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MULTIVARIATE ANALYSIS OF GROUNDWATER QUALITY IN PARTS OF LAGOS-NIGERIA

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ABSTRACT

The quality of twenty-six groundwater sources in Lagos state was evaluated. Data on physico-chemical parameters (Hydrogen ion, Electrical Conductivity, Total Dissolve Solids, Calcium, Chloride, Total Hardness, Magnesium, Sodium, Potassium, Bicarbonate and Sulfate) were collated from the database of Lagos Water Corporation. The result shows that all the parameters are within the maximum permissible limit of WHO, while Mg and HCO_3 exceeded the SON limit of 0.2 and 3.0mg/L, respectively, for drinking water. The co-efficient of variation shows that all the groundwater parameters examined are highly variable except pH (10.92%).The factor analysis employed indicates that of the two Factors I and II, Factor I, which explains 62.73% of the total variance, has a strong positive loading on EC, TDS, TH, Na, Cl, Ca, K and SO_4 . Factor II explains 17.43% of the total variance and has a strong positive loading on pH and HCO_3. The computed WQI value ranges from 1.41 to 261.48. The high value of WQI at these sampling locations has been found to be mainly from the higher values of TH, pH, TDS, Cl and Ca in the study area. The study demonstrates the effectiveness of factor analysis and water quality index in evaluating the hydrochemical processes of groundwater and the determination of the suitability of groundwater for drinking purpose, respectively, in the study area.

KEYWORDS: Groundwater; Lagos; Water quality; water quality index; Multivariate technique;

INTRODUCTION

Groundwater usage has increased significantly in the last decades due to its widespread occurrence and overall good quality. It, therefore, constitutes an important source of water for drinking, agriculture and industrial production with about two billion people directly depending on aquifers for drinking water, and 40 percent of the world's food being produced through irrigated agriculture that relies largely on groundwater (Morris et al., 2003).

Despite its importance, contamination from natural, human activities, steady increase in per capita water demand due to rising population, changes in climates and over-exploitation, among others, has significantly impacted groundwater quality.

Several incidents have been reported indicating that the quality of many boreholes in Lagos metropolis are polluted (Oteri, 2003; Longe, 2011). For example, the occurrence of saline water intrusion in Lagos is a major concern considering the competition for water among users such as domestic, commercial and industrial. For instance salt water intrusion has been found to occur in the confined aquifers of the Coastal Plain Sands in a zone stretching from Apapa to Lekki and around Ikeja within the Lagos metropolis (Coode et al., 1997; Oteri & Atolagbe, 2003).

Furthermore, high rate of urbanization has also contributed to increased water demand globally (Oteri & Atolagbe, 2003; Vaknin, 2005; WHO/UNICEF, 2005; UNESCO, 2006; Longe, 2011).

The hydrochemistry of groundwater depends on several factors such as lithology, chemical composition of the aquifers, climatic conditions prevailing during formation, quantum of water available in the aquifer and its rates of circulation (Todd & Mays, 2005).

Because of the chemical and biochemical interactions between groundwater and dissolved inorganic chemical constituents in various concentrations, groundwater is rendered unsuitable for human consumption (Todd & Mays, 2005).

During the process of infiltration, water reaches the saturated zone and thus becomes enriched with some major cations and anions. Similarly, as groundwater moves along its flow path or the hydraulic gradient in the saturated zone, an increase in total dissolved salts occurs (Todd & Mays, 2005).

Among the multivariate techniques, R-mode factor analysis has been widely employed for understanding hydrogeochemical association and processes controlling them (Briz-kishore & Murali, 1992). These methods explain the relationships among different groundwater chemical species, suggesting hydrochemical processes and defining the hydrochemical facies important to groundwater evolution (Dalton & Upchurch, 1978; Adams et al. 2001).

Early studies on the characterization of groundwater facies and chemical evolutionary history utilized graphical representations of major ionic

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composition of groundwater (Piper, 1944; Stiff, 1951; Schoeller, 1962; Hem, 1989). These schemes were useful in visually describing differences in major-ion chemistry in groundwater and classifying water compositions into identifiable groups (Freeze & Cherry, 1979). Similarly, factor analysis has been used with remarkable success as a tool in the study of groundwater chemistry.

