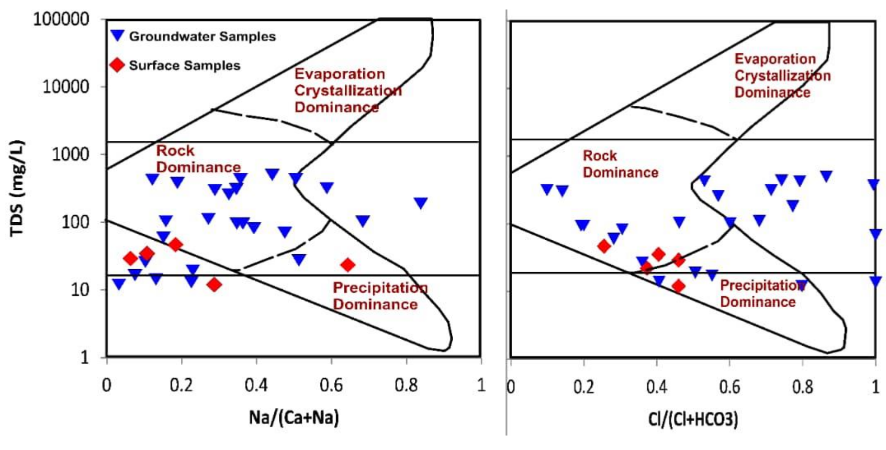

Figure 4: Gibbs plots indicating the mechanism that determines the major composition of surface and groundwater in the study area

Water quality index (WQI) calculation

WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall water quality (Mitra and ASABE Member, 1998). World Health Organization (2017) standards for drinking water quality have been used to calculate the WQI. The relative weight (Wi) was assigned for water quality parameters based on their relative importance on water quality for drinking purposes (Table 3). The WQI values are classified into five categories as listed in Table 4. In the study area, the computed WQI values ranged from 1.15 to 7.53 and 0.23 to 7.57 for surface and ground water respectively. All these samples showed excellent water and suitable for drinking purposes.

Table 3: Relative weight of chemical of physicochemical parameters (after Chegbelen *et.al.*, 2020 and Krishna Kumar *et.al.*, 2015)

Chemical parameters	**WHO 2017(si)**	**Weight (wi)**	**Relative Weight (Wi)= wi/∑wi**
pH	7.5	5	0.106
Electrical Conductivity (µS/cm)	1500	4	0.085
TDS (mg/l)	500	4	0.085
Ca^{2+} (mg/l)	75	2	0.043
Mg^{2+} (mg/l)	50	2	0.043
Na^{+} (Mg/l)	200	2	0.043
K^{+} (Mg/l)	10	2	0.043
Cl^{-} (Mg/l)	200	3	0.064
HCO_3^{-} (Mg/l)	300	3	0.064
NO_3^{-} (mg/l)	45	5	0.106
SO_4^{2-}(Mg/l)	400	3	0.064
PO^{2-}_4 (mg/l)	0.3	4	0.085
∑Fe (Mg/l)	0.1	3	0.064
Pb (Mg/l)	0.01	5	0.105
		∑47	∑1.001

Table 4: Water quality index categorization (after Sahu and Sikdar, 2008)

Range	**Type of water**
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking purposes

CONCLUSIONS

Geochemical characteristics of surface water and groundwater in parts of Niger State, north central Nigeria, have been studied. The aim was to determine the suitability of water from the area for drinking purposes. Results of physicochemical parameters reveal that the quality of both the surface water and groundwater in the area are satisfactory in respect to the parameters analysed except for a few water samples with anomalous pH, Ca^{2+}, PO_4^{2-}, ∑Fe and Pb^{2+}having values that are outside of the recommended limits. Water types are 43.3% Ca^{2+} + Mg^{2+}, Na^{+} + K^{+} – SO_4^{2-} demonstrating the dominance of alkaline earths over alkali.53.3% of the surface water and groundwater chemistry evolved from the dissolution of rocks in-situ whereas 23.3% of the chemistry of water from both sources was derived from precipitation. The computed WQI values range from 1.15 to 7.53 and 0.23 to 7.57 for surface and ground water. All these showed excellent water, suitable for drinking purposes.

REFERENCES

APHA (1995) Standard methods for the examination of water and wastewater 19th edn. American Public Health Association, Washington, pp 1–467.

Brown, R.M., McClelland, N.I., Deininger, R.A. and O'Connor, M.F., (1972). A water quality index—crashing the psychological barrier. In *Indicators of environmental quality* (pp. 173-182). Springer, Boston, MA.

Chegbeleh, L.P., Akurugu, B.A. and Yidana, S.M., (2020). Assessment of groundwater quality in the Talensi District, Northern Ghana. *The Scientific World Journal*, *2020*

Chowdhury, R.M., Muntasir, S.Y. and Hossain, M.M., (2012). Water quality index of water bodies along Faridpur-Barisal Road in Bangladesh. *Glob Eng Tech Rev*, *2*(3), pp.1-8.

