

## IDENTIFYING PROCESSES OF GROUNDWATER CHEMISTRY IN PARTS OF LAGOS, NIGERIA

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**Abstract:** Forty-five groundwater samples were collected from protected dug wells using a random sampling technique in parts of Lagos, Nigeria. Direct field measurements were recorded for pH, electrical conductivity and total dissolved solids. Fournier equation was employed in determining groundwater hardness. The cations and anions were analysed using standard procedure. The study aimed at identifying the processes of groundwater chemistry in the study area. Statistical techniques such as descriptive, multivariate and graphical method were employed in analysing the data used for this study. Piper's diagram aided the characterization of the groundwater facies composition. The ArcMap software version 10 was employed to generate the map of the study. The result of the correlation shows that there is a significant relationship between *TDS* and major ions at  $p < 0.05$ . The linear regression model reveals that *EC* and *Cl* have a significant linear relationship with *TDS* obtained at 0.999 and 1.000 respectively. The factor analysis accounted for 84.52% of the total variance and indicate two major processes i.e. reverse cation exchange and carbonate mineral weathering controlling the groundwater chemistry of the study area while the sources of groundwater deterioration are linked to salinity and anthropogenic factors. The total cation index and the scatter plot between  $Mg^{2+} + Ca^{2+}$  against  $SO_4^{2-} + HCO_3^{2-}$  revealed that silicate weathering predominate. The Gibbs plot indicates rock-mineral weathering as the process responsible for the groundwater chemistry of the study area. The Revelle index shows that only 4.4% of the samples are strongly affected by salinity. The Piper diagram characterise four water types, namely *Ca-HCO<sub>3</sub>*, *Ca-Cl*, *Mg-HCO<sub>3</sub>* and *Mg-Cl* accounting for 44.4, 31.1, 20 and 4.4 per cent respectively. The paper recommended a robust conceptual model for simulating groundwater in the aquifer system of the study area. Proper monitoring of groundwater abstraction, effective land use planning and handling of industrial effluent before being discharged into the subsurface was also recommended.

**Key words:** Gibbs plot, Groundwater, Groundwater-chemistry, Lagos-Nigeria, Multivariate analysis, Piper's diagram, Scatter plot

### 1. INTRODUCTION

Groundwater is the most reliable source of water that requires little or no treatment due to its quality for various uses compared to surface water. Morris et al., (2003) estimate that, worldwide, about 600 – 700 km<sup>3</sup>/year is drawn each year. The increasing pressure on water resources, especially in groundwater resource due to the rising demand and intensified water quality degradation coupled with over abstraction of groundwater, the use of inefficient irrigation techniques and the proliferation of pollution sources (fertilizers and pesticides, untreated wastewater discharges, uncontrolled solid waste disposal, mining, urbanization, etc.) Have a

significant effect on groundwater availability, quality and sustainability. For example, in most urban areas, the aquifers have become deteriorated and unsuitable for human use due to contamination from both natural and anthropogenic origins.

Despite the importance of groundwater resource, it is exploited haphazardly and indiscriminately by government, private institutions, and individuals without much control, management or organization in Nigeria (FGN, 2004). This act of indiscriminate exploitation of groundwater resource without recourse to expert evaluation has continued to be a source of major concern due to the adverse environmental consequences such as water table decline, land subsidence, and saline intrusion among

others (Longe, 2011; Oteri & Atolagbe 2003). The regulations guiding water resources management in the country seem to be weak and are poorly enforced.

Studies have shown that shallow unconfined aquifers are very susceptible to contamination from surface activities than deep confined aquifers. Therefore, shallow unconfined aquifer systems could serve as open receptors of contaminants, and where surface activities are not regulated, the level of contamination can be high (Yidana et al., 2012). For instance, the effects of seawater due to excessive groundwater withdrawal in coastal countries have serious implication on the hydraulic head below sea level which that aid seawater intrusion (Yidana et al., 2012; Helstrup et al., 2007; Trabelsi et al., 2007; Antonellini et al., 2008; Yidana & Yidana, 2010).

Several methodologies have been widely used to characterize groundwater hydrochemistry. For example, multivariate statistical techniques such as factor and cluster analyses have been widely used and have gained global acceptance as an effective tool in interpreting hydrochemical relationships. Their application has assisted in solving many environmental problems such as the identification of geochemical controls on the composition of water, e.g. aquifer boundaries, groundwater flow paths and hydrochemical parameters. Apart from the understanding of the processes influencing the quality of water in the aquifer system, it aids the ranking of the various processes influencing groundwater hydrochemistry in order of importance or significance (Yidana et al., 2012). Typical examples include; Meng & Maynard (2001); Güler & Thyne (2004); Thyne et al., (2004) and Helstrup et al., (2007). Wang et al., (2001); Locsey & Cox (2003); Sanchez- Martos et al., 2001; and Adams et al., (2001).