The effectiveness of factor analysis in hydrochemical studies has been aptly demonstrated in several studies. These include the delineation of zones of natural recharge to groundwater in the Floridan aquifer (Lawrence & Upchurch, 1983), the delineation of areas prone to salinity hazard in Chitravati watershed of India (Briz-Kishore & Murali, 1992) and the delineation of effluent contaminated groundwater at two industrial sites at Vasakhapatnam in India (Sabbarao et al, 1996). The effectiveness of this method in groundwater chemistry discrimination over the traditional piper and stiffs schemes stems from its ability to reveal hidden inter-variable relationships and allows the use of virtually limitless numbers of variable, thus trace elements and physical parameters can be used as part of the classification parameters.

This study assessed the hydrochemistry of groundwater and its suitability for human drinking in the study area using multivariate analysis technique and water quality index.

The study area

Lagos State lies approximately between latitudes 6^o22^N and $6^o52'$ and longitudes $2^o42'^E$ and $3^o42'^E$. It is bounded in the South by the Guinea Coast, in the West by the Republic of Benin and in the North and East by Ogun State (Odumosu et al, 1999). The state covers an area of 3,577 km^2 with population of about 9,013,534 (NPC, 2006). The climate is tropical, hot and wet and the environment is characterized by coastal wetlands, sandy barrier islands, beaches, low-lying tidal flats and estuaries. Average temperature is 27^0C with annual average rainfall of 1532 mm.

The major seasons are the wet and dry seasons. The wet season lasts for 8 months (April to November) while the dry season covers a period of 4 months (December to March).

The dominant vegetation type consists of tropical swamp forest comprising the fresh waters and mangrove swamp forests and the dry lowland rain forest (Fig.1).

