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# Geo-Statistical Analysis of Hydro-geochemical Parameters of Groundwater in Jebba and Its Environs, Central Nigeria

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## Abstract

The Geo-statistical analysis of the hydrogeochemical evolution of groundwater in Jebba, Nigeria was carried out using Multivariate statistical analysis such as Correlation Analysis (CA), Factor Analysis (FA), Hierarchical Cluster Analysis (HCA) and Principal Components Analysis (PCA) to classify the groundwater and to identify geochemical processes controlling groundwater geochemistry. A total of forty-two groundwater samples (21 samples for cations analysis and 21 samples for anion analysis) were collected. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) technique was used for cation analysis, DR 2010 Spectrometer was used for Sulphate and Nitrate determination while the Total Alkalinity was determined volumetrically. From the result, relative abundance of major cation and anion concentrations are Na>Ca> Mg> K and HCO<sub>3</sub><sup>-</sup>> CO<sub>3</sub><sup>-</sup>>Cl<sup>-</sup>>SO<sub>4</sub><sup>-</sup>>NO<sub>3</sub><sup>-</sup> respectively. Trace elements show an increasing order of Fe>Ba>Al>Mn>Zn>Pb in the hand-dug wells and Fe>Ba>Mn >Al> Zn >Pb in the borehole. Gibbs diagrams show that the source of ions in the groundwater is from rock weathering and little contribution from precipitation. Correlation matrix shows that most of chemical parameters of the groundwater have very high, high and moderate correlations. Factor analysis indicated 5 factors. Factor 1 is a typical characteristic of fresh water and suggests multiple sources of the ions. Factors 2, 3, 4 and 5 typically suggests anthropogenic sources. In summary, the vari-factors obtained from Factor analysis indicated (supporting the Gibbs diagram) that the parameters responsible for groundwater quality variations are mainly related to groundwater-rock interaction (particularly weathering of silicate minerals) and anthropogenic sources. Four clusters generated from cluster analysis show that HCO<sub>3</sub><sup>-</sup> dominates most of the water samples with high concentrations of Ca, Na and Mg ions indicating fresh water type and interpreted as rock-water interaction or natural mineralization.

**Keywords:** Groundwater, correlation analysis, factor analysis, hierarchical cluster analysis and principal components analysis

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## Introduction

The chemistry of groundwater plays a very significant role in evaluating its suitability for domestic, agricultural and industrial purposes. Groundwater quality is being controlled by numerous factors such as soil features, climate, passage of groundwater over rock formations, topography and human activities (Rajesh *et al.*, 2002, Lakshmanan *et al.*, 2003, Cloutier *et al.*, 2008, Prasanna, *et al.* 2010). Multivariate statistical analysis is one of the statistical tools that are useful in hydrogeochemical studies. Across the globe, several researchers have adopted this method in simplifying the understanding of hydrogeochemical data. Steinhorst and Williams (1985) made use of multivariate statistical analysis of water chemistry data in two field studies to delineate the different sources of groundwater. Prasanna, *et al.* (2010) used multivariate statistical analysis of water chemistry data to delineate the source of elemental composition in the groundwater of Gadilam River Basin, South Indian. In their findings, they concluded that Factor analysis showed that dissolution and leaching of secondary salts, weathering and anthropogenic impacts are dominant controlling factors in their area of study. Hence, multivariate analysis was used in this present work to delineate sources of ions in the chemistry of groundwater in Jebba, central Nigeria.

## The Study Area

The study area, Jebba and environs lies between latitude 9° 11' 29" N to 9° 06' 55" N and longitude 4° 48' 24" E to 4° 51' 06" E, covering an area of about 56 km<sup>2</sup> lies within the Nigeria Basement Complex (Figs. 1 and 2.) which covers about 60 % of land area of the country and the study area is also overlain by Cretaceous and Tertiary sedimentary facies. The area consists of a suite of Precambrian rocks, which include-migmatized gneisses, schist, quartzite, amphibolites, and other are non-fractured granite and diorite (Ajibade and Woakes, 1976). The hydrogeology of the study area is greatly influenced by the nature of rocks. The mineral composition and texture of the rock greatly influence the potential of groundwater accumulation. The climate of the study area usually alternates between dry and rainy seasons. The area lies within the middle belt of Nigeria with a total annual rainfall between 1270 mm and 1524 mm which spread over the month of April to October (Mc Curry, 1976). Usually, highest temperatures are recorded in March (35°C) while the lowest temperatures are recorded in August, 25°C (Ajibade, 1982). The vegetation of the area comprises of various species of shrubs and forest most especially along the stream channels and valleys in the area of study.

## Materials and Methods

Forty-two groundwater samples were collected in January 2015 when precipitation is very low from different hand-dug wells and boreholes in the study area (Fig. 2).

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Twenty-One water samples were prepared for cations analyses while the other Twenty-One was prepared for anion analyses. Hand-dug wells in constant use were selected for sampling purposes. During the collection of the samples, field measurements were carried out and parameters such as pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Temperature were determined using pH Meter (HI 98107), TDS Meter (HI 98300), EC Meter (HI 98130) and Thermometer respectively.

The samples were collected in air tight white water bottles with stoppers and prepared for laboratory analysis to see the variations in the quality of the parameters. Water samples for cations analysis were acidified with concentrated nitric acid to prevent the precipitation of the cations from the water and were subjected to laboratory analysis using Inductively Coupled Mass Spectrometric (ICP-MS) technique and this was carried out in ACME laboratory while the water samples for the anions analysis were carried out in the Nigerian Geological Survey Agency, Kaduna.  $\text{HCO}_3^-$  was determined using volumetric analysis and DR 2010 Spectrometer was used to determine the concentrations of  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  respectively. All concentrations were expressed in ppm except pH and EC ( $\mu\text{S}/\text{cm}$ ). Multivariate Statistical analyses were performed to determine the relationship between groundwater parameters using Statistical Software (SPSSv16).