Similarly, application of graphical techniques such as tannery, Stiff, Piper, Durov and Gibbs diagram have also been extensively used in groundwater data set to show water classification and trends. These techniques help to enhance the understanding of groundwater flow path, water composition and the water quality in the aquifer (Dalton & Upchurch, 1978). The literature abounds on groundwater hydrochemistry For instance, Jiang et al., (2009) applied multivariate technique in Yunan, China. Yidana et al., (2010) used a similar method to study the sources of the spatial variations and the distribution of groundwater salinity in the Keta basin in Ghana. Helstrup et al., (2007) used principal component analysis and Q-mode to classify groundwater from with varied depths in the Keta Basin in parts of Togo. Howari & Banat (2001) studied the hydrochemical characteristics of Jordan and Yarmouk Rivers. Shankar et al., (2011) assessed

the hydrogeochemistry of the Paravanar River, in Tamilnadu, India. Machado et al., (2008) applied cluster and factor analysis to explain the hydrochemical origin of groundwater in Cariri, Brazil. Banens (1987) examined the geochemical characteristics of upland water in NE South Wales using Cluster analysis. Zaporozec (1972) applied graphical methods show the various arrays of features in groundwater data. Kilham (1990) studied the mechanism controlling the chemical composition of Lakes and Rivers in Africa. Ophori & Toth (1989) studied the pattern of groundwater chemistry in Ross Creek Basin, Alberta, Canada.

The present work aimed at identifying processes in the hydrochemistry of Lagos using factor analysis, regression model and graphical methods.

## 2. THE STUDY AREA

The study site is situated approximately between latitudes 6°25'30"N and 6° 36'0N and longitudes 3°20'0E and 3°34'0E (Akoteyon, 2012; 2013a), The Eastern and Northern parts of the study area are bounded by Ibeju-Lekki and the Lagos Lagoon respectively. The Southern and Western areas are bordered by the Atlantic Ocean and parts of metropolitan Lagos respectively (Fig. 1).

The area is characterized by hot and wet tropical climate. The wet season spans between April to November while the dry season covers the months of December to March (Adepelumi et al., 2009; Akoteyon, 2012; 2013a). The average temperature and mean annual rainfall are reported to be about 27°C and 1,532 mm, respectively (Adepelumi et al., 2009; Akoteyon, 2012; 2013a). The major vegetation in the area comprised of tropical swamp forest (fresh water and mangrove Swamp forests and dry lowland rain forest). The hydrology consists of coastal wetlands, sandy barrier islands, beaches, low tide and estuaries (Adepelumi et al., 2009).

The geology of the study area is underlain by the Benin Basin formation which is characterised by sand with interbedded shales and limestone formation (Longe et al., 1987). Deposit of recent alluvium made up of littoral and lagoonal sediments is found along the coastal area within the formation. The coastal area is characterized by mangrove (saltwater) and freshwater swamps and are vulnerable to saline water intrusion (Nwankwoala, 2011). The major aquifer in the region increase with age from Recent Sediments, Coastal Plains Sands, Ilaro, Ewekoro and Abeokuta Formations to the Basement Complex (Longe et al., 1987). The recent sediments are usually found along the coastal area as alluvial deposits of rivers.