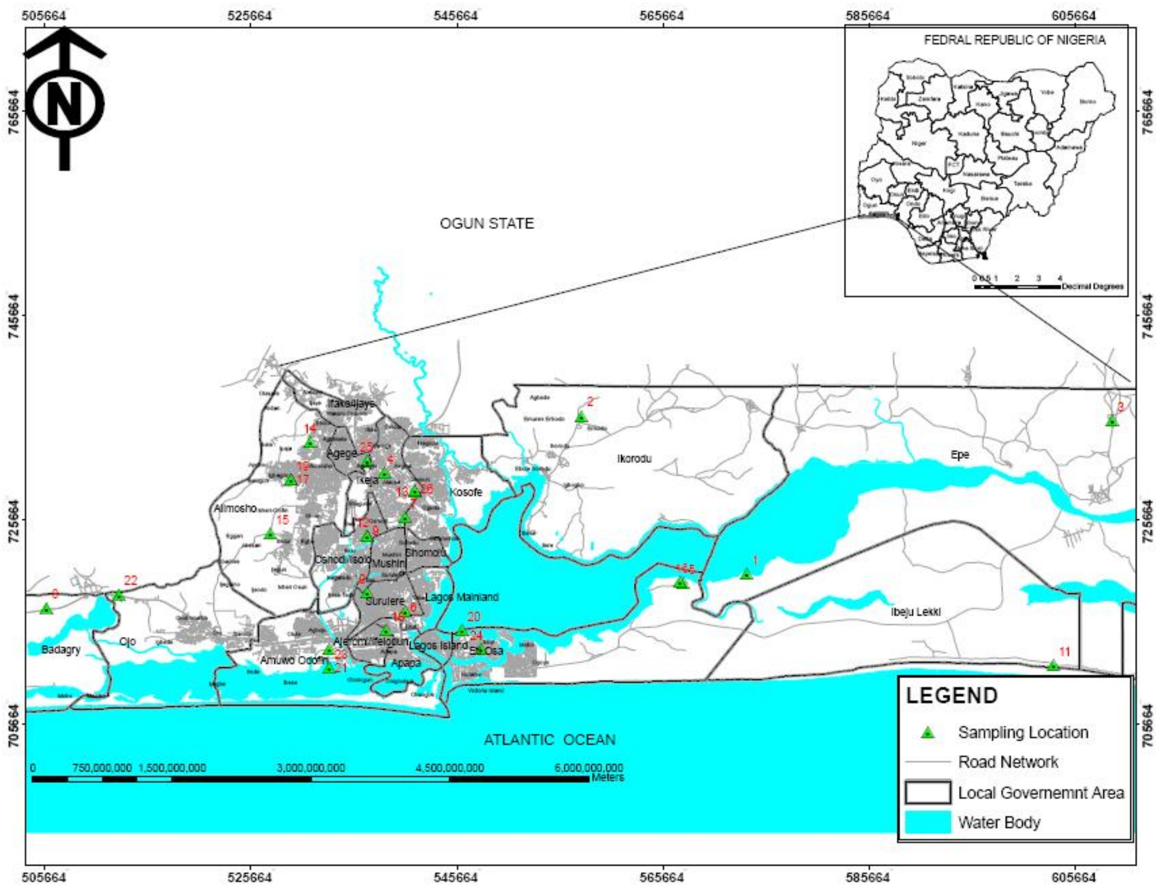

Fig.1: Study area showing sampling locations

The drainage system is characterized by a maze of lagoons and waterways which constitute about 22% the state's total landmass. The area is drained by River Ogun in the centre, the Ona and Osun Rivers in the East and, Yewa River in the West, a sub-basin of Ogun-Osun River Basin.

According to Coode et al., (1997) the aquifers underlying Lagos area are a complex lithology of alternating sequence of sand and clay deposits.

Groundwater serves as a major source of public water supply in Lagos state. It accounts for almost 97% of water supply in the state while river intake accounts for only 3% (LWC, 2008). Over 95% of all boreholes in Lagos state obtain their water from the Coastal Plain Sand. In this aquifer, there is a lot of lateral variation in lithology and water quality. Salinity level in the aquifer changes from north to south. In the northern and central parts of the state is the fresh water-bearing aquifer while in the southern coastal belt the salt water-bearing aquifer is found. See Fig.2

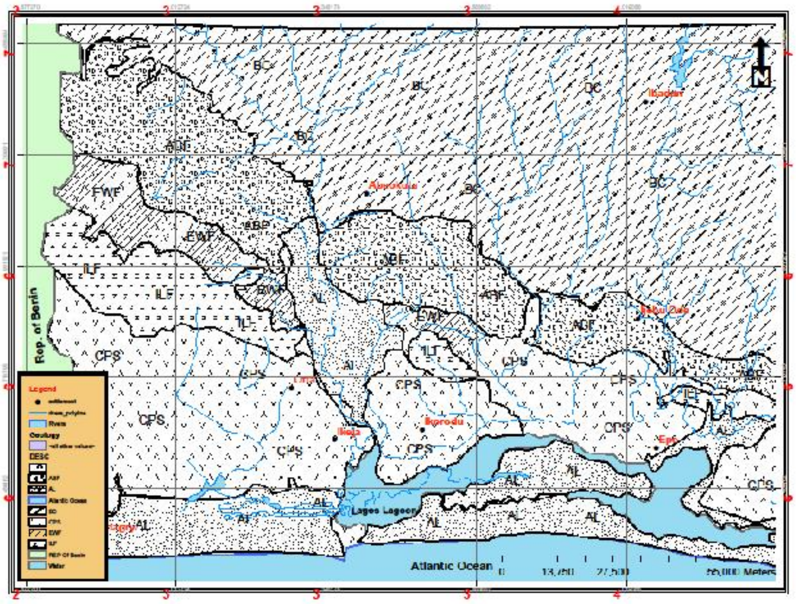

Fig. 2: The Hydrogeology of Lagos area (modified from Coode et al., 1997)
BC-Basement Complex, ABF-Abeokuta Formation, AL-Aluvium, CPS-Coastal Plain Sand, EWF- Ewekoro Formation, ILF-Ilaro Formation.

The surface geology is made up of the Benin formation (Miocene to Recent) and the recent littoral alluvial deposits which consist of ferruginous and white sands materials. The hydrogeology falls within the Dahomey sedimentary basin and is made up of unfossiliferous sandstones and gravels weathered from underlying Precambrian basement rock (Coode et al, 1997).

