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Statistical Assessment of Groundwater Quality in Ogbomosho, Southwest Nigeria

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Abstract Groundwater quality in Ogbomosho area of southwest Nigeria was investigated in this study using multivariate statistical analysis. Factor analysis was applied to the Hydrochemical data in order to extract the principal factors responsible for the different Hydrochemical facies. By using Kaiser Normalization, the principal factors were extracted from the data. The analysis reveals six sources of solutes which correspond to six possible sources of groundwater pollution. Five factors (1, 2, 3, 4 and 6) originate from the natural sources while factor 5 is from anthropogenic source. Based on the calculated water quality index, the groundwater in the area falls under poor water and it was attributed to the enrichment of the groundwater with fluoride, major ions and heavy metals. The water type in the area is calcium-bicarbonate type. The efficacy of factor analysis and water quality index in the characterization of groundwater geochemistry in Ogbomosho, southwest Nigeria has been demonstrated in the present study.

Keywords: *statistical assessment, groundwater quality, ogbomosho, southwest Nigeria*

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1. Introduction

Water supply and good sanitation remains a vital component of urban and rural infrastructure. The insufficiency in quality and quantity of water supply remains a challenge in many developing countries. Water supply in many urban and semi-urban area in Nigeria are grossly inadequate and most villagers trek several kilometers in search for water in rural areas. The absence or seasonal nature of surface water sources has shifted attention in the exploration and development of groundwater resources. According to WHO (2006) more than one billion people lack access to good water supply and sanitation globally.

Groundwater forms a major source of drinking water and a crucial part in the maintenance of plant and animal life (Amadi, 2010). It is a vital resource of life but is increasingly being polluted in the wake of modern civilization, industrialization, urbanization and population growth that has led to the degradation of groundwater resources as well as several other anthropogenic activities that are impacting daily on the area (Yisa and Jimoh, 2010). Water being an important component of the ecosystem, any imbalance either in quantity or quality affects the whole ecosystem negatively (Aminu and Amadi, 2014).

Groundwater contains impurities whose nature and amount vary. Metals are introduced in the groundwater system through weathering of rocks and leaching of soils, dissolution of aerosol particles and other human activities such as mining and metal processing. The increase in the use of metal based fertilizer in agricultural revolution of the government could result in continued rise in the concentration of metal pollution in shallow freshwater aquifers due to surface run off and infiltration mechanism (Amadi *et al*., 2014). Studies revealed that 85% of all communicable diseases affecting humans are either water borne or water related (WHO, 2006; Amadi *et al*., 2013). The need to evaluate the quality of groundwater in Ogbomosho and environs for domestic and other purposes gave rise to this study.

2. Material and Methods

2.1. Location and Accessibility

Ogbomosho is situated at 57 km northwest of Oshogbo, capital of Osun State, Southwestern Nigeria. Ogbomosho town lies between longitudes 4°10´E to 4°20´E of the Greenwich Meridian and between latitudes 8°00´N to 8°15´N of the Equator. The area is accessible through Ogbomosho-Ilorin road. Ogbomosho is relatively rugged with undulating topography with elevation ranging between 330 m and 390 m averaging about 360 m above the sea level (Figure 1). The study area falls within a tropical rain forest and is characterized by several hills. The area is well drained by several rivers (Figure 2).

2.2. Geology and Hydrogeology of the Area

The major lithologic units in the area include Migmatite-gneiss, granites and quartzites (Figure 3). The quartzites occur as long elongated ridges trending NW-SE and are mostly massive. The gneisses are the most dominant rock type. They occur as granite-gneiss and banded gneiss with coarsed to medium grained texture. Noticeable minerals include quartz, feldspar and biotite. Structural features exhibited by these rocks are foliation, faults, joints and micro-folds which have implications on groundwater potential. Basement complex rocks are regarded as poor aquifers because of the lack primary porosity and permeability. However, secondary porosity and permeability are imposed on them by fracturing, fissuring, jointing and weathering through which water percolates and migrates.

2.3. Sampling

Sampling stations were selected, taking into account the direction of groundwater flow, direction of prevailing winds and the density of the population within the studied area. Glassware and vessels were treated in 10% (v/v) nitric acid solution for 24 h and were washed with distilled and deionized water. The samples for cation determination were collected in polypropylene containers, labeled and immediately few drops of HNO_3 (ultra-pure grade) to pH < 2 were added to prevent loss of metals, bacterial and fungal growth and then stored in a refrigerator while samples for anion analysis were collected in glass containers. The physical parameters were determined insitu in the field using appropriate instruments. The samples were stored on ice in cooler boxes and transported to the laboratory. A GPS was used to mark and identify the sampling sites and the values obtained were used to generate the digital terrain model of the area (Figure 4).

