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Assessment of Groundwater System Characteristics in Ilorin Metropolis, South-Western Nigeria

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Abstract: Geochemical analysis of shallow groundwater from Ilorin metropolis was carried out with the aim of assessing the hydrogeochemical characteristics of the groundwater. Thirty (30) boreholes were examined and samples were collected from these boreholes. These samples were subjected to chemical analyses to determine both cations and anions compositions of the groundwater. The concentrations of cations (trace elements) were determined using AAS at the Department of Geology while major cations were determined using flame photometry emission at the Centre for Multidisciplinary Research Laboratory University of Ibadan. The compositions of anions in the samples were analyzed using titration method at the National Geo-Hazard Research Laboratory, Ibadan. Some physical parameters such as TDS, pH, EC as well as colour and odour were determined in-situ. The results of the physical parameters show that EC ranged from 44.3 - 1079µs/cm; TDS 10.6 – 501.0mg/l. The results of the chemical analysis in mg/l for trace elements showed that Cd (0.57 – 0.58), Co (3.84 – 3.87), Cr (3.41 – 3.79) and Ni (0.00 – 0.11); Major elements: Ca (1.20 – 6.60); Mg (2.40 – 5.53); K (1.45 - 5.86) while the results of the anions showed that concentrations (mg/l) of Cl ranged from (6.00 – 229.95), HCO_3 (0.20 – 2.18), SO_4 (0.01 – 1.47) and NO_3 (0.09 – 0.35). Further evaluation of the results shows that samples from areas that are densely populated and dominated with lot of commercial activities have high concentrations of chloride, nitrate, Cd and bicarbonate. The results of the analysis were compared with the WHO Standards and it was observed that Cd and chloride were far greater than WHO Standards recommended for safe drinking water.

Keyword: Ilorin Metropolis, Groundwater, Hydrogeochemical Assessments

1. Introduction

Generally, groundwater plays a number of very important roles in our environment and socio-economic development of any society (Tijani, 2016). It is a valuable natural resource providing a primary source of water for domestic, agriculture and industrial uses throughout the world (Tijani, 2016).

Usually, surface water is prone to pollution and contamination from domestic sewage and industrial wastes and therefore there is need for water quality monitoring. Nonetheless, monitoring the quality of water can be expensive; the cost of exploitation of surface water and management (construction of dams) is high. This has led to the increasing exploitation and development of groundwater.

Groundwater is generally believed to be relatively protected because groundwater is held within pores spaces, fractures and weathered regolith's depending on the geologic setting, which makes it widely and generally free from sediments and biological impurities.

Although, groundwater is generally regarded as being protected from contamination compared to surface water, increasing population and anthropogenic impacts warrants hydrochemical quality assessment of groundwater sources, and the need for quality monitoring. Consequently, this study presents an overview of quality of groundwater system in Ilorin metropolis (Figure 1), with the aim of assessing possible human impacts on the chemical components of the ground water sources in the area.

Over the past decade there has been increased research on the evaluation, exploitation and quality assessment of groundwater in the basement complex of Nigeria especially in the South Western part of the country (Idowu et al., 2007; Ako, 1970; Ajadi, 2010). However, the present work only serves as means of providing additional information on the hydrological and hydrochemical investigations that have been carried out in the study area.

Ilorin metropolis is one of the densely populated areas in North-Central Nigeria and the population is in excess of 800,000 inhabitants (FRN, 2007) and most of the houses do not have good drainage system. This act causes great havoc on the environment (most especially waterway such as river). In as much as there are contaminants and pollutants in waterway, there will always be reason to carry out water analysis. This study was carried out to examine the quality of groundwater within Ilorin metropolis and possible ways of controlling them before they lead to loss of life.

The study area, Ilorin lies within the Basement Complex of southwestern Nigeria (Oyawoye, 1972). The predominant rock types in the study area are granite gneiss and quartzite schist (Oluyide et al., 1998). These rocks are covered by weathered regolith, the thickness of which varies from place to place. Basement Complex rocks are poor aquifers as they are characterized by low porosity and negligible permeability, resulting from their crystalline nature. Appreciable porosity and permeability may however be developed through weathering and fracturing, depending on the lithology and texture of the parent rocks. The availability of groundwater would therefore depend on the presence and extent of the weathered overburden/regolith and the presence of faults and fractures in the underlying bedrock (Ademilua, 1997).