Materials and Methods

The study involved the collation of the physico-chemical data on groundwater quality from the database of Lagos Water Corporation. The data covered the hydrochemical properties of 26 selected boreholes in Lagos State from 1996 to 1997. The data from the twenty-six (26) boreholes were analyzed using descriptive and multivariate statistical methods. The water quality index analysis was also adopted to determine the potability of the water of the study area. The groundwater quality parameters considered were pH, Conductivity, Chloride, Total Dissolved Solids, Total hardness, Magnesium, Calcium, Bicarbonate, Potassium, Sodium, and Sulfate.

In computing the Water Quality Index (WQI) for drinking and domestic purposes, the method proposed by Asadi et al., (2007) was adopted. Three steps were used in the computation.

In the first step, 8 parameters were assigned a weight (wi) according to their relative importance in the overall quality of water for drinking/domestic purposes (Asadi et al.,2007; Table 4). In the second step, the Relative weight (Wi) was computed using the following equation:

$$W = \frac{wi}{\sum_{i=1}^{n} wi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, W_i is the relative weight, wi is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale (qi) for each parameter was determined by dividing the concentration of each water parameter by its respective standard according to the guidelines by World Health Organization maximum permissible limits (WHO, 2006; Table 1) and the result was multiplied by 100 as shown in Equation 2:

$$qi = \left(\frac{Ci}{Si}\right) x100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where q_i is the quality rating, C_i is the concentration of each water parameter in each water sample and S_i is the WHO drinking water quality standards.
To compute the WQI, the SI was determined first, for each water parameter using the following equations:

$$SIi = Wi.qi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$WQI = \sum SIi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where SI_i is the sub-index of ith parameter; q_i is the rating based on concentration of ith parameter and n is the number of parameters.

Based on the WQI values, the suitability of the water can be categorized into five types, "excellent water" to "water, unsuitable for drinking" (Asadi et al., 2007; Table 5.

RESULTS AND DISCUSSION

The level of detected physico-chemical parameters is presented in Table 1. The result shows that the concentration of pH and TDS in all the sampling locations are within the maximum permissible limits of WHO except at location 1 where the TDS value (610mg/L) exceeded the WHO limits for drinking water .The concentration of EC in all the sampling locations shows that only 4 locations (1, 7 to 9) were found to be above the maximum permissible limits of WHO (Fig.3a).

The concentration of Ca and Mg were found to be within the maximum permissible limits of WHO in all the sampling locations. At locations 1 and 9, the concentration of TH was found to be above the required standard for drinking water quality prescribed by WHO as shown in Fig.3b.

Table 1: Level of Detected Physico-Chemical Parameters

S/No.	EC	TDS	pH	Ca	Mg	TH	Na	K	Cl	HCO3
1	993.25	610.0	4.9	37.88	1.28	39.16	145	15.25	195.44	12.65
2	150.15	101.0	5.45	13.49	1.24	14.73	10.75	3.75	21.49	9.55
3	87.78	66.0	4.2	5.5	0.49	5.99	8.4	4.3	17.99	3.6
4	330.0	254.8	4.63	14.4	5.4	19.8	33.3	4.6	54.3	11.89
5	80.41	52.0	4.65	3.48	0.62	4.1	10.5	0.8	21.5	6.33
6	100.0	53.5	4.7	4.81	0.98	2.9	10.1	0.5	13.0	8.63
7	556.0	341.5	4.2	13.47	1.28	7.38	70.05	11.25	67.98	8.05
8	735.5	430.0	5.55	20.2	2.05	22.25	95.5	11.75	140.96	29.9
9	721.8	417.5	5.1	36.07	1.95	38.02	70	6.7	113.46	21.85
10	451.0	327.0	5.5	43.77	1.54	22.66	51.5	16.63	47.99	28.18
11	171.1	101.0	6.4	12.67	1.49	7.08	22.25	6.33	28.99	74.4
12	59.51	39.0	5.1	3.07	0.25	3.32	7.5	1.5	10.0	16.0
13	95.15	73.0	5.4	3.11	2.13	5.24	9	4.5	24.99	50.6
14	104.72	79.7	5.5	3.89	1.18	5.07	12.5	4.6	18.49	50.6
15	44.33	32.0	4.4	3.11	0.71	3.82	3.2	0.6	7.5	9.78
16	230.1	135.0	6.2	16.83	0.0	16.83	32	4.9	12.5	108.9
17	90.87	58.0	5.2	11.22	0.0	11.22	12	2.0	3.97	34.65
18	77.16	52.0	5.5	5.61	0.98	6.59	16.5	4.5	5.96	29.5
19	89.35	44.0	5.5	5.61	0.0	5.61	15	5.0	7.94	38.5
20	91.08	56.0	5.32	6.41	0.49	6.9	12.5	2.5	16.87	29.15
21	52.61	24.0	5.05	3.21	0.49	3.7	19.5	4.5	5.96	17.6
22	39.7	28.0	4.9	3.37	0.0	3.37	4.5	0.0	5.0	11.0
23	38.01	29.0	5.3	3.21	0.0	3.21	5	1.0	5.0	12.1
24	37.63	25.0	4.7	2.4	0.49	2.89	4.8	0.04	4.0	10.35
25	137.35	94.5	5.6	11.13	0.18	11.31	15.6	1.2	8.5	32.78
26	33.0	21.0	4.4	3.64	0.22	3.86	3.85	0.3	4.5	8.05