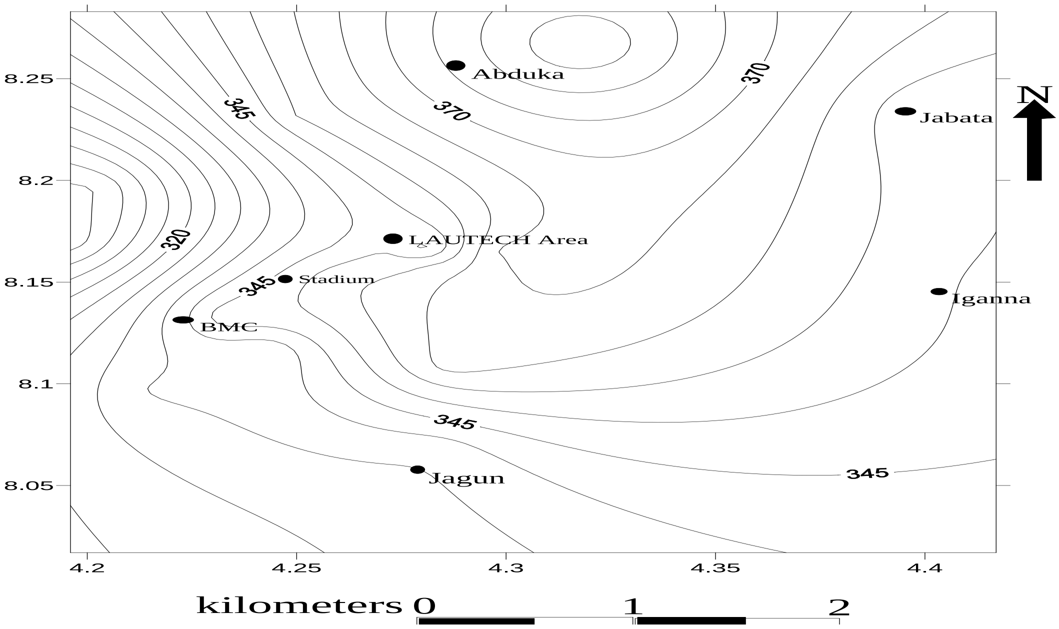

Figure 1. Topo map of the study area

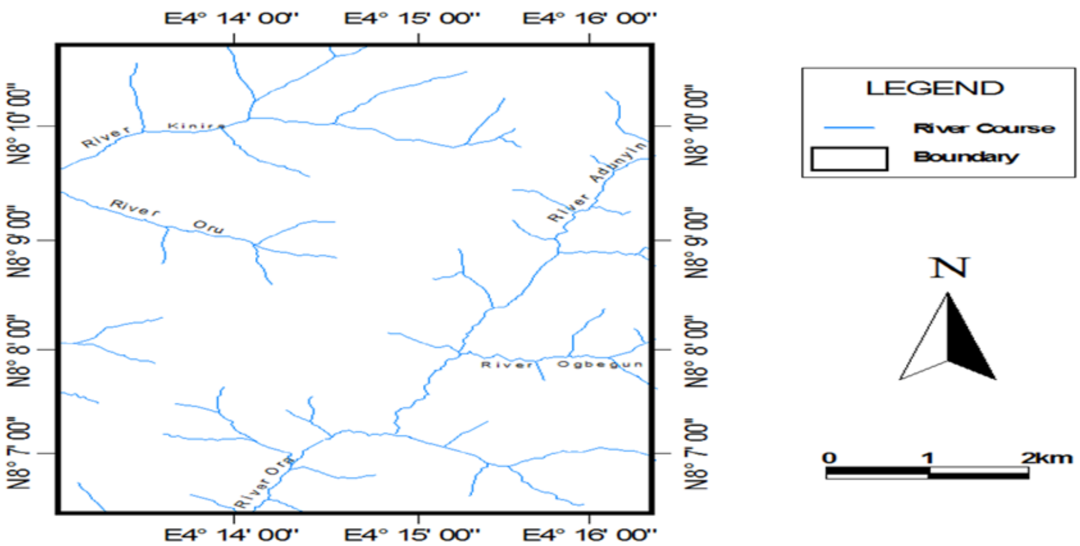

Figure 2. Drainage map of the study area

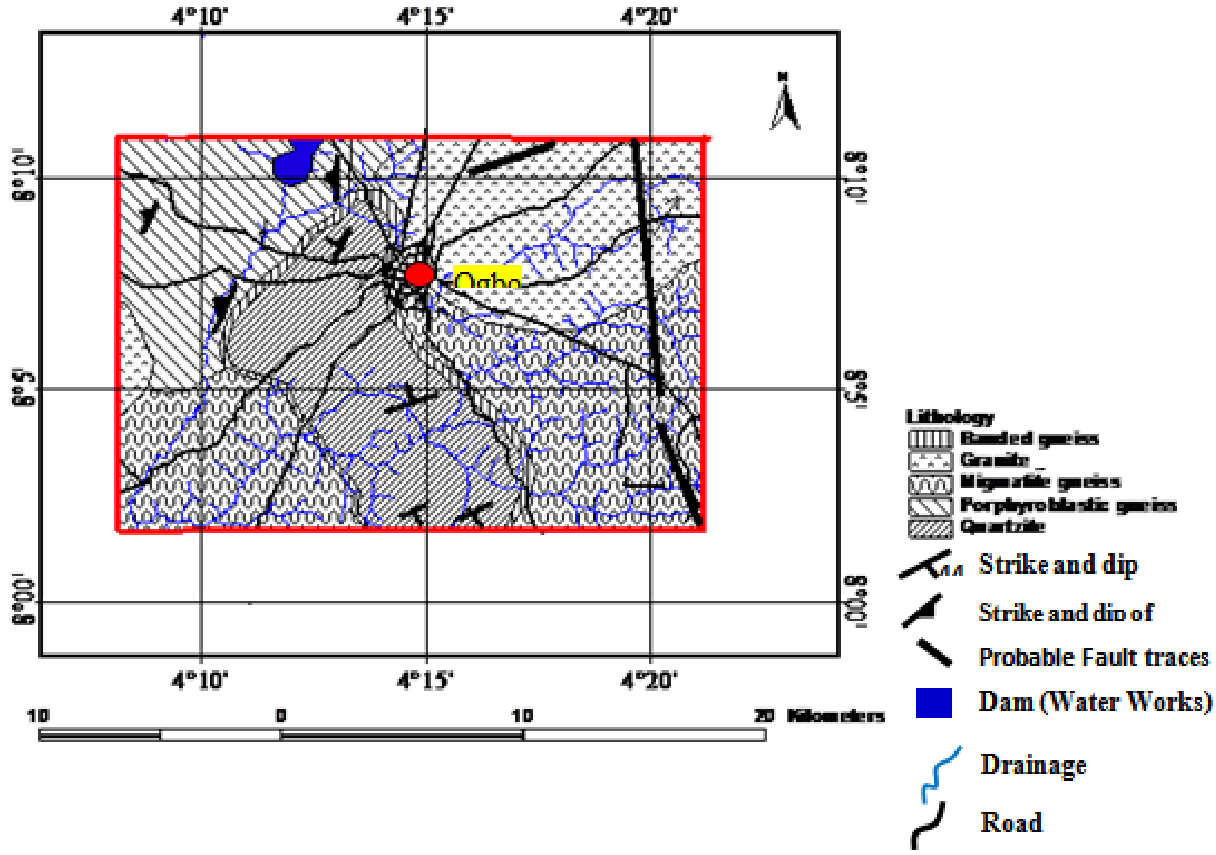

Figure 3. Geology map of the area

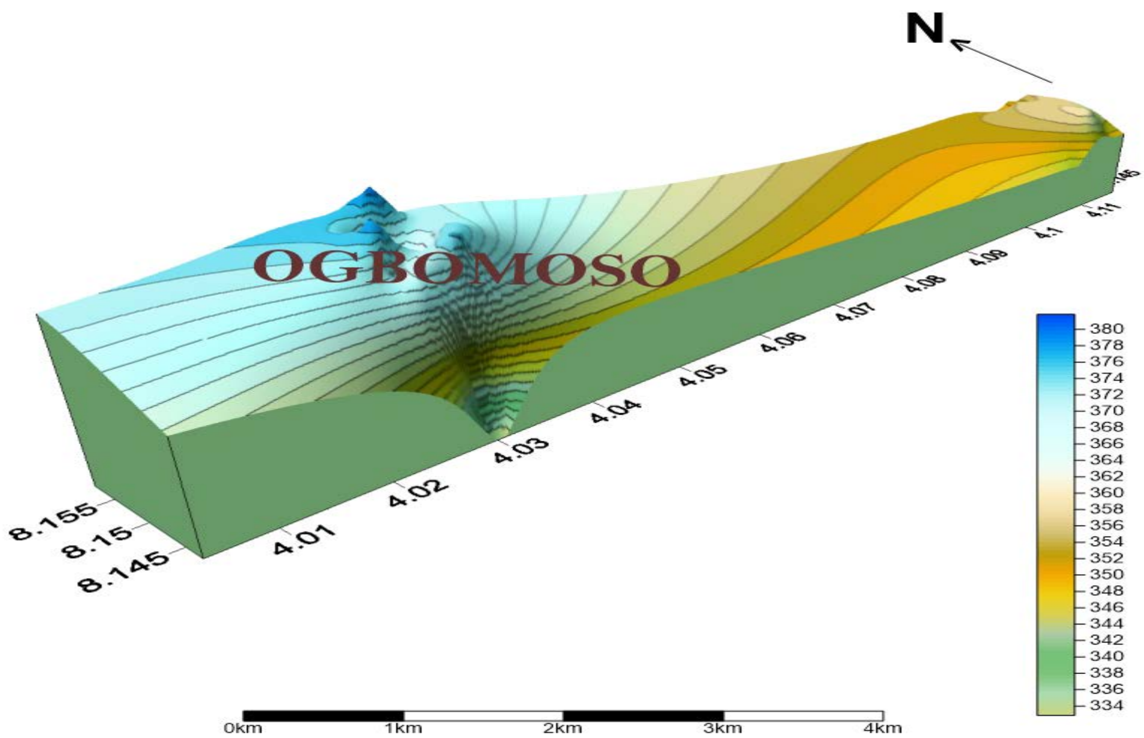

Figure 4. Digital terrain model of Ogbomosho, Southwest Nigeria

2.4. Laboratory Analysis

The method used for the determination of these physico-chemical parameters was described by APHA, 2005). The chemicals and reagent used for the analysis were of analar grade. The pH and conductivity were determined with a consort digital pH meter and consort digital conductometer respectively. JENWAY 6310 spectrophotometer was used to determine calcium and magnesium while JENWAY PFP-7 flame photometer was used for the determination of potassium and sodium. The heavy metals were analyzed using Atomic Absorption

Spectrophotometer, Model Pye Unicam SP-9 Cambridge, UK.

2.5. Statistical Analysis

2.5.1. Factor Analysis

Factor analysis (FA) is a statistical technique that focuses on data reduction in order to identify a small number of factors that explain most of the variables observed in a much larger number of manifest variables (Abdullah and Aris, 2007; Amadi, *et al*., 2010). It attempts to identify new underlying variables or factors that give a better understanding of the pattern of correlation within a set of observed