The two main types of aquifer in the area are the weathered basement and jointed/fractured basement aquifers with latter usually occurring below the former (Azeez, 1971). The aquifers are localized and disconnected but occur essentially as unconfined to semi-confined under water table conditions. Although the crystalline nature of the basement rocks precludes development of the porosity and permeability necessary for good groundwater occurrence, Davis and De Weist (1966) asserted that appreciable porosity and permeability may have been developed within these rocks through fracturing and weathering processes. Basically, there are three hydrogeological structures identifiable within the geological setting in the area, these are:- Basement Complex; the Cretaceous sediments and the River alluvium area. Schist and quartzite's occurs as lenses within the regional trend of the granitic and gneisses metasomatic rocks. Shallow groundwater is tapped by hand-dug wells and boreholes in the basement areas from the regolith and mottled materials where in-situ weathering has taken place to appreciable depths, Groundwater exists under water table conditions, boreholes and hand-dug wells could be successful in these areas. The water in basement rocks is either in the fractured zones or the weathered zones.

2. Materials and Methods

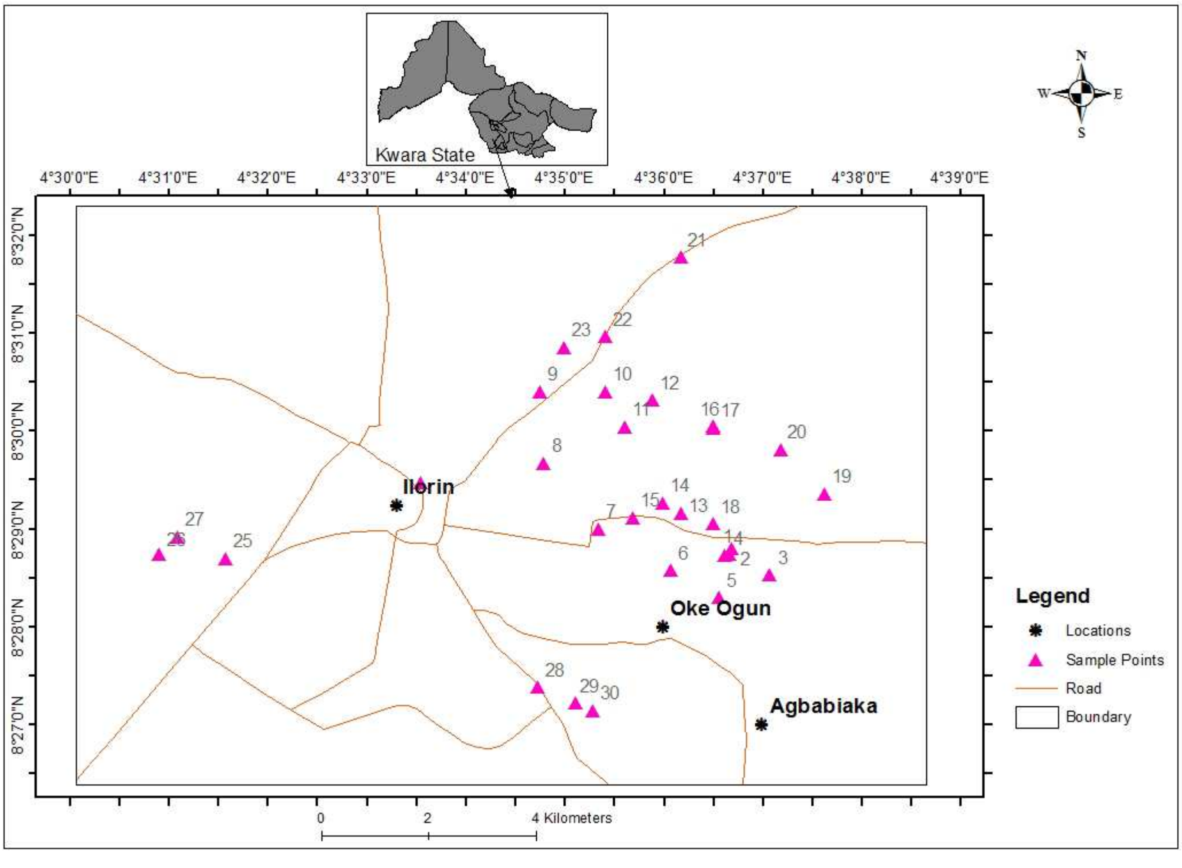


Figure 1. The Location Map of the Study Area.