Source: Coode et al (1997)
All units are in mg/L except pH and EC

In all the sampling locations, the concentration of Na, K, Cl and HCO_3 were within the WHO limits for drinking water (Fig. 3c)

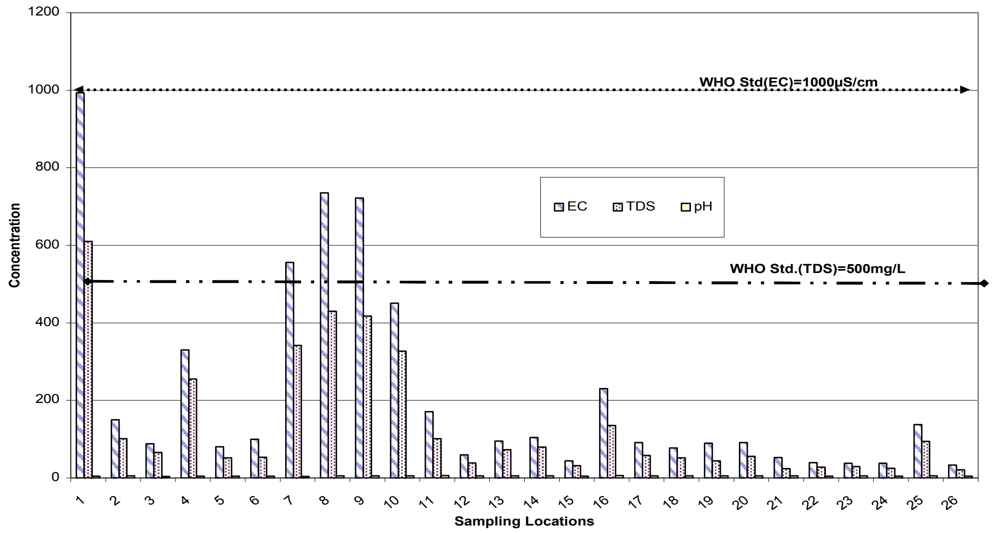

Fig.3a: Physical parameters of groundwater quality

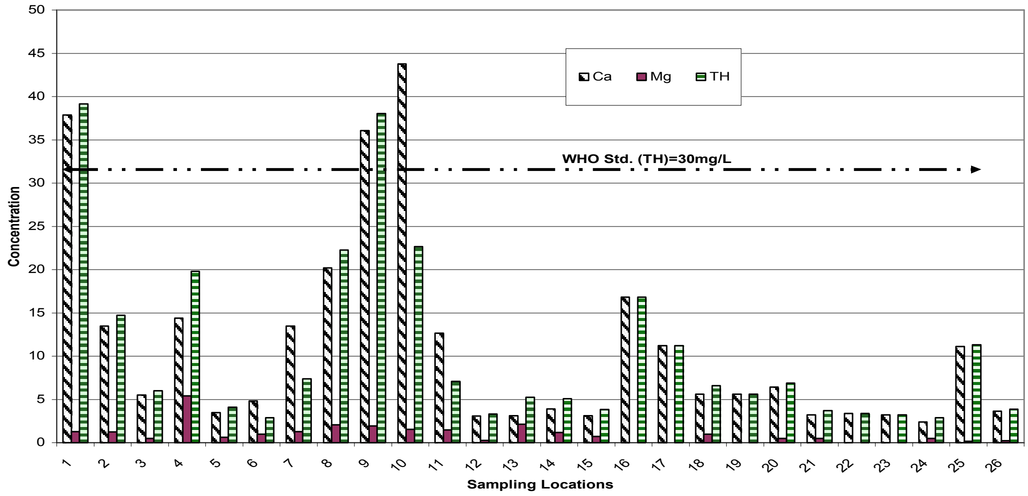

Fig.3b: Chemical parameters of groundwater quality

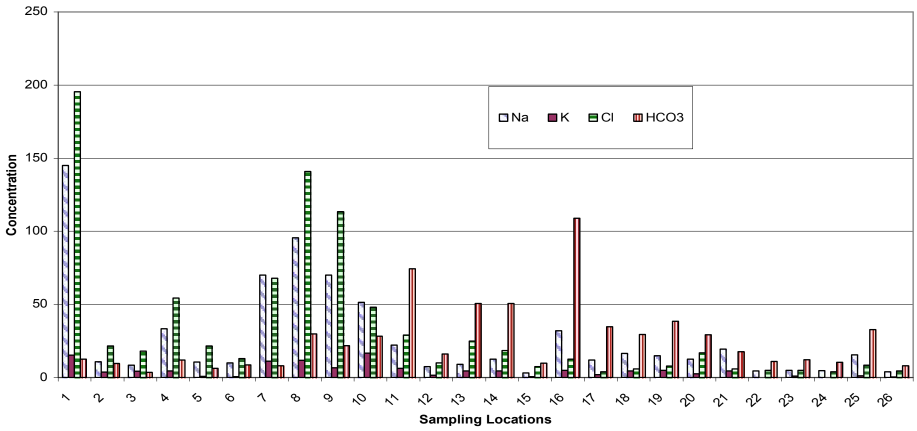

Fig.3c: Chemical parameters of groundwater quality

Table 2 presents the descriptive statistics of the selected groundwater parameters. Conductivity ranges from 33.0 to 993.25mg/L, with a mean of 215.29 indicating a fresh water source (Todd & Mays, 2005). Total Dissolved Solids (TDS) varies between 21.0mg/L and 610.0mg/L, with a mean of 136.33mg/L also indicating a fresh water type (Todd & Mays,2005). pH ranges from 4.2 to 6.4, with a mean of 5.13, indicating an acidic condition (Todd & Mays,2005).

Table 2: Descriptive Statistics of Groundwater Parameters

Parameter	Range		Mean	Std. Error	S.D	Confidence Level,95%	C.V (%)	Max Limit of WHO(SON)Std.
	Min	Max						