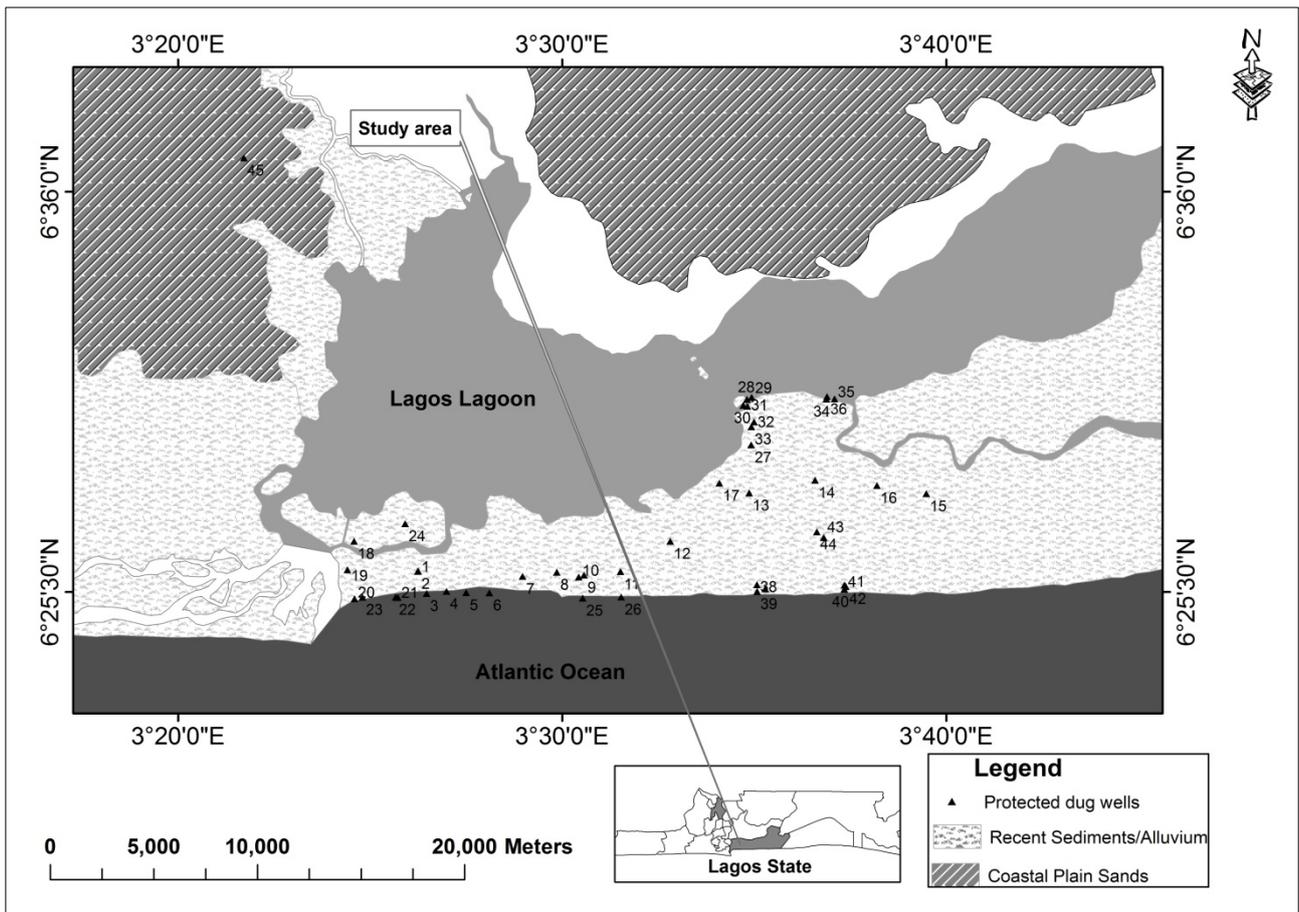


Figure 1. The study area

The geology of the study area is underlain by the Benin Basin formation which is characterised by sand with interbedded shales and limestone formation (Longe et al., 1987). Deposit of recent alluvium made up of littoral and lagoonal sediments is found along the coastal area within the formation. The coastal area is characterized by mangrove (saltwater) and freshwater swamps and are vulnerable to saline water intrusion (Nwankwoala, 2011). The major aquifer in the region increase with age from Recent Sediments, Coastal Plains Sands, Ilaro, Ewekoro and Abeokuta Formations to the Basement Complex (Longe et al., 1987). The recent sediments are usually found along the coastal area as alluvial deposits of rivers. They consist of unconsolidated sands, clays and are characterised by coarse, clayey, unsorted sands with clay lenses and occasional pebble beds. The coastal plains sands (CPS) are also another aquifer in the region, which consists of soft, very poorly sorted, clayey sands, pebbly sands, sandy clays and rare thin lignites (Longe et al., 1987). The CPS aquifer is both unconformable and conformable upon the Ilaro formation. The thickness increases from North to South and can be up to 200 metres (Longe et al., 1987).

Unlike the Abeokuta formation, it consists of

Ise, Afowo and Araromi formations of the Cretaceous age. This aquifer covers the whole width of the outcrop of sedimentary rocks and thickens towards the west and dips down towards the coast. It is more than 280 metres thick at the Benin border, but only 120 metres thick at the eastern edge of the outcrop (Longe et al., 1987). In the northern part of Lagos region, the Abeokuta formation is made up of very thick sands, with high coarse to very coarse grained clean quartz and is confined beneath younger sediments.

The Hydrogeology of the Lagos region shows that the aquifer is divided into four, with the first aquifer being the recent sediments. The upper and lower coastal plain sands are the second and third aquifers respectively, while the fourth is the Abeokuta formation. The major materials found within the recent sediments, coastal plain sands as well as the Abeokuta formation are sand and gravel whereas in the north-south section from Agege to Apapa, the first three aquifers are separated by clay layers (Longe et al., 1987). The cones of depression have piezometric levels close to sea level and have induced small scale and localized reversal of groundwater flow. The recent sediment is a shallow water table aquifer and the water from this aquifer

usually has a higher total dissolved solid (TDS) and conductivity compared to the CPS aquifer. The recent sediment is exploited through shallow hand dug wells. Because of its shallow water table and the porous, permeable sand in the aquifer, it is normally susceptible to sewage, waste disposal and saltwater encroachment. Studies have shown that only a thin layer of fresh water is found in some localities while in other areas, the whole of the water table aquifer is salty (Longe et al., 1987) whereas, in other places, the thickness of the freshwater lenses ranges between 20 to 40 metres.

The variation in the thickness between the first and third CPS aquifer ranged between 200m and 250m, respectively (Adelana et al., 2008). Mean groundwater storage of the first CPS aquifer is estimated at approximately  $2.87 \times 10^3$  m<sup>3</sup> while the water table ranges between 0.4–21m with an annual variation of less than 5m (Asiwaju-Bello & Oladeji, 2001). Longe (2011) reported that the CPS is the principal aquifer in the Lagos metropolis which accounts for more than 30% of groundwater supply to meet domestic, municipal and industrial water demands. It indeed serves as the source of water supply in Lagos state mainly through the mini water Works.