variables (Praus, 2005). Factor analysis is based more on explaining the covariance structure of the variables than with explaining the variances (Lambarkis, *et al.,* 2004). The purpose of factor analysis is to interpret the structure within the variance-covariance matrix of a multivariate data collection. It uses the extraction of the eigenvalues and eigenvectors from the matrix of correlation or covariance. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset (Prasad and Narayana, 2004; Olobaniyi and Owoyemi, 2006). SPSS-window-16 version was the statistical software used to perform factor analysis on the datasets.

2.6. Water Quality Index

Water quality index (WQI) is one of the most efficient and effective means of communicating information about the quality of water to all stakeholders in the water sector. It is a good platform for the assessment and management of water resources. It is a scale used to estimate an overall quality of water based on the values of the water quality parameters (Amadi, 2011). It is a composite rating that reflects the impact of different water quality parameters on a given water resources. WQI is calculated from the point view of the suitability of groundwater for human consumption (Amadi *et al*., 2010).

2.7. Calculation of WQI

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter (*qi*) was calculated by using this equation:

$$qi = \left(Ci / Si\right) \times 100$$

A quality rating scale *(qi)* for each parameter is assigned by dividing the mean concentration *(Ci)* in each water sample by its respective standard *(Si)* and the result multiplied by 100.

Similarly, relative weight *(Wi)* was calculated using the equation:

$$Wi = 1 / Si$$

Thus the relative weight is inversely proportional to the recommended standard *(Si)* of the corresponding parameter. The overall Water Quality Index (WQI) was calculated by aggregating the quality rating *(qi)* with unit weight *(wi)* linearly. Where: qi: the quality of the ith parameter, wi: the unit weight of the ith parameter and n: the number of the parameter considered.

Generally, WQI were discussed for a specific and intended use of water. In this study the WQI for drinking purposes is considered and permissible WQI for the drinking water is taken as 100. The WQI value less than 100 implies that the water is of good quality while values greater than 100 are an indication that the water is poor in quality.

3. Results and Discussion

The statistical summary of the physico-chemical parameters of groundwater samples in Ogbomosho and environs are contained in Table 1. The computed WQI values of the groundwater are shown in Table 2 while the standard water quality classification is summarized in Tables 3. The results of Varimax rotated factor loading on the data are illustrated in Table 4.