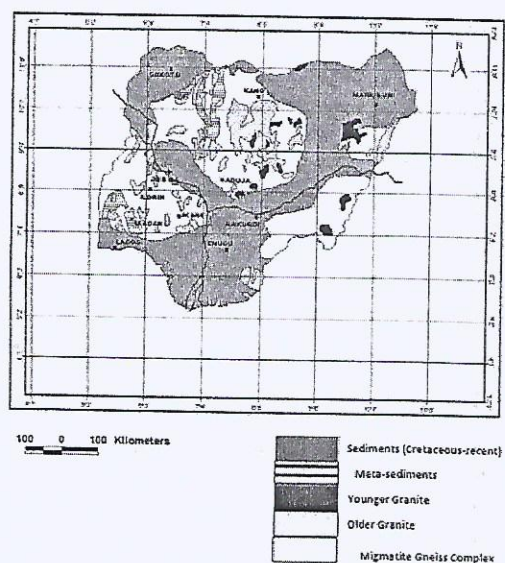


Fig. 1: Generalized geological map of Nigeria (*Geological Survey of Nigeria, 2004*)

Study Area

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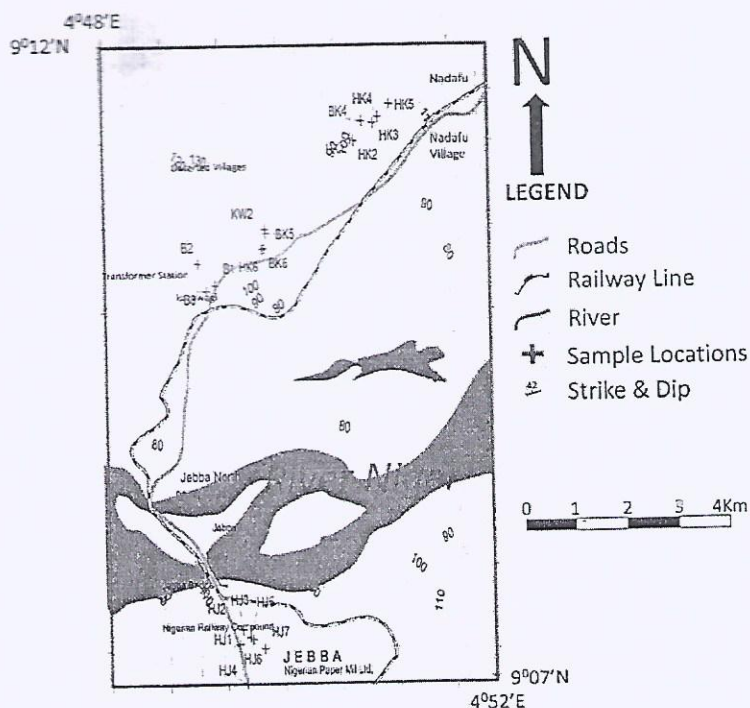


Figure 2: Location map of the study area showing the sampling points

## Results and Discussion

The hydrochemical results of groundwater in the study area (including their descriptive statistics) are presented in Tables 1 and 2 respectively. Profiles of the average concentrations of the ions are presented in Figure 3a-c. The values of EC ranged from 100 to 700  $\mu\text{S}/\text{cm}$  in the boreholes and 100 to 1600  $\mu\text{S}/\text{cm}$  in the hand-dug wells. Similarly, TDS ranged from 40 to 410 ppm in boreholes and 30 to 880 ppm in the Hand-dug wells. The pH ranged from 6.6 to 8.0 in boreholes and 6.0 to 7.8 in the hand-dug wells. The high variability in the EC and TDS of the analyzed water samples in the study area is as a result of the influence of anthropogenic activities on the hand-dug wells. The average pH value of the boreholes indicates that the water is slightly alkaline in nature while that of the hand-dug wells indicate that the water is alkaline in nature. The higher alkalinity of the boreholes is due to more activities of the weathering of rock types on the borehole water.

The average values of  $\text{HCO}_3^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4$ ,  $\text{CO}_3$  and Cl in boreholes and hand-dug wells are: 186.86:140.86 ppm ( $\text{HCO}_3^-$ ); 0.56:7.57 ppm ( $\text{NO}_3^-$ ); 15.71: 25.71 ppm

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(SO<sub>4</sub>); 41.6: 69.00 ppm (CO<sub>3</sub>); and 21.33: 56.86 ppm (Cl) respectively (Fig. 3). Hence, relative abundance of the major anions in the boreholes and hand-dug wells respectively is as follows: HCO<sub>3</sub><sup>-</sup> > CO<sub>3</sub><sup>2-</sup> > Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup>. Higher concentrations of NO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> in the hand-dug wells are an indication of the seepage of sewage and refuse wastes into the groundwater.

The average concentrations of Na, Ca, Mg and K ions in the boreholes and hand-dug wells are: 46.52: 63.1 ppm (Na<sup>+</sup>), 42.9: 53.31 ppm (Ca<sup>2+</sup>), 15.71: 24.24 ppm (Mg<sup>2+</sup>) and 4.48: 12.97 ppm (K<sup>+</sup>) respectively (Fig. 3). The relative abundance of the major ions in borehole and hand-dug wells is Na<sup>+</sup> > Ca<sup>2+</sup> > Mg<sup>2+</sup> > K<sup>+</sup> respectively. The spatial distributions of some of the ions are presented in Figure 4. Relatively higher concentration of Ca<sup>2+</sup> was noticed and recorded in the NW and SE directions of the study area where various agricultural practices were prominent. However, relatively lower values were recorded at the SW direction around the settlement area where we have lesser agricultural practices. Moreover, relatively higher values of Na<sup>+</sup> were recorded in the SE direction where agricultural and municipal activities are very high. Relatively lower values were recorded around the NW/SW axis. The higher concentrations of the major ions in the hand-dug well water are due to the greater influence of anthropogenic activities over the geogenic activities in the study area.

Total Hardness (TH) values ranged from 22.6 to 247.2 mg/l (average=171.8 mg/l) in boreholes and 19.1 to 704.0 mg/l (average=232.9 mg/l) in hand-dug wells. This shows that TH exhibited a very high variance in the groundwater. Hence, it indicates a great variability in the lithostratigraphy of the study area (Tathy *et al.*, 2011). The average values for both boreholes and hand-dug wells indicated that the groundwater is very hard according to Environmental Canadian classification.

The relatively higher concentrations of Fe, Al and Pb ions were observed at the northern part of the study area along Jebba-Mokua main road where there is heavy traffic of trailers and settlements. Consequently, various vehicular activities must have also contributed to the concentration of Pb ions in the groundwater of the area above the geogenic activities (weathering of rock types).

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Table 1: values of the physical parameters and the major anions of the water samples from the study area

| BOREHOLES |            |           |           |      |                        |                       |                       |                       |         |
|-----------|------------|-----------|-----------|------|------------------------|-----------------------|-----------------------|-----------------------|---------|
| Sample ID | Ec (µS/cm) | TDS (ppm) | Temp (°C) | PH   | HCO <sub>3</sub> (ppm) | NO <sub>3</sub> (ppm) | SO <sub>4</sub> (ppm) | CO <sub>3</sub> (ppm) | Cl(ppm) |
| B1        | 700        | 410       | 30        | 8    | 300                    | 0.98                  | 30                    | 80                    | 19      |
| B2        | 700        | 410       | 32        | 7.8  | 292                    | 0.92                  | 26                    | 24                    | 36      |
| B3        | 500        | 310       | 29        | 7.9  | 240                    | 0.80                  | 25                    | 40                    | 19      |
| BK4       | 100        | 40        | 33        | 6.6  | 40                     | 0.21                  | 2                     | 80L                   | 2       |
| BK5       | 300        | 200       | 29        | 7.7  | 224                    | 0.63                  | 10                    | 32                    | 80L     |
| BK6       | 600        | 330       | 29        | 7.7  | 184                    | 0.25                  | 12                    | 32                    | 50      |
| B7        | 300        | 150       | -         | -    | 20                     | 0.034                 | 5                     | -                     | 2       |
| Mean      | 457.14     | 265.71    | 30.33     | 7.62 | 185.86                 | 0.56                  | 15.71                 | 41.60                 | 21.33   |
| Min       | 100.00     | 40.00     | 29.00     | 6.60 | 20.00                  | 0.03                  | 2.00                  | 24.00                 | 2.00    |
| Max       | 700.00     | 410.00    | 33.00     | 8.00 | 300.00                 | 0.98                  | 30.00                 | 80.00                 | 50.00   |
| Median    | 500.00     | 310.00    | 29.50     | 7.75 | 224.00                 | 0.63                  | 12.00                 | 32.00                 | 19.00   |