### 3. MATERIALS AND METHODS

A total of 45 randomly selected protected dug wells were used to evaluate the hydrochemical characteristics of the groundwater samples in the study area. Samples were stored in clean 150ml polyethylene bottles and preserved for onward delivery to the chemistry department, University of Lagos, Akoka. A direct method was employed for measuring pH, electrical conductivity and total dissolved solids on the field using pH-102 (RoHS), EC DiST-3 (HANNA, HI 98303) and TDS-3, TDS/TEMP (HM Digital) potable meters respectively as reported by Akoteyon (2013a&b) in a similar study. Appropriate standard buffer solutions were used to calibrate the potable water kits prior to the measurement. The cations (sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), calcium (Ca<sup>2+</sup>), magnesium (Mg<sup>2+</sup>) and anions (chloride (Cl<sup>-</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>), carbonate (CO<sub>3</sub><sup>-</sup>), sulfate (SO<sub>4</sub><sup>2-</sup>) were determined in the laboratory using standard methods after the American Public Health Association (APHA) (APHA, 1998) while the concentration of total hardness (TH) was evaluated using the formula given by Fournier (1981) in equation 1. Calcium was determined using 0.05 N EDTA titration, and chloride by a standard solution of 0.005 N AgNO<sub>3</sub> argentometry titration using potassium chromate as

an indicator. Titration method using standard H<sub>2</sub>SO<sub>4</sub> solution (0.0392 N) was adopted for analyzing bicarbonate and carbonates parameters in the groundwater samples. The atomic absorption spectrometry (AAS) (Hanna, HI 98180) model aided the analysis of magnesium, potassium and sodium while spectrophotometer (HACH, DR/2000) model was employed to determine sulphate. The scattered diagrams and the Gibb's plot were plotted using excel software while RockWare (2006) software was utilized to plot the Piper diagram. The Gibb Ratio (Gibbs, 1970) was calculated using the formula given in equations 2 and 3.

$$\text{Total Hardness (TH) (Fournier, 1981)} = 2.5 \text{ Ca (mg/L)} + 4.1 \text{ Mg (mg/L)} \quad (\text{Eq.1})$$

$$\text{Gibb Ratio I (Gibbs, 1970)} = \frac{Cl}{Cl + HCO_3^-} \quad (\text{Eq.2})$$

$$\text{Gibb Ratio II (Gibbs, 1970)} = \frac{(Na^+ + K^+)}{(Na^+ + K^+ + Ca^{2+})} \quad (\text{Eq.3})$$

Where the concentrations of the ions are in meq/L  
The groundwater salinization was evaluated using Revelle index (1941) as stated in equation 4.

$$\text{Revelle index (Revelle, 1941)} = \frac{rCl}{[rHCO_3^- + rCO_3^{2-}]} \quad (\text{Eq.4})$$

Where *r* is mill equivalents per litre (meq/L)

Revelle index <0.5meq/L is unaffected; 0.5-6.6meq/L is slightly affected while RI > 6.6meq/L is strongly involved.

The data used for this study were analyzed using correlation, factor analysis and regression methods with the aid of SPSS software 17.0 version. The co-ordinates of the sample locations were taken using the global positioning system (GPS) (Garmin map, 76CSX model) and were exported into ArcMap 10 software environment to generate map of the study area. Probable inconsistencies in the analysis of the major ions were examined according to Hounslow (1995). The computation was carried out using the charge balance error (CBE) formula given by Appelo & Postma (2005) as stated in equation 5.

$$\text{CBE (Appelo \& Postma, 2005)} = \frac{\text{Sum of cations} - \text{sum of anions}}{\text{sum of cations} + \text{sum of anions}} \times 100(\%) \quad (\text{Eq.5})$$

The concentrations of the major ions were expressed in meq/L. The calculated CBE as reported by Akoteyon (2013a) shows that nearly 31% of the samples are less than or equal to  $\pm 10.4\%$ . The %CBE ranged between -61.7 and 77.1 with a mean value of 9.6 (Akoteyon, 2013a).

#### 4. RESULTS AND DISCUSSION

The descriptive statistics of the groundwater parameters are presented in table 1. In order to examine the relationships between the groundwater parameters in the study area, a correlation matrix of twelve variables was carried out. The values of electrical conductivity, calcium, magnesium, chloride, sodium, and sulphate shows strong positive correlations ( $r > 0.75$ ) with statistically significant relationship except for bicarbonate and carbonate (Table 2). These values indicate their interdependence on total dissolved solid in the study area. The strong positive correlation found between  $\text{Na}^+$  and  $\text{Cl}^-$  and between  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  implies that most of the groundwater samples originate from a common source.

The scatter diagram of  $\text{Na}^+$  vs  $\text{Ca}^{2+}$  reveals that most of the sample points are below the equiline (Fig. 2). The samples below the equiline indicate silicate weathering. Similarly, the scatter diagram of  $\text{Cl}^-$  vs  $\text{Na}^+$  (Fig.3) show that most of the samples are below the 1:1 equiline suggesting silicate weathering (Datta & Tyagi, 1996; Yakubo et al., 2009).