This study was carried out in Ilorin metropolis which is one of the capital cities in North Central Nigeria. It lies within Latitudes N08°27.2' to N08°35.2' and Longitudes E003°00" to E003°09" (Figure 1). Notable areas covered during this study include Tanke, Sango, Basin, Taoheed, Oyun Village, Opomalu, Adewole, Offa Motor park and its neighborhoods. The study area falls within the tropical savannah region. Ilorin metropolis is characterized by both wet and dry seasons; the annual rainfall in Ilorin is about 1318mm with the mean temperature being between 30°C to 33°C. Relative humidity ranges from 65% to 80%. Ilorin is mainly drained by Asa River, whose course enters the southern end of the industrial estate from Asa Dam and it runs northwards through residential and commercial areas of Ilorin metropolis (Ajadi et al, 2011).

A total of thirty (30) water samples were collected randomly from thirty boreholes between December 2015 and January 2016. Boreholes were allowed to pump for at least 10 minutes before sampling. Samples were collected before the onset of raining season in order to ensure that effluents from surface run-off did not influenced the quality of the sampled water. The samples were collected in 1lilter capacity plastic bottles after they have been thoroughly rinsed with the sample and preserved airtight in order to avoid evaporation. Two sets of samples were collected at every sampling borehole; one being acidified with two drops of concentrated HNO_3 for determination of cations while the other sets were not for anions' determination. Physical parameters such as TDS, EC and pH of the sampled water were determined in situ using HANA Model HI 83200 multi-meter. These samples were kept refrigerated prior to analysis. Major ions' concentrations (Na^+, K^+, $Mg^{2+,}$ Ca^{2+}) were determined by Flame Spectrophotometry at the University of Ibadan Multidisciplinary Research Laboratory; trace elements contents were determined using Atomic Absorption Spectrometry at the Department of Geology, University of Ibadan while the major anions (Cl^-, NO_3^-, HCO_3^-, SO_4^{2-} and CO_3^{2-}) were determined by by Calorimetric ($HCO_3^-$and NO_3^{2-}), Volumetric (Cl^-) and Turbidimetric (SO_4^{2-}) methods with values recorded in mg/l. at the National Geo-Hazard Research Centre, Ibadan. Standard procedures (APHA 1998) were used. Alkalinity measurements were carried out by acid titration with 0.02N H_2SO_4 added to each sample to reach its titration end point marked by a pH of 4.5. For quality control of the chemical measurements, standards and blanks were used in between runs to provide a measured of background noise, accuracy and precision (Ali, et al., 2008).

3. Results and Discussion

The chemical nature of water continually evolves as it moves through the hydrological cycle. The kind of chemical constituents found in groundwater depends in part on the chemistry of the precipitation and recharge water as well as on the geologic environment (Adams et al., 2004). The movement of water through the geologic environment result in the dissolution of soluble minerals until a point of equilibrium is reached between dissolved species and aqueous phase. Chemical elements and compounds often dissolved in water, in varying amount affect the taste, odour and general quality. The principal water quality problems usually result from high salinity, enriched iron, elevated SO_4^{-2} and excessive Ca^{2+} and Mg^{2+}, which render the groundwater unsafe for various purposes.

The results of the analyses of the water samples from the study area are presented in Table 1. The range and mean concentrations of the different parameters analyzed in the samples were compared with the WHO standards.

Table 1. *Summary of the Physico-chemical results of water samples from the study area.*

Parameters	Min.	Max.	Mean	WHO (2008)
Bicarbonate	0.20	2.18	0.62	100
Chloride	6.00	229.95	40.38	250
Nitrate	0.09	0.35	0.24	50
Sulphate	0.01	1.47	0.35	400
K	1.45	5.86	2.76	10
Mg	2.40	5.53	3.88	50
Ca	1.20	6.60	2.20	75
Na	1.2	3.5	1.75	50
Pb	3.41	3.79	3.50	0.01
Ni	0.00	0.11	0.04	0.02
Cd	0.57	0.58	0.57	0.003
Co	3.84	3.87	3.86	-
Mn	0.01	0.33	0.03	0.3
Cr	3.41	3.79	3.50	0.05
TDS	10.6	501.0	109.3	1000
EC (µs/cm)	48.5	1079	249.3	1400
T (°C)	20.0	32.4	28.76	27

All units except temperature and EC are in mg/l.