| HAND-DUG WELLS |            |           |           |      |                        |                       |                       |                       |         |
|----------------|------------|-----------|-----------|------|------------------------|-----------------------|-----------------------|-----------------------|---------|
| Sample ID      | Ec (µS/cm) | TDS (ppm) | Temp (°C) | PH   | HCO <sub>3</sub> (ppm) | NO <sub>3</sub> (ppm) | SO <sub>4</sub> (ppm) | CO <sub>3</sub> (ppm) | Cl(ppm) |
| HJ1            | 100        | 60        | 29        | 7.5  | 68                     | 5.16                  | 15                    | 80L                   | 3       |
| HJ2            | 400        | 240       | 29.5      | 7.4  | 114                    | 6.09                  | 18                    | 80L                   | 24      |
| HJ3            | 300        | 180       | 30        | 7.7  | 144                    | 4.02                  | 16                    | 80L                   | 16      |
| HJ4            | 1100       | 580       | 26        | 7.7  | 376                    | 9.63                  | 48                    | 80                    | 70      |
| HJ5            | 1500       | 820       | 30        | 7.6  | 312                    | 10.11                 | 66                    | 36                    | 129     |
| HJ6            | 1400       | 770       | 32        | 7.7  | 240                    | 8.21                  | 58                    | 48                    | 117     |
| HJ7            | 1500       | 880       | 32        | 7.8  | 420                    | 8.17                  | 102                   | 112                   | 148     |
| HK1            | 400        | 220       | 28        | 6.5  | 40                     | 3.01                  | 2                     | 80L                   | 31      |
| HK2            | 1500       | 810       | 31        | 7.2  | 116                    | 12.93                 | 13                    | 80L                   | 136     |
| HK3            | 100        | 80        | 32        | 6.5  | 36                     | 6.11                  | 2                     | 80L                   | 6       |
| HK4            | 100        | 40        | 34        | 6    | 28                     | 7.75                  | 2                     | 80L                   | 4       |
| HK5            | 100        | 30        | 33        | 6    | 32                     | 7.72                  | 2                     | 80L                   | 1       |
| HK6            | 1000       | 580       | 33        | 7.2  | 36                     | 12.08                 | 8                     | 80L                   | 94      |
| KW2            | 200        | 120       | -         | -    | 10                     | 0.046                 | 8                     | 80L                   | 17      |
| Mean           | 700.00     | 386.43    | 30.73     | 7.14 | 140.85                 | 7.57                  | 25.71                 | 69.00                 | 56.86   |
| Min            | 100.00     | 30.00     | 26.00     | 6.00 | 10.00                  | 0.05                  | 2.00                  | 36.00                 | 1.00    |
| Max            | 1500.00    | 880.00    | 34.00     | 7.80 | 420.00                 | 12.93                 | 102.00                | 112.00                | 148.00  |
| Median         | 400.00     | 230.00    | 31.00     | 7.40 | 91.00                  | 7.88                  | 14.00                 | 64.00                 | 27.50   |

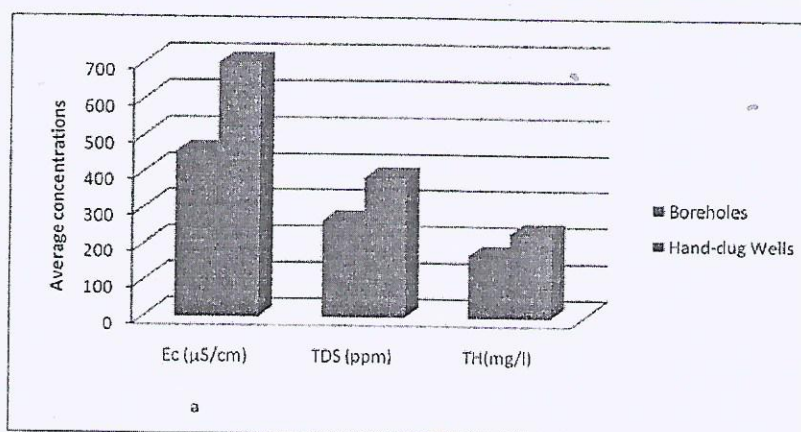
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Table 2: concentrations of the selected cations of the water samples from the study area

| BOREHOLES |         |         |         |         |        |         |         |         |         |         |          |
|-----------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|----------|
| Sample ID | Al(ppm) | Ba(ppm) | Ca(ppm) | Fe(ppm) | K(ppm) | Mg(ppm) | Mn(ppm) | Na(ppm) | Pb(ppm) | Zn(ppm) | TH(mg/l) |
| B1        | 0.014   | 0.13635 | 57.67   | BDL     | 3.24   | 19.16   | 0.08704 | 90.33   | 0.0004  | 0.1009  | 222.8    |
| B2        | 0.01    | 0.27579 | 66.24   | BDL     | 3.94   | 19.89   | 0.26219 | 67.91   | 0.0006  | 0.0091  | 247.2    |
| B3        | 0.015   | 0.22563 | 49.91   | BDL     | 4.46   | 15.67   | 0.01593 | 52.52   | 0.0003  | 0.0854  | 189.1    |
| BK4       | 0.017   | 0.15452 | 6.05    | 0.041   | 7.53   | 1.82    | 0.00638 | 4.19    | 0.0011  | 0.0269  | 22.6     |
| BK5       | 0.009   | 0.39593 | 34.15   | 0.363   | 5.07   | 19.24   | 0.26606 | 30.25   | 0.0002  | 0.0027  | 164.4    |
| BK5       | 0.011   | 0.55576 | 61.65   | BDL     | 2.8    | 20.7    | 0.00921 | 46.85   | 0.0007  | 0.0259  | 239.1    |
| B7        | 0.045   | 0.31103 | 24.63   | 0.538   | 4.23   | 13.46   | 0.26596 | 23.68   | 0.0003  | 0.0067  | 116.9    |
| Mean      | 0.02    | 0.29    | 42.90   | 0.31    | 4.49   | 15.71   | 0.13    | 46.52   | 0.00051 | 0.037   | 171.8    |
| Min       | 0.01    | 0.14    | 6.05    | 0.04    | 2.80   | 1.82    | 0.01    | 4.19    | 0.00020 | 0.003   | 22.6     |
| Max       | 0.05    | 0.56    | 66.24   | 0.54    | 7.53   | 20.70   | 0.27    | 90.33   | 0.0010  | 0.101   | 247.2    |
| Median    | 0.01    | 0.28    | 49.91   | 0.36    | 4.23   | 13.15   | 0.09    | 46.85   | 0.00040 | 0.026   | 189.1    |