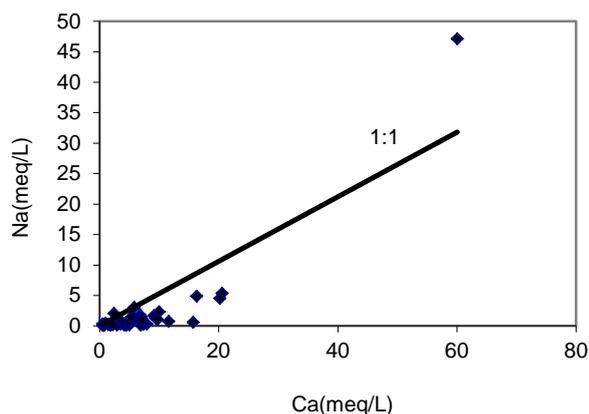


Figure 2. Scatter diagram of Na vs Ca

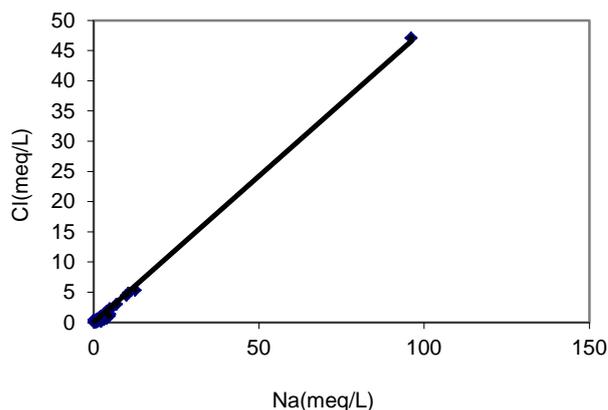


Figure 3. Scatter diagram of Cl vs Na

The contribution of groundwater by silicate weathering was evaluated by plotting the Total cation index against  $(\text{Na}^+ + \text{K}^+)$  (Sarin et al., 1989; Hussein & Mohammed, 2006; Yakubo et al., 2009). The plot suggests that the cations in the groundwater are derived from silicate weathering (Fig. 4).

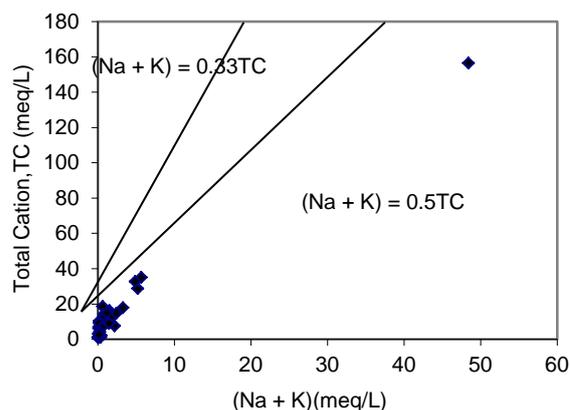


Figure 4. Scatter diagram of (Total cations vs Na+ K)

Table 1: Descriptive Statistics of groundwater parameters

S/N	Parameters	Minimum	Maximum	Mean	Std. Error	Std. Deviation
1	pH	3.40	8.55	6.04	0.13	0.86
2	EC( $\mu\text{Scm}^{-1}$ )	40.0	4040.0	522.70	91.25	612.11
3	TDS	30.0	2436.0	346.91	55.71	373.70
4	$\text{Ca}^{2+}$	12.0	1200.0	147.84	27.77	186.26
5	$\text{Mg}^{2+}$	2.0	580.0	51.14	12.93	86.72
6	Total hardness (TH)	20.6	1786.6	205.58	39.63	265.81
7	$\text{Na}^+$	0.63	1080.1	47.08	23.87	160.15
8	$\text{K}^+$	0.17	52.32	5.20	1.21	8.13
9	$\text{Cl}^-$	6.0	3400.0	169.61	74.90	502.45
10	$\text{HCO}_3^-$	0.0	621.6	123.62	22.55	151.30
11	$\text{CO}_3^-$	0.0	848.0	154.39	28.94	194.12
12	$\text{SO}_4^{2-}$	2.0	1250.0	36.34	27.60	185.12

All parameters are in  $\text{mg/L}^{-1}$  except pH and EC ( $\mu\text{Scm}^{-1}$ )

Table 2. Relationship of groundwater parameters

		pH	EC	TDS	Ca <sup>2+</sup>	Mg <sup>2+</sup>	TH	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
pH	r	1											
	Sig.												
EC	r	0.119	1										
	Sig.	0.438											
TDS	r	0.118	.999**	1									
	Sig.	0.441	0										
Ca <sup>2+</sup>	r	0.07	.949**	.944**	1								
	Sig.	0.65	0	0									
Mg <sup>2+</sup>	r	0.135	.929**	.918**	.880**	1							
	Sig.	0.376	0	0	0								
TH	r	0.093	.968**	.961**	.988**	.943**	1						
	Sig.	0.544	0	0	0	0							
Na <sup>+</sup>	r	0.12	.935**	.917**	.917**	.957**	.954**	1					
	Sig.	0.433	0	0	0	0	0						
K <sup>+</sup>	r	0.154	.957**	.949**	.944**	.928**	.964**	.950**	1				
	Sig.	0.312	0	0	0	0	0	0					
Cl <sup>-</sup>	r	0.103	.940**	.922**	.924**	.960**	.961**	.999**	.955**	1			
	Sig.	0.499	0	0	0	0	0	0	0				
HCO <sub>3</sub> <sup>-</sup>	r	0.282	.365*	.388**	.334*	0.257	.318*	0.18	.352*	0.184	1		
	Sig.	0.061	0.014	0.008	0.025	0.088	0.033	0.237	0.018	0.226			
CO <sub>3</sub> <sup>-</sup>	r	-0.189	-0.006	0.007	-0.032	0.027	-0.014	-0.072	-0.128	-0.06	-.362*	1	
	Sig.	0.214	0.969	0.961	0.835	0.862	0.929	0.639	0.401	0.694	0.015		
SO <sub>4</sub> <sup>2-</sup>	r	0.095	.884**	.861**	.869**	.934**	.914**	.986**	.890**	.983**	0.071	-0.032	1
	Sig.	0.536	0	0	0	0	0	0	0	0	0.645	0.834	

r-correlation, sig.- Significance, \*\* Correlation is significant at 0.01, \* Correlation is significant at 0.05