The results of the physical parameters revealed that the Electrical Conductivity (EC) ranged from 44.3 - 1079µs/cm (av.349.3 µs/cm); TDS ranged from 10.6 – 501.0 mg/l (av. 109.3 mg/l) while the temperature ranged from 23.8 to 34.0°C (av. 28.76°C) (Table 1). Comparing these concentrations ranges of the physical parameters with the recommended the WHO (2008) permissible limits showed that TDS and EC were far below the standards while temperature ranges were slightly higher than the recommended limits. TDS occur naturally but can be derived from anthropogenic sources such as landfill, leachate, feedlot, or sewage. According to Health (1987) classifications, the water samples can be classified as fresh water. Samples collected within Adewole area recorded highest EC while samples collected around Offa motor park have high temperature relatively to other locations. The high temperature recorded in groundwater around this motor park area may be as a result of impact of high vehicular movement and emission that characterized this area.

The concentrations of anions (HCO_3^-, Cl^-, NO_3^- and SO_4^{2-}) from the studied groundwater samples ranged from 0.2 to 2.98 mg/l (av. 0.62 mg/l); 6.0 to 230.0 mg/l (av. 40.38 mg/l); 0.09 to 0.35 mg/l (av. 0.24 mg/l) and 0.01 to 1.47 mg/l (av. 0.35 mg/l) respectively. These concentrations values were compared with the recommended WHO permissible standards and the results showed that all sampled water were within the permissible limits of WHO (2008). The relatively high concentrations of Cl recorded in this study is an indication of leachate inputs from the waste dumpsites and sewage effluents. High concentrations of Cl observed in some locations most especially in and around Hausa community in Sango areas of the metropolis could have resulted from localized sources of contamination such as localized dumps and leachate from soak-away and pit latrines.

Likewise, the concentrations of major cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) ranged in mg/l from 1.45 to 5.86 mg/l (av. 2.76 mg/l); 1.2 to 3.5 mg/l (av. 1.75 mg/l); 1.2 to 6.6 mg/l (av. 2.2 mg/l) and 2.4 to 5.53 mg/l (av. 3.88 mg/l) respectively. While the concentrations of potentially toxic metallic ions such as Pb^{2+}, Ni^{2+}, Cd^{3+}, Co^{2+}, Mn^{2+} and Cr^{3+} ranged from 3.41 to 3.79 mg/l (av. 3.50 mg/l); 0.0 to 0.11 mg/l (av. 0.04 mg/l); 0.57 to 0.58 mg/l (av. 0.57 mg/l); 3.84 to 3.87 mg/l (av. 3.86mg/l); 0.01 to 0.33 mg/l (av. 0.03) and 3.41 to 3.79 mg/l (av. 3.5 mg/l) respectively (Table1). Comparing the concentrations and the average values of major cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) with their respective WHO recommended permissible limits revealed significantly low concentrations. The low concentrations of Mg and Ca is an indication that the groundwater from the study has no laxative effect and this is further confirmed by the relatively low concentrations of bicarbonate and sulphate. Ashano et al, (2006) is of the opinion that if the sum of sulphate and magnesium water exceeds 100mg/l, the users of such water experience laxative effects. Similarly, comparing the concentrations values of the potentially hazard metallic ions with their respective recommended WHO standards showed that all the metallic ions analysed with the exception of Mn were significantly enriched in the groundwater far above their recommended standards.

4. Discussion

4.1. Anions Hydro-Geochemistry of the Water Samples

Bicarbonate concentrations ranged from 0.20 – 2.18 mg/l with a mean concentration of 2.18 mg/l. Samples from Opomalu area have higher concentrations while samples Tanke area of the metropolis were of low concentrations. It has been concluded that most bicarbonate ions in groundwater originate in soils from respiring organism and decaying vegetation. Suggesting that groundwater within Opomalu area of the metropolis have been significantly impacted by anthropogenic activities which have led to higher concentrations of HCO_3^- in groundwater in this area compared to groundwater from Tanke. Chloride has concentration range of 6.00 – 229.95 mg/l (Table 1) with an average of 40.38 mg/l. All samples collected within Hausa community from Sango area showed higher concentrations of chloride relatively to other areas of the metropolis. Water that contains less than 150 mg/l chloride ion as in the study area is satisfactory for most purposes, while those more than 200 mg/l is objectionable for municipal water supply. It can be concluded that the high concentration of chloride ion recorded in water samples from Sango area was attributed to domestic and commercial wastes generated in this area and this has health implications on the entire community.