| HAND-DUG WELLS |         |         |         |         |        |         |         |         |         |         |          |
|----------------|---------|---------|---------|---------|--------|---------|---------|---------|---------|---------|----------|
| Sample ID      | Al(ppm) | Ba(ppm) | Ca(ppm) | Fe(ppm) | K(ppm) | Mg(ppm) | Mn(ppm) | Na(ppm) | Pb(ppm) | Zn(ppm) | TH(mg/l) |
| HJ1            | 0.073   | 0.06638 | 9.19    | 0.767   | 6.38   | 2.81    | 0.16237 | 10.65   | 0.0038  | 0.0195  | 34.5     |
| HJ2            | 0.019   | 0.16389 | 26.55   | BDL     | 17.89  | 12.01   | 0.00155 | 44.07   | 0.0002  | 0.0035  | 115.7    |
| HJ3            | 0.022   | 0.10246 | 23      | 0.024   | 14.96  | 8.81    | 0.00341 | 32.82   | 0.0003  | 0.0079  | 93.7     |
| HJ4            | 0.031   | 0.1618  | 95.32   | BDL     | 37.35  | 49.76   | 0.07156 | 82.48   | 0.0003  | 0.008   | 442.8    |
| HJ5            | 0.046   | 0.04294 | 152.41  | BDL     | 4.81   | 78.61   | 0.17336 | 84.29   | 0.0005  | 0.0148  | 704.0    |
| HJ6            | 0.035   | 0.19729 | 107.06  | 0.098   | 24.68  | 48.7    | 0.03912 | 121.93  | 0.0018  | 0.4085  | 467.7    |
| HJ7            | 0.025   | 0.03239 | 63.71   | BDL     | 1.69   | 66.38   | 0.02324 | 238.1   | 0.0007  | 0.0095  | 432.2    |
| HK1            | 0.123   | 0.87183 | 29.27   | 0.109   | 9.57   | 10.43   | 0.04404 | 18.37   | 0.0016  | 0.0111  | 116.0    |
| HK2            | 0.022   | 1.05616 | 117.86  | 0.029   | 30.06  | 23.43   | 0.00732 | 131.85  | 0.0006  | 0.0301  | 411.3    |
| HK3            | 0.015   | 0.17589 | 11.92   | 0.017   | 3.52   | 3.25    | 0.00429 | 7.1     | 0.0004  | 0.0071  | 43.1     |
| HK4            | 0.018   | 0.1691  | 6.1     | 0.011   | 4.33   | 1.9     | 0.00536 | 4.14    | 0.0009  | 0.0066  | 23.1     |
| HK5            | 0.036   | 0.11452 | 5.31    | 0.019   | 3.74   | 1.41    | 0.00369 | 2.37    | 0.0008  | 0.0039  | 19.1     |
| HK6            | 0.014   | 1.12863 | 77.28   | BDL     | 16.89  | 20.96   | 0.00521 | 88.8    | 0.0003  | 0.0092  | 279.2    |
| KW2            | 1.222   | 0.45768 | 21.42   | 2.557   | 5.66   | 5.92    | 0.15599 | 21.42   | 0.0043  | 0.0219  | 77.8     |
| Mean           | 0.18    | 0.34    | 53.31   | 0.40    | 12.97  | 24.24   | 0.050   | 63.099  | 0.0012  | 0.0401  | 282.9    |
| Min            | 0.01    | 0.03    | 5.31    | 0.01    | 1.69   | 1.41    | 0.002   | 2.370   | 0.0002  | 0.0035  | 19.1     |
| Max            | 1.22    | 1.13    | 152.41  | 2.56    | 37.35  | 78.61   | 0.173   | 233.100 | 0.0043  | 0.4085  | 704.0    |
| Median         | 0.03    | 0.17    | 27.91   | 0.03    | 7.98   | 11.22   | 0.015   | 33.445  | 0.0007  | 0.0094  | 115.9    |



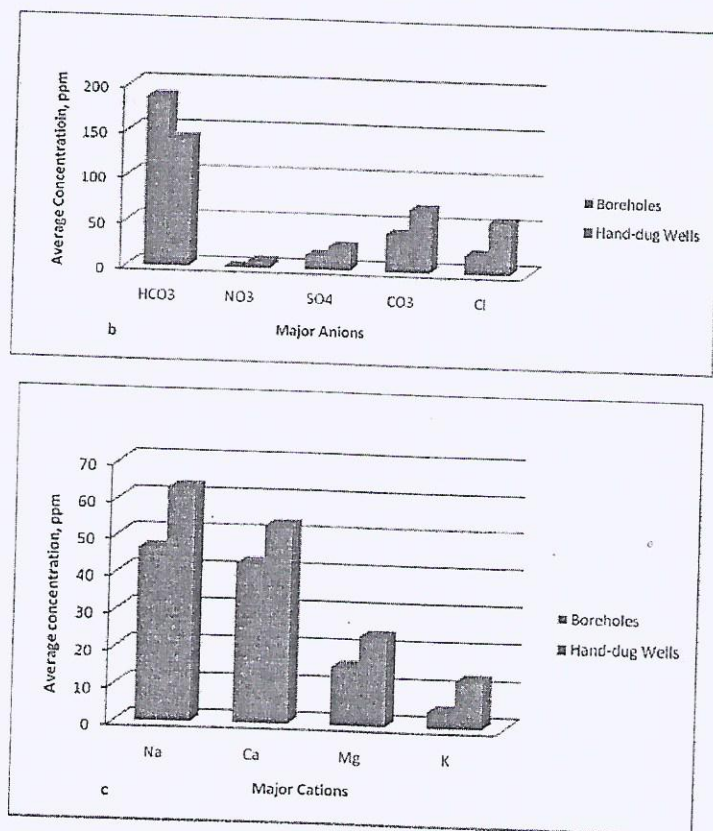
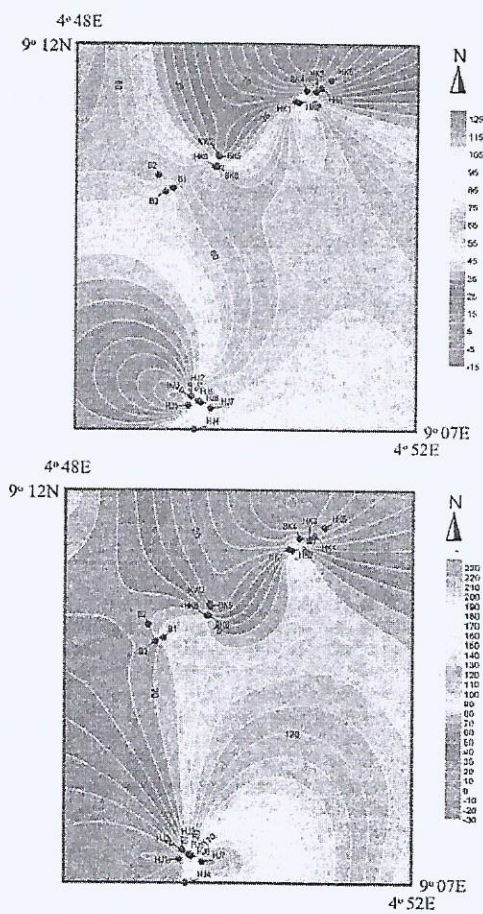
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Figure 3: Profiles of the average concentrations of (a) physicochemical parameters (b) major anions (c) major cations in the groundwater of the study area