Table 1. Statistical summary of the Groundwater physico-chemical parameters analyzed

Parameters	Min.	Max.	Mean	Range	St.Deviation	Variance	Skewness	Kurtosis
Alkalinity	26.00	69.00	44.4429	43.00	15.63350	244.406	0.306	-0.892
Bicarbonae	48.00	84.00	64.0714	36.00	11.89127	141.402	0.382	0.312
Cadmium	0.00	0.01	0.0030	0.01	0.00216	0.000	0.000	-1.200
Calc.Hardness	135.00	604.00	3.3757E2	469.00	177.86124	3.163E4	0.281	-1.451
Calcium	69.00	301.00	1.8143E2	232.00	88.62629	7.855E3	0.046	-1.828
Carbonate	15.30	35.00	22.8857	19.70	6.63486	44.021	1.011	0.793
Chromium	0.01	0.09	0.0457	0.08	0.02992	0.001	0.528	-1.117
Colour	0.08	0.82	0.3243	0.74	0.25967	0.067	1.294	1.473
Conductivity	6.87	1705.00	5.5087E2	1698.13	604.49632	3.654E5	1.234	1.542
Copper	0.10	1.06	0.4171	0.96	0.35617	0.127	1.166	0.433
Fluoride	1.35	2.69	2.1686	1.34	0.46980	0.221	-0.792	0.010
Iron	0.01	0.48	0.2143	0.47	0.16861	0.028	0.496	-0.655
Magnesium	0.11	0.79	0.3586	0.68	0.23227	0.054	1.003	1.127
Manganese	0.00	0.07	0.0256	0.07	0.02789	0.001	1.034	-0.737
Nickel	0.00	0.09	0.0414	0.09	0.03532	0.001	0.344	-1.788
Nitrate	0.00	42.00	26.6714	42.00	14.71255	216.459	-1.088	0.592
Nitrite	0.03	0.17	0.0943	0.14	0.05442	0.003	0.229	-1.672
pH	6.71	7.23	6.9357	0.52	0.20024	0.040	0.835	-0.924
Potassium	0.41	18.51	8.6257	18.10	6.87857	47.315	0.297	-1.503
Sodium	0.14	9.68	2.2086	9.54	3.41371	11.653	2.297	5.473
Sulphate	0.00	60.60	25.4600	60.60	21.38724	457.414	0.668	-0.526
T.Hardness	205.00	920.00	5.2929E2	715.00	273.58345	7.485E4	0.214	-1.663
TDS	81.30	1108.00	4.6116E2	1026.70	350.05770	1.225E5	0.917	1.304
Zinc	0.00	0.81	0.3214	0.81	0.36921	0.136	0.503	-2.283

Table 2. Calculated Water Quality Index for Groundwater in Ogbomosho area

Parameters	Mean (C_i)	NSDWQ (S_i)	C_i/S_i	q_i	W_i	$q_i.w_i$
pH	6.936	6.50-8.50	0.925	92.48	0.133	12.299
Conductivity	675.571	1000.00	0.676	67.557	0.001	0.0676
TDS	461.157	500.00	0.922	92.231	0.002	0.1845
Colour	0.324	15.00	0.022	2.16	0.0667	0.14407
Alkalinity	44.44	200.00	0.222	22.22	0.005	0.1111
Calcium	181.428	200.00	0.907	90.714	0.005	0.4536
Chloride	0.0457	0.30	0.152	15.233	3.33	50.726
Chromium	0.0743	0.05	1.486	148.600	20.00	2972.00
Copper	0.417	1.00	0.417	41.700	1.00	41.700
Fluoride	2.168	1.50	1.445	144.533	0.667	96.4035
Calcium	337.57	200.00	1.688	168.785	0.005	0.8439
Magnesium	0.358	200.00	0.0018	0.179	0.005	0.000895
Iron	0.214	0.30	0.713	71.333	3.33	237.539
Manganese	0.0255	0.20	0.128	12.75	5.00	63.75
Nickel	0.0414	0.02	2.070	207.00	50.00	10350.00
Nitrite	0.0942	0.20	0.471	47.10	5.00	235.50
Potassium	8.625	100.00	0.086	8.625	0.01	0.0863
Sulfate	25.46	100.00	0.255	25.46	0.01	0.2546
Zinc	0.321	3.00	0.107	10.7	0.33	3.531
Carbonate	22.885	250.00	0.0915	9.154	0.004	0.0366
T. Carbonate	64.071	250.00	0.256	25.628	0.004	0.1025
T. Hardness	529.285	500.00	1.059	105.857	0.002	0.2117
Sodium	2.20	200.00	0.0104	1.1035	0.005	0.005578
Cadmium	0.003	0.003	1.00	100	0.01	1.00
Nitrate	26.671	50.00	0.533	53.342	0.02	1.067
					88.945	14068.018

Table 3. Classification of groundwater from the hand-dug wells based on WQI

WQI Value	Category	Water Samples (%)
<50	Excellent	11
50-100	Good water	29
100-200	Poor water	25
200-300	Very poor water	20
>300	Unsuitable for drinking	15