Cocker, M.D. (1995). Geochemistry and hydrochemistry of the Oconee River Basin. In: Hatcher KJ (ed) Proceedings of 1995 Georgia water resources conference held on the 11–12 April 1995, University of Georgia pp 67–70.

Gibbs, R.J., (1970). Mechanisms controlling world water chemistry. *Science*, *170*(3962), pp.1088-1090.

Hoko, Z., (2005). An assessment of the water quality of drinking water in rural districts in Zimbabwe. The case of Gokwe South, Nkayi, Lupane, and Mwenezi districts. *Physics and Chemistry of the Earth, Parts A/B/C*, *30*(11-16), pp.859-866.

Karunanidhi, D., Aravinthasamy, P., Deepali, M., Subramani, T. and Roy, P.D., (2020). The effects of geochemical processes on groundwater chemistry and the health risks associated with fluoride intake in a semi-arid region of South India. *RSC Advances*, *10*(8), pp.4840-4859.

Krishna, K., S., Logesh K., A., and Magesh, N.S. (2015). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Appl Water Sci* **5,** 335–343 https://doi.org/10.1007/s13201-014-0196-4.

Langguth, H.R. (1966). Gundwasserverhältnisses im Bereich des Velberter Sattels (Rheinisches Schiefergebirge): Düsseldorf. *Deutschland, Minister für Ernäherung und Gesundheit*.

Lloyd, J.W. and Heathcote, J.A.A., (1985). Natural inorganic hydrochemistry in relation to groundwater.

Mallick, J., (2017). Hydrogeochemical characteristics and assessment of water quality in the Al-Saad Lake, Abha Saudi Arabia. *Applied Water Science*, *7*(6), pp.2869-2882.

McMurry, J., and Fay, R.C. (2004). Hydrogen, oxygen, and water. *McMurry Fay Chemistry*. *KP Hamann, (Ed.). 4th Edn. New Jersey: Pearson Education*, *575*, p.599.

Mitra, B.K., Asabe M. (1998). *Spatial and temporal variation of ground water quality in sand dune area of aomori prefecture in Japan*.

Mendie, U., (2005). The nature of water. *The Theory and Practice of Clean Water Production for Domestic and Industrial Use. Lagos: Lacto-Medals Publishers*, *1*, p.21. Nigeria Standard for Drinking Water Quality (NSDWQ) 2005. Guidelines for Drinking Water Quality. 1, pp.1-30.

Pazand, K., Hezarkhani, A., Ghanbari, Y. and Aghavali, N., (2012). Groundwater geochemistry in the Meshkinshahr basin of Ardabil province in Iran. *Environmental Earth Sciences*, *65*(3), pp.871-879.

Piper, A.M., (1944). A graphic procedure in the geochemical interpretation of water analyses. *Eos, Transactions American Geophysical Union*, *25*(6), pp.914-928.

Raju, N.J., Shukla, U.K. and Ram, P., 2011. Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. *Environmental monitoring and assessment*, *173*(1), pp.279-300.

Ramesh, K. and Elango, L., (2012). Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. *Environmental monitoring and assessment*, *184*(6), pp.3887-3899.Rao, N.S., 2006. Seasonal variation of groundwater quality in a part of Guntur District, Andhra Pradesh, India. *Environmental Geology*, *49*(3), pp.413-429.

Ravikumar, P. and Somashekar, R.K., (2017). Principal component analysis and hydrochemical facies characterization to evaluate groundwater quality in Varahi River basin, Karnataka state, India. *Applied Water Science*, *7*(2), pp.745-755.

Sahu, P. and Sikdar, P.K., (2008). Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environmental Geology*, *55*(4), pp.823-835.

Sánchez, E., Colmenarejo, M.F., Vicente, J., Rubio, A., García, M.G., Travieso, L. and Borja, R., (2007). Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. *Ecological indicators*, *7*(2), pp.315-328.

Shekwolo, P. D. (1990). Regional hydrogeology of Bida Basin. Unpublished Ph.D. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Srinivas, Y., Oliver, D.H., Raj, A.S. and Chandrasekar, N., (2013). Evaluation of groundwater quality in and around Nagercoil town, Tamilnadu, India: an integrated geochemical and GIS approach. *Applied Water Science*, *3*(3), pp.631-651.

Srivastava, S.K. and Ramanathan, A.L., (2018). Geochemical assessment of fluoride enrichment and nitrate contamination in groundwater in hard-rock aquifer by using graphical and statistical methods. *Journal of Earth System Science*, *127*(7), pp.1-23.

VanLoon, G.W. and Duffy, S.J. (2017). *Environmental chemistry: a global perspective*. Oxford university press.

World Health Organization, (2011). *Safe drinking-water from desalination* (No. WHO/HSE/WSH/11.03). World Health Organization.

World Health Organization, (2017). *Global diffusion of eHealth: making universal health coverage achievable: report of the third global survey on eHealth*. World Health Organization.