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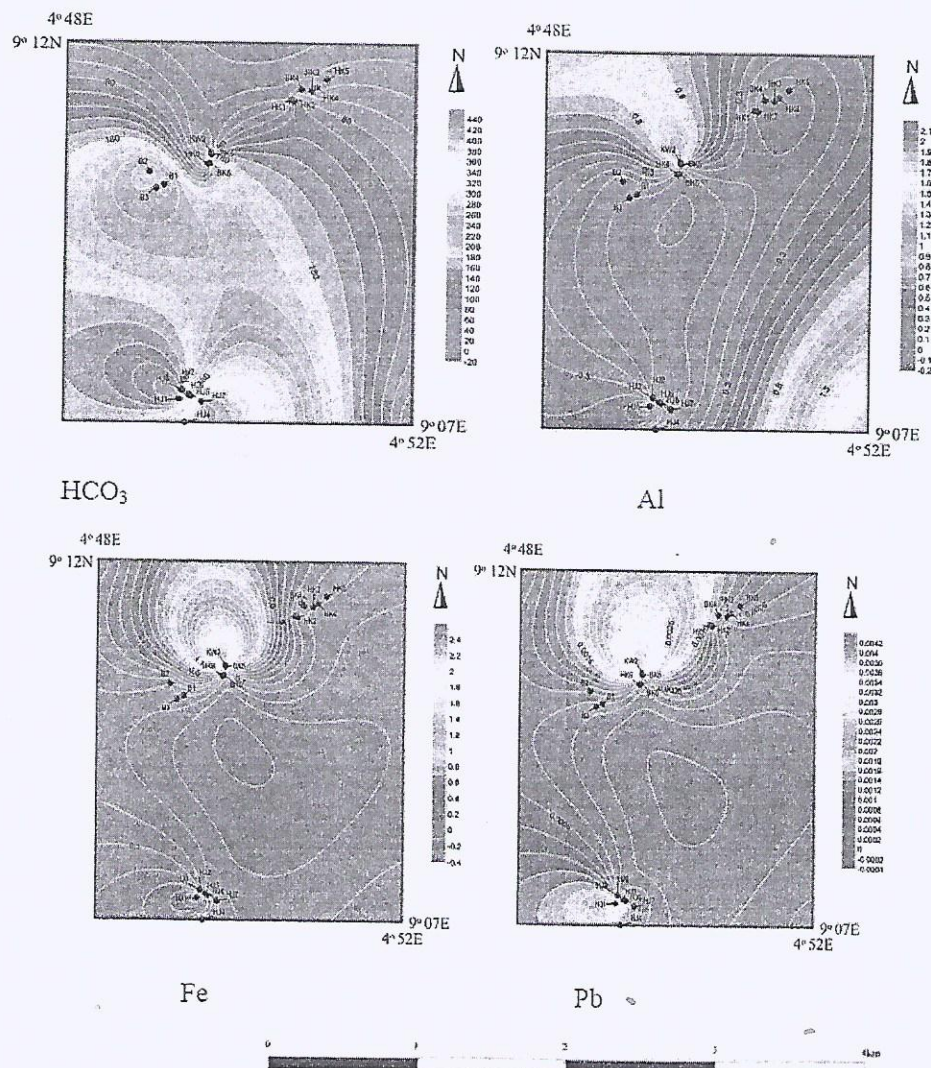


Figure 4: Spatial distribution of some elements ( $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{HCO}_3$ , Al, Fe, Pb)

### Gibbs

The Gibbs's diagram was used to determine some of the main sources of ions in the groundwater. 80% of the ions fall within rock dominance zone of the Gibbs diagram while about 20% fall within precipitation zone. This shows an influence of weathering processes of rock types on the groundwater as well as some

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## Correlation Analysis

Correlation Analysis according to Kura et al, 2013 classification showed that High correlation ( $r = 0.75$ ) exist between Pb and Fe ions (0.798), Pb and Al ions (0.932) as well as Fe and Al ions (0.912), which is contributed to the presence of mixed sulfide minerals in the study area. High correlation is also observed between Na and Cl ions (0.866), Mg and Cl ions (0.850), Ca and Cl ions (0.855) due to the influence of sewage/refuse and dissolution of evaporate. High correlation of 0.777 is observed between Mg and  $\text{HCO}_3$  ions which can be as a result of water-rock interaction. High correlation exists between the following pairs; Ca and Mg ions (0.849), Mg and Na ions (0.729),  $\text{HCO}_3$  and  $\text{CO}_3$  ions (0.903),  $\text{CO}_3$  and  $\text{SO}_4$  ions (0.831) and  $\text{HCO}_3$  and  $\text{SO}_4$  ions (0.839) (Figure 5). This shows that they are from similar sources or somehow related. The correlation matrix is presented in Table 3.

Table 3: Table showing the correlation matrix of the parameters of the water samples in the study Area

|       | Correlation between Variables |       |       |       |       |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
|-------|-------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|---|----|----|----|----|----|----|----|
|       | EC                            | TD S  | pH    | HC O3 | CO 3  | SO 4  | Cl    | NO 3  | Ca    | Mg    | Na | K | Al | Fe | Cu | Pb | Zn | Ba | Mn |
| EC    | 1.000                         |       |       |       |       |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
| TD S  | .998                          | 1.000 |       |       |       |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
| pH    | .436                          | .467  | 1.000 |       |       |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
| HC O3 | .673                          | .685  | .648  | 1.000 |       |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
| CO 3  | .607                          | .613  | .543  | .903  | 1.000 |       |       |       |       |       |    |   |    |    |    |    |    |    |    |
| SO4   | .785                          | .784  | .505  | .839  | .831  | 1.000 |       |       |       |       |    |   |    |    |    |    |    |    |    |
| Cl    | .968                          | .961  | .291  | .526  | .477  | .733  | 1.000 |       |       |       |    |   |    |    |    |    |    |    |    |
| NO 3  | .565                          | .545  | -.320 | .049  | .026  | .286  | .655  | 1.000 |       |       |    |   |    |    |    |    |    |    |    |
| Ca    | .915                          | .915  | .455  | .617  | .457  | .616  | .857  | .487  | 1.000 |       |    |   |    |    |    |    |    |    |    |
| Mg    | .898                          | .893  | .466  | .777  | .703  | .897  | .850  | .431  | .849  | 1.000 |    |   |    |    |    |    |    |    |    |