Table 4. Factor loading of the Groundwater data after Varimax rotation

	Factors					
Parameters	1	2	3	4	5	6
pH	.228	.050	.553	.681	.127	.599
Conductivity	.746	.119	-.560	-.022	.292	.176
TDS	.799	-.018	-.195	.081	.523	.209
Colour	-.093	-.163	-.385	.570	.767	-.083
Alkalinity	.822	.451	-.004	-.172	-.154	-.260
Calcium	.807	-.291	.503	.023	.095	.038
Chromium	-.436	-.617	.364	.521	.009	.162
Copper	.418	.616	-.328	.419	.270	.299
Fluoride	-.360	.187	.574	.430	.062	.650
Calc.Hardness	.864	-.170	.425	-.131	-.158	.031
Magnesium	.827	-.057	.319	-.233	-.388	.075
Iron	-.729	.131	.568	.075	.130	.326
Manganese	-.201	-.753	.298	.583	.123	-.236
Nickel	-.432	.100	.726	-.337	.401	.056
Nitrate	.456	.539	.398	-.038	.511	-.283
Nitrite	-.103	.369	.458	-.251	.567	.409
Potassium	.482	.822	.203	.119	.189	.030
Sulphate	.545	-.771	-.407	.158	.127	.044
Zinc	-.577	.788	-.065	-.097	.179	.016
Carbonate	.265	.518	.592	.518	-.206	.001
Bicarbonae	.849	.265	.288	-.093	-.211	-.270
Cadmium	-.362	-.285	.708	-.535	.024	-.018
T.Hardness	.859	-.197	.442	-.119	-.115	.012
Sodium	.234	.758	.071	.600	-.071	-.029

The overall water quality index using the formula:

$$WQI = \frac{\sum qwi}{\sum wi} = 14068.018/88.945 = 158.165$$

corresponding to poor water (Table 3). The following quality parameters (calcium, chromium, copper, fluoride, iron, manganese, nickel and zinc) exceed their respective maximum permissible limit in some locations and may be the reason for the poor quality of the groundwater system in the area. The enrichment of these parameters in the groundwater system led to the observed high conductivity and total dissolved solid.

Factor analysis was applied to dataset and it generated six significant factors (Eigenvalues >1) which explained 87.3% of the variance in datasets and this suggests six different sources of pollution. The first factor consists of calcium, magnesium, sulphate, bicarbonate, alkalinity, total hardness, conductivity and total dissolved solid (Table 4) which accounts for 28.2% of the total variance. The enrichment of these elements in the groundwater system can be attributed to bedrock dissolution, weathering and rock/water interaction processes. Hardness of water is caused by calcium and magnesium ions and can be tied to bedrock geochemistry. The major ions are responsible for the high conductivity and total dissolved solid of the groundwater system.

Factor 2 explains 20.5% of the total variance and it includes potassium, nitrate, copper, zinc, carbonate and sodium and their dominance in groundwater is related to process of aquifer recharge mechanism as well rock/water interaction. Factor 3 has a high loading from pH, calcium, iron, nickel, carbonate, cadmium, fluoride (Table 4) and constitutes 14.6% of the total variance. Iron is one of the most abundant metals in the earth's crust and an essential element in human nutrition. Estimates of minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability. Excessive iron in the body does not present any health hazard, only the turbidity, taste and appearance of the drinking water will usually be affected (Amadi *et al*., 2010).

Factor 4 has a moderate loading 10.9% and comprises of pH, colour, chromium, manganese, carbonate and sodium. Factors 3 and 4 consist of mostly pH, carbonate and heavy metals. The dissolution of the host-rock accounts for the abundance of carbonate and heavy metals in the groundwater system in the area. When compared with the Nigerian Standard for Drinking Water Quality and World Health Organization (NSDWQ, 2007; WHO, 2006) the concentration of heavy metals such as iron, nickel, copper, and cadmium were slightly higher than the recommended maximum permissible limit in some location and is purely due to geogenic influence. Slightly acidic water favours rapid reaction leading to chemical weathering and release of ions into the groundwater system. Factor 5 accounts for 7.8% with TDS nitrate, nitrite and colour. Nitrate pollution of groundwater system is an indication of urban pollution and may be attributed to fertilizer application as well as leachate from dumpsites and soakaways. Factor 6 has a low loading of 5.3% coming from pH and fluoride. The scree plot of the factors is shown in Figure 5.