Similarly, Nitrate ranged from 0.09 – 0.35 mg/l (av. 0.24 mg/l). The higher concentrations of nitrate were observed in samples from Sango area most especially within Hausa community. Nitrate in groundwater originates most often from sewage waste and feedlots. Its presence in groundwater is taken as an evidence of faecal contamination. The present high nitrate concentrations observed in and around Sango area of Ilorin metropolis could be as a result of infiltration and percolation from contaminated run-offs and surface water. However, nitrate concentrations in this study fall within the WHO maximum permissible levels (50 mg/l). The safe nitrate limit for safe water recommended by the USEPA is 45mg/l. Water containing as much as 90mg/l nitrate is considered to cause toxic effect in infants.

Sulphate concentrations ranged from 0.01 – 1.47 mg/l (av. 0.35 mg/l). All samples from collected from Sango area of the metropolis showed elevated concentrations of sulphate. Sulphate in groundwater is derived principally from gypsum, anhydrite or from oxidation of pyrite. Davis and De Wiest (1966) concluded that groundwater trapped within igneous or metamorphic terrains generally contain less than 100mg/l of SO_4.

From Table 1, the relative mean concentrations of the anions follow the order of abundance: $Cl >>> HCO_3 > SO_4 > NO_3$. Based on this, the water quality of the study area can be regarded as satisfactory within the contents of WHO standards. However, if the present concentrations of anions most especially chloride and bicarbonate in areas such as Hausa community within Sango is not checked, a future epidemic outbreak may occur.

4.2. Major Cations Hydro-Geochemistry of the Study Area

The high concentrations of potassium were observed in samples collected from Oyun area of Sango while samples from Tanke area recorded low concentrations of K^+. The presence of potassium ion in groundwater has being attributed to contribution from geogenic activities such as weathering of ferromagnesian minerals like feldspars and mica. High concentrations of Mg were found in samples collected around Offa Motor Park within the metropolis while the lowest concentration was recorded in samples collected from Tanke and Iledu. Mg occurs in natural water but its concentration is always lower than that of calcium. The principal sources of Mg^{2+} in groundwater include rocks, sewage and industrial waste. The Mg^{2+} concentrations in the study area were relatively low and below the permissible limits when compared with the WHO standard. Ca^+ concentrations ranged from 1.20 – 6.60mg/l with a mean concentration of 2.20mg/l. The highest concentration of calcium was found in samples from Tanke. From Table 1, the dominant cation in the water samples was Mg with an average value of 3.88mg/l, this is followed by Potassium with an average 2.76 mg/l while Ca and Na showed an average value of 2.20 mg/l and 1.75 mg/l respectively. This revealed Mg-K dominated water type suggesting impact of bedrock on the groundwater from the study area (Tijani, 2016).

4.3. Trace Elements Hydro-Geochemistry

Nickel ranged from <0.01 to 0.11mg/l with an average of 0.04mg/l. The highest concentration of Nickel was recorded in samples collected from Sango area of the metropolis while the lowest were observed in samples 2, 6, 8 and 9 collected from Tanke areas of the study area. The average concentration of Ni in the water samples from the study area was found lower than the WHO permissible limit when compared with the WHO standard of 0.07mg/l but greater than the BIS standard of 0.02mg/l (WHO, 2008).

The concentrations of cadmium ranged from 0.57 to 0.58 mg/l (Table 1). Samples within the G. R. A recorded elevated concentration of Cd^{2+} relative to other areas of the metropolis. Cadmium replaces zinc bio-chemically in the body. It occurs along with Zn in acidic water. Concentration at high level causes high blood pressure, liver and kidney damage. It also destroys testicular tissues and red blood cells. Chromium concentrations ranged from 3.41 to 3.79 mg/l. Higher concentrations of Cr^{3+} were observed in samples collected from Adewole area of the metropolis. Cobalt ranged from 3.84 to 3.87mg/l (Table 1). Co recorded high concentration in samples collected from Oyun Village and this can be linked anthropogenic activities that characterized this area of the city. Considering the potential health implications of these metals most especially Pb and Cd on the populace, the water can be regarded as unfit for consumption. Therefore, there is need for proper treatment and groundwater monitoring in this area.