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|    |          |          |          |      |          |          |          |          |          |          |           |           |          |           |           |           |           |           |           |
|----|----------|----------|----------|------|----------|----------|----------|----------|----------|----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Na | .89<br>9 | .90<br>5 | .49<br>0 | .712 | .73<br>9 | .83<br>8 | .86<br>6 | .40<br>0 | .67<br>3 | .77<br>9 | 1.0<br>00 |           |          |           |           |           |           |           |           |
| K  | .45<br>0 | .43<br>3 | .10<br>8 | .143 | .06<br>2 | .12<br>6 | .42<br>7 | .56<br>4 | .46<br>5 | .27<br>0 | .27<br>3  | 1.0<br>00 |          |           |           |           |           |           |           |
| Al | -        | -        | .07<br>2 | -    | -        | -        | -        | -        | -        | -        | -         | 1.0<br>00 |          |           |           |           |           |           |           |
| Fe | .28<br>6 | .28<br>7 | .11<br>9 | .338 | .23<br>4 | .14<br>2 | .20<br>4 | .21<br>7 | .26<br>8 | .24<br>7 | .24<br>5  | .13<br>6  | .91<br>2 | 1.0<br>00 |           |           |           |           |           |
| Cu | -        | -        | -        | -    | -        | -        | -        | -        | -        | -        | -         | -         | -        | -         | 1.0<br>00 |           |           |           |           |
| Pb | .12<br>1 | .14<br>5 | .36<br>2 | .132 | .21<br>4 | .20<br>3 | .09<br>3 | .12<br>1 | .10<br>3 | .22<br>9 | .14<br>8  | .00<br>0  | .09<br>3 | .13<br>9  | 1.0<br>00 |           |           |           |           |
| Zn | .23<br>4 | .24<br>4 | .05<br>6 | .334 | .22<br>8 | .10<br>3 | .13<br>6 | .13<br>5 | .24<br>2 | .22<br>2 | .21<br>3  | .10<br>6  | .93<br>2 | .79<br>8  | .05<br>3  | 1.0<br>00 |           |           |           |
| Ba | .34<br>9 | .35<br>3 | .23<br>5 | .218 | .26<br>6 | .32<br>0 | .30<br>2 | .05<br>7 | .34<br>0 | .26<br>6 | .29<br>8  | .27<br>9  | .06<br>6 | .05<br>8  | .03<br>5  | .15<br>8  | 1.0<br>00 |           |           |
| Mn | .18<br>7 | .19<br>4 | .11<br>4 | .345 | .33<br>7 | .37<br>5 | .25<br>8 | .31<br>1 | .21<br>9 | .12<br>4 | .07<br>5  | .30<br>1  | .01<br>0 | .05<br>8  | .04<br>2  | .01<br>0  | .10<br>1  | 1.0<br>00 |           |
|    | .06<br>6 | .05<br>2 | .43<br>8 | .152 | .03<br>1 | .02<br>7 | .17<br>5 | .42<br>3 | .07<br>0 | .10<br>5 | .12<br>2  | .26<br>9  | .27<br>9 | .38<br>2  | .08<br>2  | .17<br>2  | .12<br>2  | .12<br>2  | 1.0<br>00 |

### Hierarchical Clustal Analysis

Based on Hierarchical cluster analysis shown in Figure 6 (Danielson et al. 1999 and Davis, 1986) the groundwater samples are classified into 4 clusters. Cluster I which includes 5 water-wells has relatively high concentrations of  $\text{HCO}_3$ , Ca, Na, and Cl ions (HK6, KW2, HK1, HK2 and B7). It has an average EC value 680  $\mu\text{S}/\text{cm}$  and it is interpreted as fresh water which is also influenced by rock-water interaction or natural mineralization. It has high salinity compared to clusters III and IV but lower than cluster II. Cluster II includes 6 water-wells with high concentrations of  $\text{HCO}_3$  and very high concentrations of other ions compared to other clusters. This has shown relatively high salinity and has more of anthropogenic influence. Cluster III (3 water-wells) has lesser salinity as compared to clusters I, II and III. It contains relatively low concentration of  $\text{HCO}_3$ , Ca, Mg and Na in comparison to other clusters. This is also the characteristic of blended water. The cluster is interpreted as having influence of rock weathering processes from the study area with some contributions from anthropogenic sources which is also suggested to results in the low concentrations of the major ions. Cluster IV (7 water-wells) has the

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characteristics of relatively low saline water due to the average EC value (385.7  $\mu\text{S}/\text{cm}$ ). It has a relatively low TDS value of 235.71 mg/l indicating little dissolution of ions in the water. Calcium ion is low compared to cluster I and II. It contains  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ . It is interpreted as rock-water interaction or natural mineralization with little anthropogenic effect. The low concentration of ions in the water is as a result of the low TDS. Detailed average values of chemical constituent for each cluster are presented in Table 4.

Table 4: Average values of chemical constituents for each cluster

| Parameters                     | Cluster I                 | Cluster II                         | Cluster III      | Cluster IV                           |
|--------------------------------|---------------------------|------------------------------------|------------------|--------------------------------------|
| Samples                        | HK6, KW2,<br>HK1, HK2, B7 | HJ5, HJ6,<br>BK6, HJ4,<br>HJ2, HJ7 | HK4, HK5,<br>BK4 | BK5, HJ1, B1,<br>B2, B3, HJ3,<br>HK3 |
| Ec ( $\mu\text{S}/\text{cm}$ ) | 680.00                    | 1,100.00                           | 100.00           | 385.71                               |
| TDS (ppm)                      | 378.00                    | 603.33                             | 36.67            | 235.71                               |
| Temp ( $^{\circ}\text{C}$ )    | 30.67                     | 29.75                              | 33.33            | 30.14                                |
| PH                             | 6.97                      | 7.65                               | 6.20             | 7.59                                 |
| $\text{HCO}_3$ (ppm)           | 44.40                     | 274.33                             | 33.33            | 187.43                               |
| $\text{NO}_3$ (ppm)            | 6.62                      | 7.08                               | 5.23             | 2.67                                 |
| $\text{SO}_4$ (ppm)            | 7.20                      | 50.67                              | 2.00             | 17.71                                |
| $\text{CO}_3$ (ppm)            | BDL                       | 61.60                              | BDL              | 44.00                                |
| Cl (ppm)                       | 56.00                     | 89.67                              | 2.33             | 16.50                                |
| Al (ppm)                       | 0.29                      | 0.03                               | 0.02             | 0.14                                 |
| Ba (ppm)                       | 0.77                      | 0.19                               | 0.15             | 0.20                                 |
| Ca (ppm)                       | 54.09                     | 84.45                              | 5.82             | 36.01                                |
| Fe (ppm)                       | 0.81                      | 0.10                               | 0.02             | 0.29                                 |
| K (ppm)                        | 13.28                     | 14.87                              | 5.25             | 5.94                                 |
| Mg (ppm)                       | 15.84                     | 46.03                              | 1.71             | 12.69                                |
| Mn (ppm)                       | 0.10                      | 0.05                               | 0.005            | 0.11                                 |
| Na (ppm)                       | 56.82                     | 102.12                             | 3.57             | 43.07                                |
| Pb (ppm)                       | 0.001                     | 0.001                              | 0.001            | 0.0009                               |
| Zn (ppm)                       | 0.02                      | 0.08                               | 0.03             | 0.03                                 |