A scatter plot of (Ca<sup>2+</sup> + Mg<sup>2+</sup>) vs (HCO<sub>3</sub><sup>-</sup> + SO<sub>4</sub><sup>2-</sup>) was used to assess the effects of carbonate and sulphate mineral dissolution in the system. The scatter plot show that most of the sample plot below the equiline suggesting that silicate weathering is the major process taking place in the study area as noted earlier (Fig. 5).

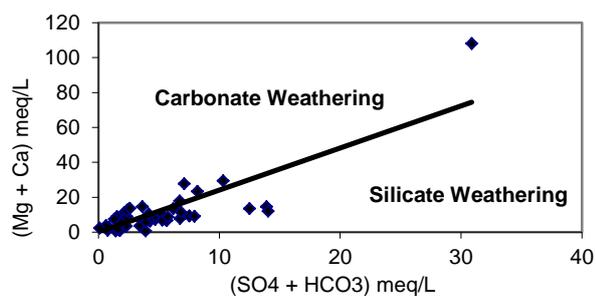


Figure 5. Scatter diagram of (Ca + Mg) vs (HCO<sub>3</sub> + SO<sub>4</sub>)

In order to determine the main process controlling the hydrochemistry of the groundwater in the study area, the Gibb's ratio was calculated for both the cations and anions of the groundwater samples. The Gibbs plot for both the cations and anions points to rock weathering as the main process controlling the groundwater chemistry of the study area (Figs. 6 and 7). The results conform with the findings of Yakubo et al., (2009); Prasanna et al., (2008); Yidana et al., (2012).

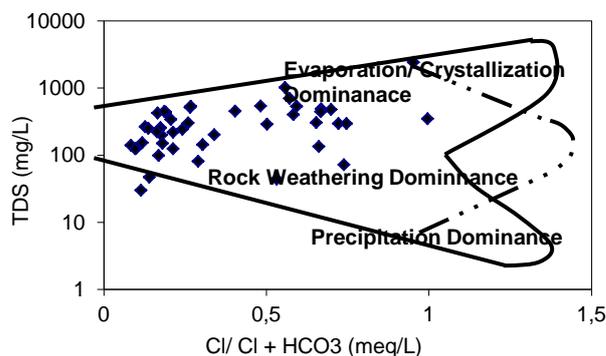


Figure 6. Gibbs diagram of the anions in groundwater chemistry

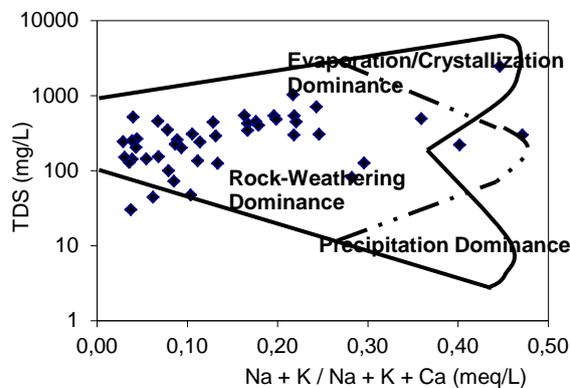


Figure 7. Gibbs diagram of the cations in groundwater chemistry

The result of the Revelle index shows that approximately 57.8% of the samples are unaffected by salinity while 37.8% and 4.4% are slightly and strongly affected by salinity in the study area.

#### 4.1 Factor analysis

Table 3 (a and b) shows the total variance explained and the rotated component matrix respectively for the examined groundwater parameters. The final factor model extracted two statistically significant factors which accounted for 84.52% of the total variance in the data set (Table 3a). The result of the factor I accounted for 70.76% of the total variance. It shows the strong positive loading on  $\text{Cl}^-$ , TH,  $\text{Na}^+$ , EC,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  TDS,  $\text{Ca}^{2+}$ , and  $\text{SO}_4^{2-}$ . A similar result has been reported by Akoteyon (2013b). It is observed that, the  $\text{Cl}^-$  ion has the highest loading with factor 1 and was identified

as the key and a representative parameter in the groundwater of the study area (Table 3b).

The high loading of chloride, electrical conductivity, total dissolved solids, sodium and sulphate under factor 1 indicate salinization in the groundwater of the study area. This result supports the findings of Akoteyon, 2013a & Lu et al., 2012; Hussein & Mohammed, 2006. Also, it is inferred that, the total hardness parameter in the groundwater of the study area is influenced by  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  as revealed by their highest positive loading. Factor 1 can be interpreted as a reverse cation exchange as indicated by the Ca-Cl facies in the groundwater composition (Akpah et al., 2013). Similarly, the loadings of  $\text{Cl}^-$  and  $\text{Na}^+$  under factor 1 are compatible and suggest a similar source for them (Yidana et al., 2012). This factor represents the major important process in the hydrochemistry of groundwater in the study area.