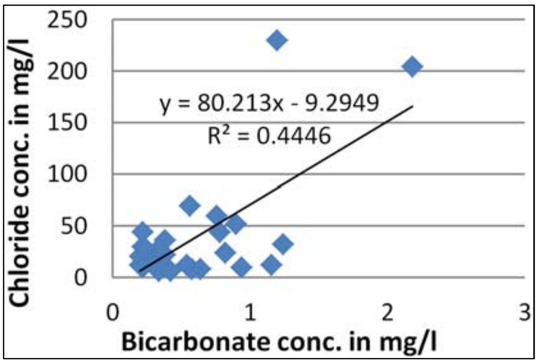
4.4. Inter-elemental relationships

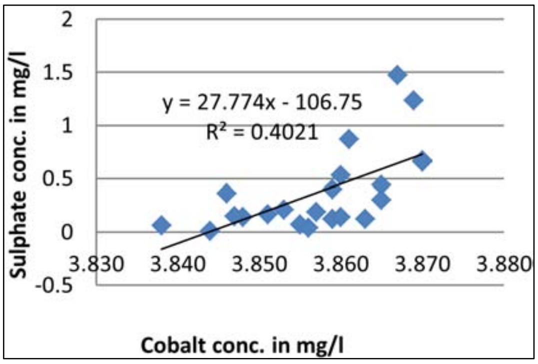
4.4.1. Correlation Analyses

The result of correlation analysis using Pearson correlation (Table 2) revealed that strong positive correlation exists between some of the chemical parameters; bicarbonate and chloride (r = 0.67), sulphate and bicarbonate (r – 0.69), sulphate and cobalt (r = 0.63), chloride and sulphate (r = 0.83), nickel and sulphate (r = 0.57) and chloride and nitrate (r = 0.41) (Figure 2). The strong and positive correlation that existed among these chemical parameters is an indication of similar source. The strong positive relation between nitrate and chloride (r = 0.41) is a clear indication of a common anthropogenic source according to Ritter and Chimside (1984) which suggest an effect of municipal wastes if correlation coefficient between nitrate and chloride is greater than 0.35.

Table 2. *Correlation Matrix of Chemical Parameters in Water Samples from the Study Area.*

	HCO_3^-	Cl^-	NO_3^-	SO_4^{-2}	K	Mg	Ca	Ni	Cd	Co	Cr
HCO_3^-	1										
Cl^-	$.67^{**}$	1									
NO_3^-	.13	$.41^{*}$	1								
SO_4^{-2}	$.69^{**}$	$.83^{**}$	.21	1							
K	.22	.29	.11	.35	1						
Mg	.38	-.06	-.05	.02	-.04	1					
Ca	-.15	.01	-.08	.10	.24	-.15	1				
Ni	.31	$.46^{*}$	.17	$.57^{**}$	$.58^{**}$	-.14	.23	1			
Cd	-.11	-.01	-.24	.22	-.10	-.14	-.24	.12	1		
Co	$.63^{**}$	$.49^{*}$	$.43^{*}$	$.63^{**}$	.30	.12	.10	$.53^{*}$	-.01	1	
Cr	.08	-.21	-.12	-.21	-.30	.18	-.14	$-.52^{*}$	-.22	-.01	1





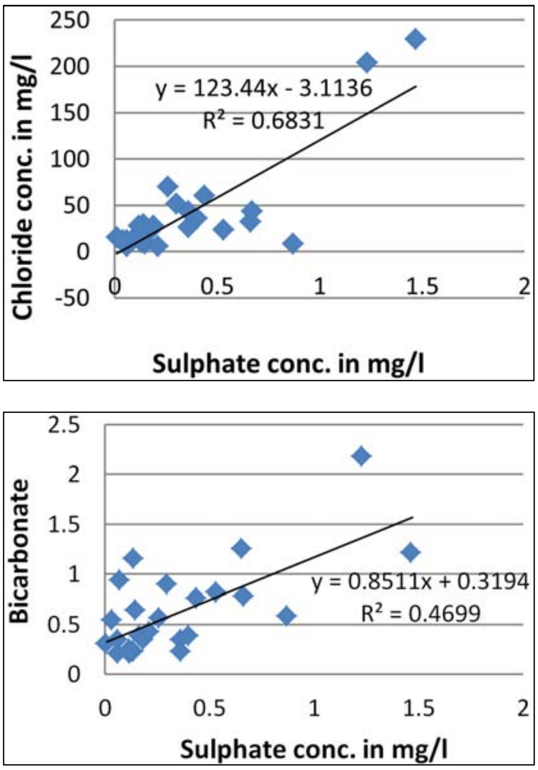


Figure 2. *Scatter Plots of some parameters.*

4.4.2. Principal Component

Principal component (PC) analysis was performed on the groundwater data for better understanding of their interrelationships and probable source of major ions. The data set were subjected to five component analysis with total variance of 81.1%. Table 3 presents the principal components and the initial eigen.