Conductivity µS/cm	33.00	993.25	215.29	50.79	258.99	319.90 ,110.68	120.29	1000 (200)
TDS (mg/L)	21.00	610.00	136.33	30.95	157.82	200.07 ,72.58	115.76	500
pH	4.20	6.40	5.13	0.11	0.56	5.35 ,4.90	10.92	8.5
Ca (mg/L)	2.40	43.77	11.21	2.26	11.52	15.87 ,6.56	102.77	75
Mg (mg/L)	0.00	5.40	0.99	0.22	1.12	1.43 ,0.52	113.13	150(0.2)
Na (mg/L)	3.20	145.00	26.18	6.63	33.79	40.60 ,13.30	129.07	200
K (mg/L)	0.00	16.63	4.44	0.89	4.54	6.41 ,2.74	102.25	NA
Cl (mg/L)	3.97	195.44	32.38	9.29	47.42	52.39, 14.09	146.45	200(250)
HCO3 (mg/L)	3.60	108.90	25.21	4.69	23.95	35.0 ,16.27	95.00	240(3)
SO4 (mg/L)	0.00	74.00	6.69	3.25	16.58	14.53 ,1.13	247.83	500(100)
TH (mg/L)	2.89	45.31	12.19	2.34	11.95	17.02,7.36	98.03	30(150)

Note: Min-Minimum, Max-Maximum, Std. Error – Standard Error, S.D- Standard Deviation, C.V- Co-efficient of Variation, WHO-World Health Organization, SON- Standard Organization of Nigeria, NA-Not Available

Calcium, Magnesium, Sodium and Potassium ranges from 2.4 to 43.77, 0.0 to 5.4, 3.2 to 145 and 0.0 to 16.63mg/L, respectively. Corresponding means are 11.21, 0.99, 26.18 and 4.44 mg/L.