Table 3 (a). Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.627	71.894	71.894	8.627	71.894	71.894	8.491	70.762	70.762
2	1.514	12.621	84.515	1.514	12.621	84.515	1.650	13.753	84.515
3	.828	6.896	91.411						
4	.722	6.015	97.427						
5	.145	1.207	98.634						
6	.079	.655	99.289						
7	.050	.419	99.707						
8	.032	.268	99.976						
9	.002	.016	99.992						
10	.001	.006	99.998						
11	.000	.002	100.000						
12	1.220E-16	1.016E-15	100.000						

Extraction Method: Principal Component Analysis.

Table 3(b): Rotated Component Matrix

Parameters	F1	F2
pH	0.056	0.620
EC	0.971	0.135
TDS	0.960	0.143
$\text{Ca}^{2+}$	0.955	0.114
$\text{Mg}^{2+}$	0.964	0.060
TH	0.984	0.100
$\text{Na}^+$	0.981	0.058
$\text{K}^+$	0.960	0.201
$\text{Cl}^-$	0.985	0.049
$\text{HCO}_3^-$	0.214	0.783
$\text{CO}_3^-$	0.044	-0.735
$\text{SO}_4^{2-}$	0.955	-0.030

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization

a. Rotation converged in 3 iterations.

Factor II explains approximately 13.75% of the total variance and are characterized by positive loading of HCO<sub>3</sub> and pH while the loading on CO<sub>3</sub><sup>2-</sup> is negative. This finding has been reported by Akoteyon (2013b). The loading of HCO<sub>3</sub> and pH under factor II represents the effects of carbonate mineral weathering in the hydrochemistry of groundwater of the study area (Yidana et al., 2012). This is the second process in the hydrochemistry of groundwater in the study area. Therefore, the factor analysis employed successfully identified the major source/process controlling the groundwater of the study area.

#### 4.2. Evaluation of the regression model

The R square value of the overall model 1 explains 99.7 percent of the variance while model 2 explains 99.9 percent (Table 4). The overall value of the R square change is 0.2. This implies that, EC and Cl explain an additional 0.2 percent of the variance. This is a statistically significant contribution as indicated by the Sig. F change value (Table 4). The ANOVA (Table 5) shows that the model as a whole which includes both variables is significant [F (2, 42)

= 27546.75, p < .0005].

#### 4.3. Evaluation of each of the independent variables

The contribution of each of the independent variables to the final equation is shown in Table 6. The result shows that, the two variables make a statistically significant contribution (less than 0.5). They are EC (beta = 1.13) and Cl (beta -0.14).

#### 4.4. Groundwater composition

The groundwater composition of the study area was characterized using trilinear diagram shown in figure 8. The plot indicates that the Ca-HCO<sub>3</sub> accounts for the highest proportion representing 44.4% of the groundwater samples. The Ca-Cl, Mg-HCO<sub>3</sub> and Mg-Cl account for 31.1, 20 and 4.4 per cent respectively in the study area. The Ca-Cl type is characterized by permanent hardness and delineated as Type I (Tay & Kortatsi, 2007). The Ca-HCO<sub>3</sub> water type occupied the part of the diamond shape designated as Type II.

Table 4. Model Summary of the Variables

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.999 <sup>a</sup>	.997	.997	20.4857	.997	14598.839	1	43	.000
2	1.000 <sup>b</sup>	.999	.999	10.5568	.002	119.921	1	42	.000

a. Predictors: (Constant), EC; b. Predictors: (Constant), EC, Cl

Table 5. ANOVA of the Variables

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6126590.134	1	6126590.134	14598.84	.000 <sup>a</sup>
	Residual	18045.502	43	419.66		
	Total	6144635.636	44			
2	Regression	6139954.90	2	3069977.45	27546.75	.000 <sup>b</sup>
	Residual	4680.746	42	111.44		
	Total	6144635.64	44			

a. Predictors: (Constant), EC; b. Predictors: (Constant), EC, Cl; c. Dependent Variable: TDS(mg/L)

Table 6. Coefficients of Variables

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	28.261	4.035		7.004	.000	20.124	36.399
	EC	.610	.005	.999	120.826	.000	.599	.620
2	(Constant)	4.592	2.999		1.531	.133	-1.460	10.645
	EC	.688	.008	1.127	90.534	.000	.672	.703
	Cl	-.101	.009	-.136	-10.951	.000	-.120	-.083

a. Dependent Variable: TDS(mg/L<sup>-1</sup>)