BDL=below detection limit

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## HIERARCHICAL CLUSTER ANALYSIS

Dendrogram using Ward Method

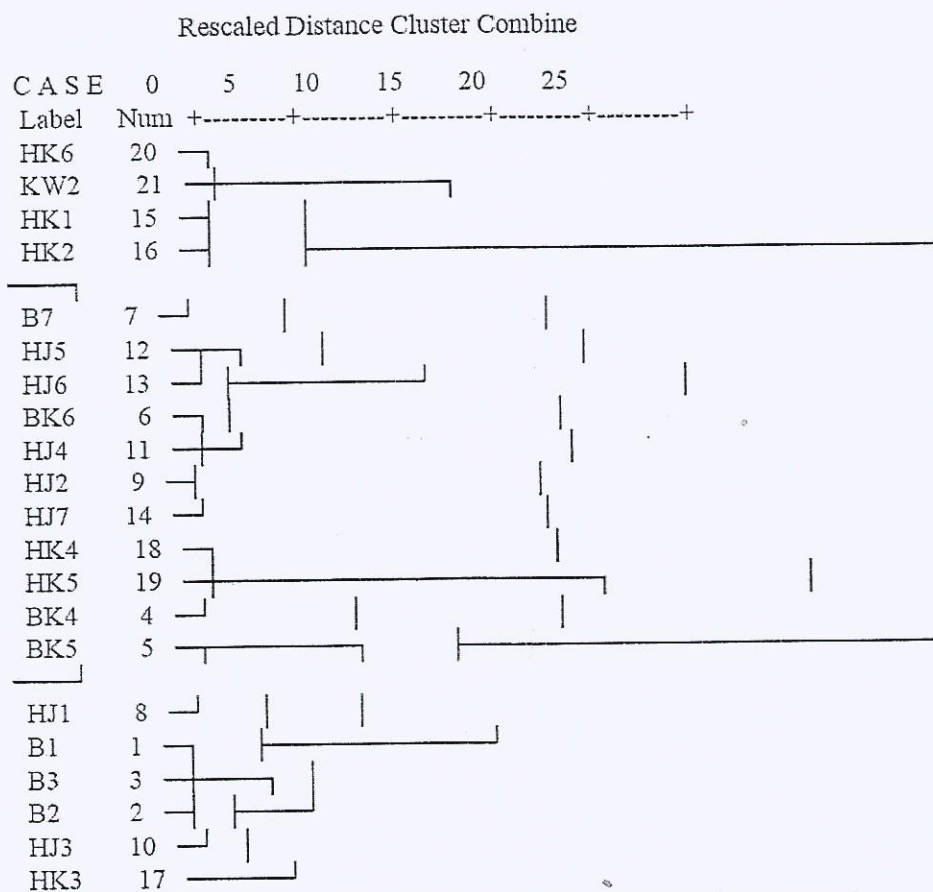


Figure 6: Dendrogram from cluster analysis (Q-mode) of water samples

## Factor Analysis

Table 5 summarizes the sorted Factor analysis results of some of the Hydrochemical data in the study area. Factor analysis extracted five factors. Factor 1 comprises high positive loadings for EC, TDS,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ , and  $\text{Cl}^-$  which accounts for over 41.99% of the total variance in the hydrochemistry. Factor 1 is a typical characteristic of fresh water and therefore suggests multiple sources of the ion in the hydrochemistry in the study area. Factor 2 records high positive correlations with Al, Fe, and Pb. It accounts for over 15.30% of the total variance in the hydrochemistry. Factor 2 typically suggests anthropogenic sources due to the

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high loading of Al, Fe and Pb. Factor 3 has high positive loading for Ba which suggests an anthropogenic source from the study area. It accounts for over 11.04% of the total variance in the hydrochemistry. Factor 4 records high positive loading for pH and Mn. It accounts for over 10.33% of the total variance in the hydrochemistry and suggests anthropogenic sources. Factor 5 has high positive loading for Cu which also suggests anthropogenic sources. It accounts for over 5.90% of the total variance in the hydrochemistry. Factor analysis indicated that the parameters responsible for groundwater quality variations are mainly related to groundwater-rock interaction (particularly weathering of silicate minerals present in the granites), and anthropogenic sources particularly agricultural activities in the study area (Subbarao, *et al.* 1995; and Davis, 1986).

Table 5: Varimax rotated factor loading matrix for groundwater chemistry in Jebba, Nigeria

| Parameters                 | Rotated Component Matrix |        |        |        |        |
|----------------------------|--------------------------|--------|--------|--------|--------|
|                            | Factor                   |        |        |        |        |
|                            | 1                        | 2      | 3      | 4      | 5      |
| EC                         | 0.945                    | -0.132 | 0.259  | -0.051 | 0.066  |
| TDS                        | 0.946                    | -0.138 | 0.259  | -0.022 | 0.051  |
| pH                         | 0.554                    | 0.053  | -0.063 | 0.717  | -0.051 |
| HCO <sub>3</sub>           | 0.796                    | -0.282 | -0.341 | 0.283  | 0.029  |
| CO <sub>3</sub>            | 0.767                    | -0.164 | -0.451 | 0.148  | -0.027 |
| SO <sub>4</sub>            | 0.92                     | -0.011 | -0.355 | -0.016 | -0.018 |
| Cl                         | 0.893                    | -0.039 | 0.319  | -0.212 | 0.034  |
| NO <sub>3</sub>            | 0.447                    | -0.084 | 0.429  | -0.693 | -0.122 |
| Ca                         | 0.832                    | -0.153 | 0.381  | 0.109  | 0.114  |
| Mg                         | 0.939                    | -0.108 | -0.025 | 0.037  | -0.067 |
| Na                         | 0.908                    | -0.106 | 0.018  | -0.052 | -0.007 |
| K                          | 0.359                    | -0.05  | 0.534  | -0.217 | 0.291  |
| Al                         | -0.151                   | 0.96   | -0.019 | 0.111  | -0.085 |
| Fe                         | -0.178                   | 0.891  | 0.044  | 0.269  | -0.115 |
| Cu                         | -0.26                    | -0.132 | 0.008  | -0.084 | 0.707  |
| Pb                         | -0.118                   | 0.956  | -0.04  | -0.031 | 0.15   |
| Zn                         | 0.39                     | 0.142  | -0.43  | -0.011 | 0.646  |
| Ba                         | -0.048                   | 0.006  | 0.891  | -0.044 | -0.119 |
| Mn                         | -0.004                   | 0.2    | -0.006 | 0.813  | -0.131 |
| Eigen value                | 8.346                    | 3.019  | 2.417  | 1.279  | 1.006  |
| Total Variance (%)         | 43.927                   | 15.891 | 12.722 | 6.734  | 5.296  |
| Cumulative (%) of Variance | 43.927                   | 59.817 | 72.54  | 79.273 | 84.57  |