Fluoride content in groundwater of the area ranged from 1.35 mg/l to 2.69 mg/l with a mean value of 2.16 mg/l (Table 1) and mean value is higher than the maximum permissible limit of 1.5 mg/l (WHO, 2006; NSDWQ, 2007). Fluorite, a hydrothermal mineral in granite and due to its fast dissolution kinetics, is probably the source of fluoride in the groundwater in the area. This implies that fluoride-rich groundwater in the area emanates from the granite aquifers (Figure 3). High concentration of fluoride in ground water causes a disease known fluorosis which affects mainly the teeth and bones (Chidambaram *et al*., 2003, Amadi *et al*., 2013). The outcomes of this investigated is targeted to serves as reference points and baseline information for metallic and fluoride contamination of groundwater system in Ogbomosho area of Southwest Nigeria. These findings suggest that the enrichment factors of the ions on the groundwater are of geogenic mean and related to the local geology of the area. The alkaline pH and high bicarbonate are responsible for release of fluoride-bearing minerals into groundwater (Chae *et al*., 2007).

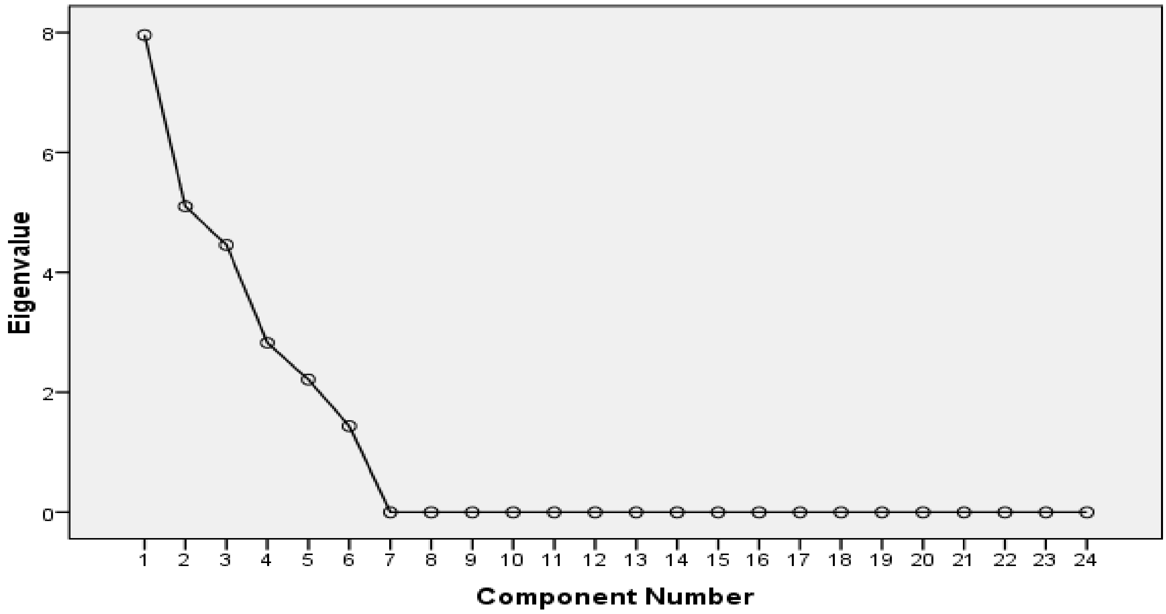

Figure 5. Factor Scree Plot

3.1. Piper and Stiff Diagram

The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3, HCO_3 and SO_4) are represented on the Piper trilinear diagram (Figure 6) by grouping the (K^+ with Na^+) and the (CO_3 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 concentration. The degree of mixing between waters can also be shown on the piper diagram (Figure 5). The Piper diagram is used to classify the hydrochemical facies of the water samples according to their dominant ions. The water in the area is Calcium-Bicarbonate type and it can be attributed to the outcome of the rock/water interaction in the area. This is a reflection of the wide range and high standard deviation and variance observed in the ionic concentration of some parameters in the dataset (Table 1).