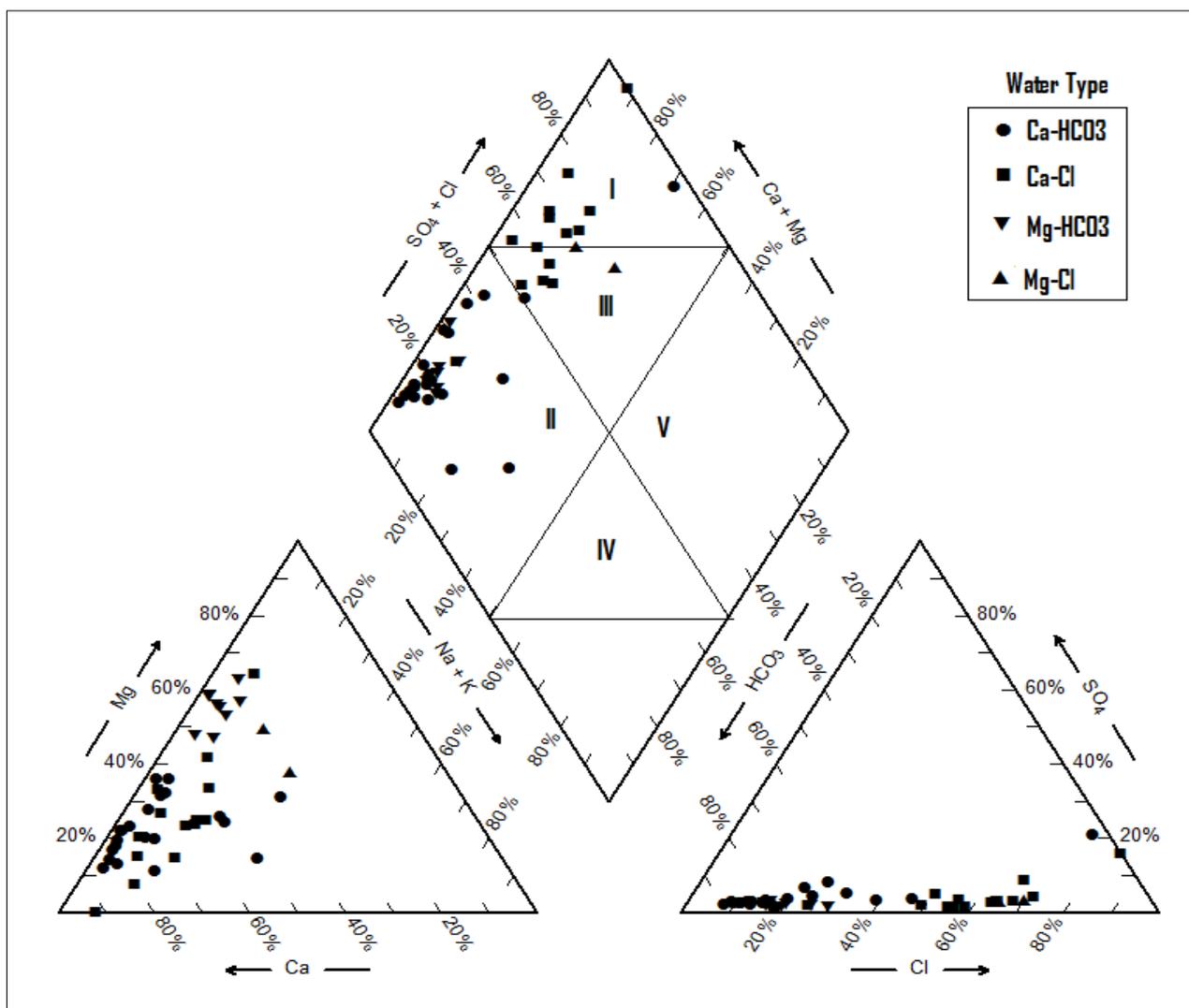


Figure 8. Piper plot of groundwater composition

Likewise, in this group is  $Mg-HCO_3$  and is characterized by temporary hardness (Tay & Kortatsi, 2007). The  $Mg-Cl$  occupies the section designated as III. The observed dominance of  $Ca-HCO_3$  water type indicates that the groundwater of the study area is the fresh water of inland origin due to the enrichment of Ca and  $HCO_3$  ions. This is in contrast to the  $Mg-Cl$  which reflects sea water influence. This finding is in accordance with the result of Tripathy & Sahu (2005).

## 5. CONCLUSIONS

A methodology has been developed for better understanding of the processes controlling the groundwater chemistry in parts of Lagos-Nigeria. The method is grounded in the combined use of factor analysis, regression analysis and graphical techniques. The findings of this study revealed that, significant relationships were established between *TDS* and most of the major ions. The factor analysis

employed revealed that, the groundwater chemistry of the study area is controlled by two major processes i.e. reverse cation exchange and carbonate mineral weathering while the sources of groundwater deterioration are linked to salinity and anthropogenic factors. The regression models revealed the influence of electrical conductivity and chloride on the extent of salinity of the groundwater chemistry in the study area. The total cation index, the scatter plots and the Gibbs diagram suggest silicate weathering/ rock-mineral weathering process responsible for the groundwater chemistry for the study area. The computed Revelle index indicates that only 4.4% of the samples are strongly affected by salinity in the study area while the Piper's diagram characterized four water types, namely  $Ca-HCO_3$ ,  $Ca-Cl$ ,  $Mg-HCO_3$  and  $Mg-Cl$ . The groundwater composition revealed that close to 44.4% and 31.1% of the samples are classified as temporary and permanent hardness respectively. The study recommended a robust simulation of

groundwater in the aquifer system of the study area.

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