### Principal Component Analysis

Table 6 presents the summary of principal component analysis for the hydrochemical data from the study area. The explained values in principal component, Eigen values and percentage of variance are evaluated using varimax rotation method, represented in Six factors were satisfactory to explain 84.57% of the variance for correlation. The total variances explained in five components are 43.927 by PC1, 15.89 by PC2, 12.72 by PC3, 6.734 by PC4, 5.296 by PC5. PC1 was highly related to EC, TDS, pH, HCO<sub>3</sub>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub>, Ca, Mg, and Na indicating that these variables have common patterns. The high positive loadings of Mg<sup>2+</sup> for the first principal component indicate the source of the weathering of ferro

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-magnesium minerals and related to dissolution of dolomite for  $Mg^{2+}$ . The higher concentrations of TDS observed on the first principal component is related to  $Ca^{2+}$  and  $SO_4^{2-}$  which is an indication of type of rocks especially limestone rocks. Enrichment of  $Na^+$  and  $Cl^-$  is also possible, related to urban wastewaters and high rate of evapo-transpiration.  $Ca^{2+}$  and  $SO_4^{2-}$  highly positive loading suggest the importance of dissolution of carbonate rocks in this aquifer system and is defined as the hardness component. High  $HCO_3^-$  indicate to the reaction of soil  $CO_2$  with the dissolution of silicate minerals. Also, high  $SO_4^{2-}$  is related to the long-history of evaporation process and also the effect of industrial pollution. Loadings on PC2 showed that Al, Fe, Mn and Pb were most important for that component. Highly positive loadings for both  $Fe^{2+}$  and  $Mn^{2+}$  indicate a similar geochemical behavior for these parameters. The sources for these elements could be the dissolution of Fe-oxides and Mn-oxides and the oxidation of sulfide minerals. The source for Al could be the dissolution of organic matter and Pb may be related to anthropogenic activities such as agriculture, industry and/ or settlement in the study area. PC3 has relatively high loading of Ba, Pb, Fe and Al and sources are same as in PC2. Briefly, the results of this study demonstrate that the multivariate statistical analysis can be a useful tool for effective groundwater quality management.

Table 6: Varimax rotated factor loading matrix for groundwater chemistry in Jebba, Nigeria

| Parameters                 | Principal Component |        |        |        |        |
|----------------------------|---------------------|--------|--------|--------|--------|
|                            | Component           |        |        |        |        |
|                            | 1                   | 2      | 3      | 4      | 5      |
| EC                         | 0.967               | -0.041 | 0.209  | -0.043 | 0.044  |
| TDS                        | 0.969               | -0.025 | 0.196  | -0.069 | 0.046  |
| pH                         | 0.509               | 0.612  | -0.151 | -0.352 | 0.223  |
| $HCO_3$                    | 0.812               | 0.288  | -0.407 | 0.028  | 0.035  |
| $CO_3$                     | 0.748               | 0.327  | -0.369 | 0.164  | -0.116 |
| $SO_4$                     | 0.868               | 0.313  | -0.136 | 0.259  | -0.189 |
| Cl                         | 0.899               | -0.109 | 0.347  | 0.023  | -0.05  |
| $NO_3$                     | 0.485               | -0.553 | 0.473  | 0.107  | -0.331 |
| Ca                         | 0.871               | -0.034 | 0.221  | -0.189 | 0.202  |
| Mg                         | 0.929               | 0.156  | 0.004  | -0.003 | -0.106 |
| Na                         | 0.906               | 0.074  | 0.058  | 0.056  | -0.083 |
| K                          | 0.41                | -0.341 | 0.44   | 0.001  | 0.264  |
| Al                         | -0.382              | 0.668  | 0.583  | 0.13   | -0.129 |
| Fe                         | -0.39               | 0.692  | 0.528  | -0.031 | -0.053 |
| Cu                         | -0.19               | -0.257 | -0.054 | 0.377  | 0.587  |
| Pb                         | -0.34               | 0.572  | 0.622  | 0.353  | -0.007 |
| Zn                         | 0.366               | 0.118  | 0.147  | 0.445  | 0.472  |
| Ba                         | 0.009               | -0.389 | 0.6    | -0.533 | 0.125  |
| Mn                         | -0.067              | 0.638  | -0.109 | -0.486 | 0.242  |
| Eigen value                |                     |        |        |        |        |
| Total Variance (%)         | 43.927              | 15.891 | 12.722 | 6.734  | 5.296  |
| Cumulative (%) of Variance | 43.927              | 59.817 | 72.54  | 79.273 | 84.57  |

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## Conclusion

The groundwater sources in Jebba, central Nigeria were evaluated for their chemical compositions. The Geo-statistical analysis of the hydrogeochemical data shows that the relative abundance of major cations and anions in hand-dug wells and boreholes are  $\text{Na}^{2+} > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^{+}$  and  $\text{HCO}_3^{-} > \text{CO}_3^{2-} > \text{Cl}^{-} > \text{SO}_4^{2-} > \text{NO}_3^{-}$  respectively. Based on the computed average values for hardness, the groundwater are considered to be very hard; based on the EC, the boreholes ranged from low salinity to medium salinity while the hand-dug wells ranged from low salinity to high salinity; and based on the TDS, the boreholes are fresh while the hand-dug wells ranged from fresh to slightly saline. Gibbs plot indicates that the chemistry of groundwater in the area is being controlled by chemical weathering of rock types in the area as well as precipitations. Four clusters generated from cluster analysis show that  $\text{HCO}_3^{-}$  dominates most of the water samples with high concentrations of  $\text{Ca}^{2+}$ ,  $\text{Na}^{+}$  and  $\text{Mg}^{2+}$  indicating fresh water type and interpreted as rock-water interaction or natural mineralization. Factor analysis indicated 5 factors. Factor 1 is a typical characteristic of fresh water and suggests multiple sources of the ions. Factors 2, 3, 4 and 5 typically suggests anthropogenic sources. Correlation, Cluster and Principal Component analyses also revealed that anthropogenic and geogenic processes in the area contributed immensely to the ionic concentrations of the groundwater in the area.

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