Table 3. *Result of the R-mode analyses.*

Parameters	1	2	3	4	5	Extraction
Bicarbonate	.73	.50	.23	.12	.07	.86
Chloride	.85	.09	.11	-.15	-.29	.84
Nitrate	.50	.17	-.39	-.50	-.21	.71
Sulphate	.88	.01	.25	.16	-.22	.91
K	.56	-.26	-.20	-.33	.53	.81
Mg	-.02	.62	.04	.34	.56	.81
Ca	.12	-.11	-.65	.66	-.27	.95
Ni	.75	-.44	-.11	.19	.23	.85
Cd	.02	-.46	.76	.17	-.07	.82
Co	.78	.26	.01	.10	-.01	.68
Cr	-.35	.72	.12	-.07	-.19	.69
Initial Eigen values	3.87	1.74	1.34	1.04	.94	
% of Variance	35.16	15.78	12.14	9.47	8.8	
Cumulative%	35.16	50.94	63.08	72.55	81.1	

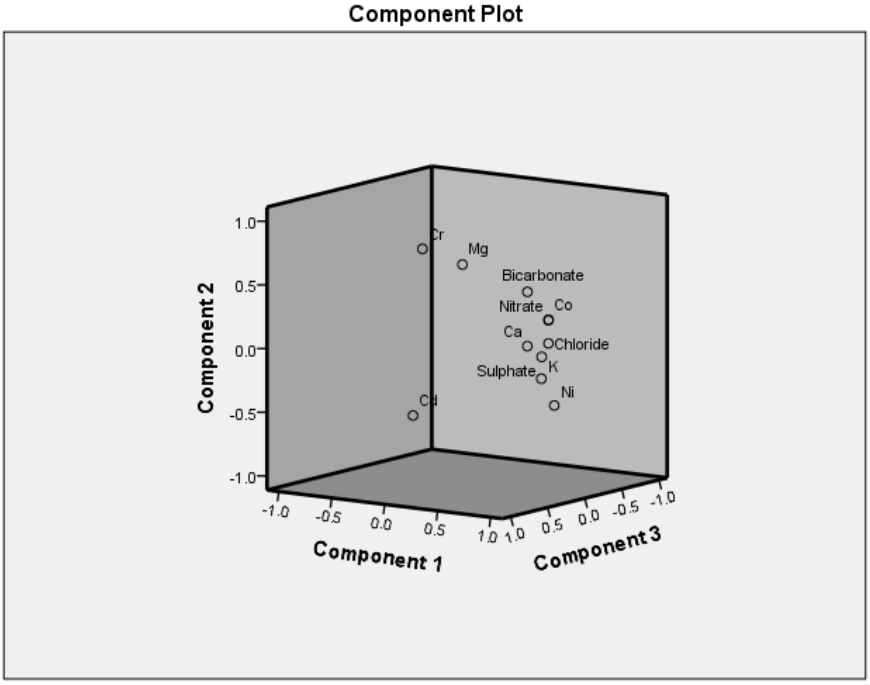


Figure 3. *Screen plot of principal component analysis.*

The principal component 1 (PC-1) has an eigen value of 3.87 which accounts for 35.2% of the total variance in the groundwater. This factor is strongly and positively loaded with parameters such as bicarbonate (0.73), Chloride (0.85), Sulphate (0.88), Co (0.78) and Ni (0.75) but moderately and positively loaded with nitrate (Table 3 and Figure 3). This association showed that all these variables have common source which accounts for their precipitations in the groundwater of the study area. The PC-2 has an eigen value of 1.74 which accounts for 15.8% of the total variance. This factor is strongly and positively loaded with the following parameters; Chromium (0.72), Magnessium (0.62) and bicarbonate (0.50) but moderately and negatively loaded with cadmium. This association shows that all these variables have similar sources responsible for their precipitations in the groundwater from the study area. The PC-3 has an eigen value of 1.34 which accounts for 12.14% of the total variance. This factor is strongly and positively loaded with Cadmium (0.76) This showed that Cd an inorganic potentially toxic metallic ion has multiple sources responsible for its precipitation into the groundwater of the study area. The PC-4 has an eigen value of 1.04 which accounts for 9.47% of the total variance. This factor is moderately and strongly loaded with the following parameters; Sulphate (-0.50) and Calcium (0.66) while PC-5 has an eigen value of 0.94 which accounts for 8.8% of the total variance. This factor is moderately and positively loaded with the following parameters; Potassium (0.53) and Magnesium (0.56).