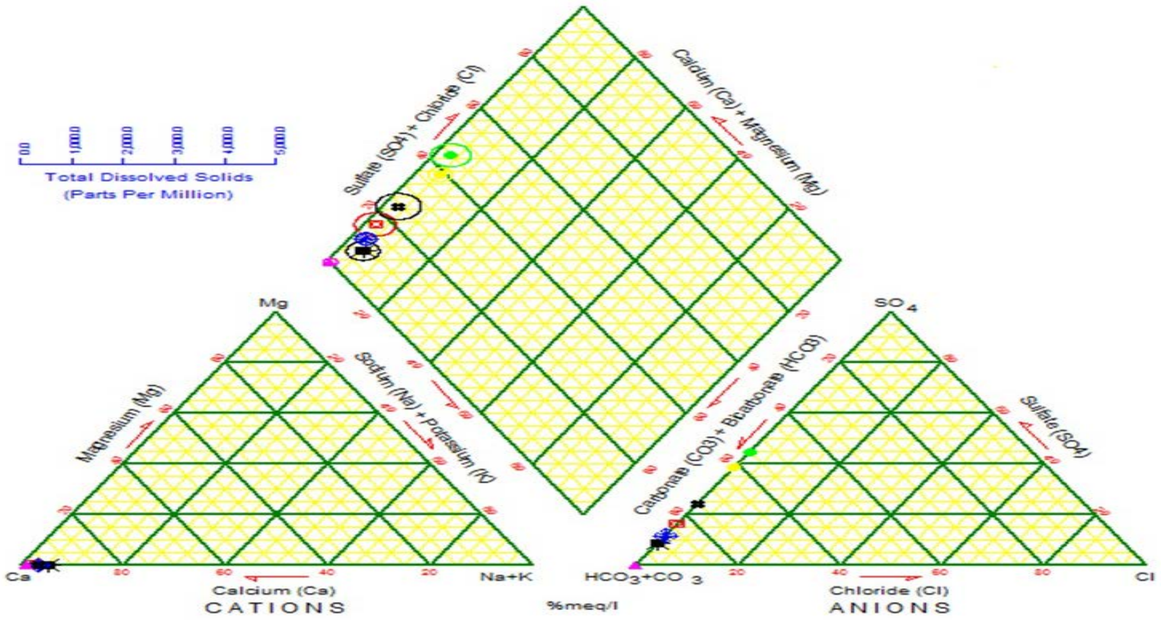

Figure 6. Piper diagram of groundwater in the area

Stiff diagrams are plotted for individual samples as a method of graphically comparing the concentration of major anions and cations for several individual samples (Figure 7). The shape formed by the Stiff diagrams will quickly identify samples that have similar compositions and are particularly useful when used as map symbols to show the geographic location of different water facies.

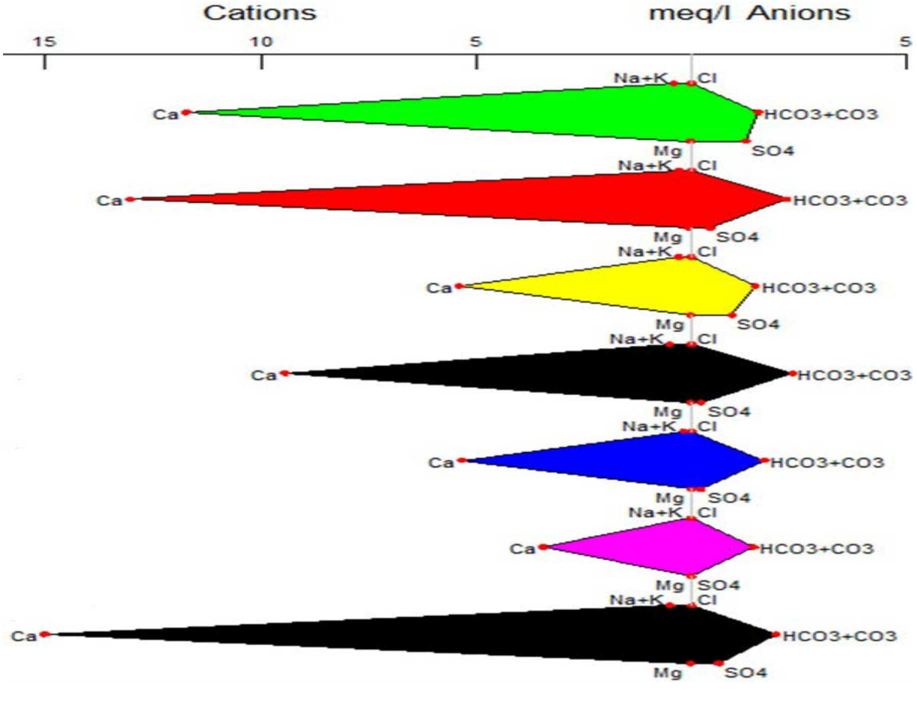

Figure 7. Stiff plots of groundwater in the area

4. Conclusions

The result of the multivariate statistical analysis, as applied to the hydrochemical data set in Ogbomosho, southwest Nigeria, provides an insight into the underlying factors controlling groundwater hydrogeochemical processes. The observed wide range, high standard deviation and variance in some of the parameters are indications that there are substantial differences in the groundwater quality within the study area. The WQI value was 158.16 which classify the groundwater in the area as poor in quality. The high value of WQI obtained was due to the high concentration of fluoride and trace elements in the groundwater and their presence can be attributed to both natural and anthropogenic sources. The dissolution of these elements in water accounts for the observed high conductivity and total dissolved solid. Factors analysis reduces the dataset into six major components representing the different sources of the contamination. Contributors of factors 1 to 4 and 6 are lithogenic/natural phenomenon while factor 4 is anthropogenic in origin. The water in the area is Calcium-Bicarbanate type from Piper and Stiff diagrams. The effectiveness of multivariate statistical analysis in groundwater quality studies have been demonstrated in this study.

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