These associations showed that most of these parameters in the groundwater of the study area were contributions from different sources. PC-1 and -3 can be assigned as contributions from anthropogenic sources while PC-2, -4 and -5 were contributions from rock-water interactions (. dissolution of minerals-rocks).

4.5. Groundwater Classification

Piper trilinear plot (Piper, 1944) was used in classifying the groundwater type of the study area. The plot indicates that the Magnesium-calcium chloride water type is dominant water type. This is largely a reflection of dissolution/weathering of amphibole, pyroxene, and biotite in felsic to intermediate silicate rocks as well as olivine plus chlorite dissolution in ultramafic silicate rocks during recharge of fresh water (Walther, 2005). Also, this water type suggests the mixing of freshwater with surface contamination sources such as fertilizers, domestic wastewater and septic tank effluents containing Cl ions.

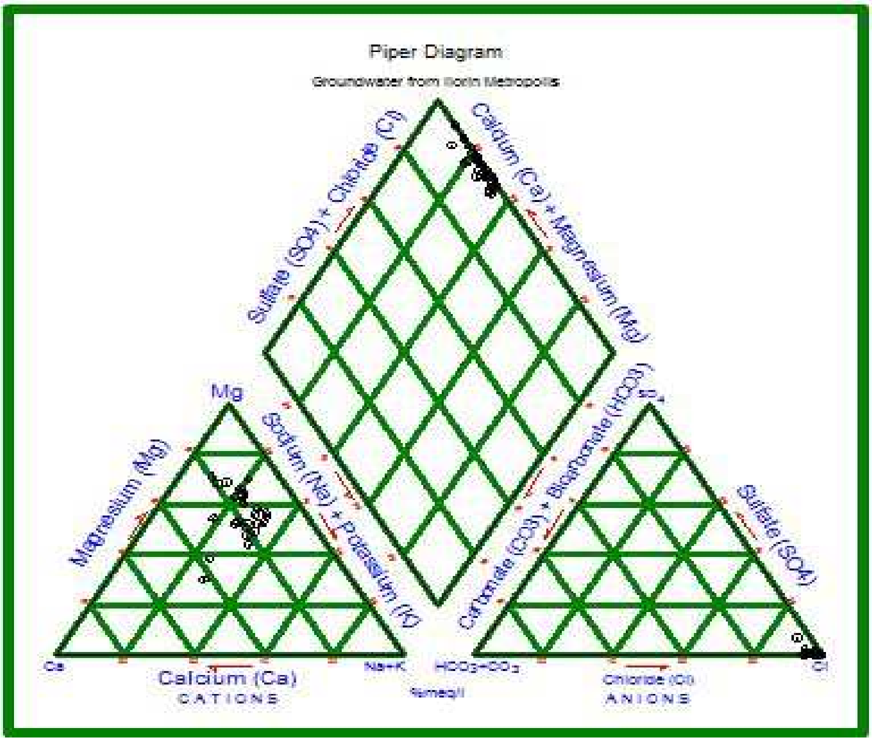


Figure 4. *Piper Trilinear diagram of groundwater in the study area.*

5. Conclusion

Comparing the results of the physio-chemical properties of the groundwater from Ilorin metropolis with the WHO standards for drinking water showed that groundwater in the study area is chemically suitable for drinking when the contents of major cations and anions. However, the relatively high level of chloride ions and some potentially harmful metallic ions such as Cd, Pb and Cr in some locations obviously raises some reservations about the overall quality of the groundwater in the metropolis in view of the possible attendance of health implication of these potentially harmful elements. The water type in the study area suggests mixing of freshwater with surface contaminations containing Cl ions.

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