Chloride, Bicarbonate and Sulfate vary between 3.97 and 195.44, 3.6 and 108.9, and 0.0 and 74.0 mg/L, respectively with a mean of 32.38, 25.21 and 6.69mg/L. Total Hardness ranges from 2.89 to 45.31, with a mean of 12.19mg/L indicating soft water (Sawyer & McCarty, 1967).

The result of the co-efficient of variation (C.V) shows that all the groundwater parameters examined are heterogeneous in nature except pH with a CV of 10.92%. Highest variability is recorded in Sulfate with CV of 247.83%.

The regulatory drinking water standards adopted (WHO and SON) showed that all the parameters are within the maximum permissible limit of the former. In respect of the SON limit for drinking water also, only Mg and HCO_3 exceeded the 0.2 and 3.0mg/L limits, respectively.

Table 3 presents the correlation among the examined groundwater parameters in the study area. Conductivity showed a low positive correlation at $p<0.05$, with Mg. TDS also showed a positive low correlation at $p<0.05$, with Mg. Mg also posted low positive correlation with TH and Cl.

Table 3: Correlation Matrix of Groundwater quality parameters

	EC	TDS	pH	Ca	Mg	TH	Na	K	Cl	HCO_3	SO_4
EC	1										
TDS	0.99	1									
pH	0.01	-0.00	1								
Ca	0.84	0.86	0.20	1							
Mg	**0.43**	**0.48**	-0.07	0.34	1						
TH	0.85	0.88	0.12	0.99	**0.42**	1					
Na	0.98	0.97	0.03	0.79	0.34	0.79	1				
K	0.82	0.85	0.18	0.82	0.36	0.83	0.84	1			
Cl	0.97	0.96	-0.03	0.74	**0.43**	0.76	0.96	0.75	1		
HCO_3	-0.02	-0.03	0.82	0.11	-0.06	0.09	0.00	0.14	-0.09	1	
SO_4	0.62	0.62	0.07	0.81	0.22	0.79	0.51	0.51	0.54	-0.05	1

Correlation is significant at the 0.05 level (2-tailed), in bold

Since correlation analysis reveals similarities or differences in the behavior of pairs of ions, and does not conveniently identify groups of ions that behave similarly, factor analysis was carried out for the groundwater parameters to enhance the hydrogeochemical interpretation of the data.

Result of the factor analysis for the groundwater chemistry (Table 4) indicates two factors that can be related to various controlling processes of the hydrochemistry. The rotated factor matrix statistics show that the two factors extracted explain 80.16 % of total variance. The communalities of the variables and proportion of their variance explained by the extracted common factors vary from 0.25 to 0.97, suggesting the factor analysis model can be represented adequately based on the overall variance of the data set.

Factor I, explains 62.73% of the total variance and has a strong positive loading on EC, TDS, TH, Na, Cl, Ca, K and SO_4. This is an indication that the quality of groundwater in the study area is mainly controlled by the high loading parameters. The negative loading of HCO_3 as shown by Factor I revealed that the concentration of HCO_3 in the groundwater does not contribute significantly to EC, TDS, TH, Na, Cl, Ca, K and SO_4 values. This factor can be ascribed to the intrusion of seawater into the aquifer system which increases the concentrations of these ions and hence values of the dissolved solids.

Factor II explains 17.43% of the total variance and has a strong positive loading on pH and HCO_3. The negative loadings of EC, TDS, Mg, Na, and Cl on Factor II suggest that the concentrations of EC, TDS, Mg, Na, and Cl do not contribute significantly to pH and HCO_3.

This factor reflects the signatures of natural water recharge and water-soil/rock interaction. Surface water charged with atmospheric and biogenic CO_2 infiltrates into the subsurface and aggressively attack aluminosilicates including feldspars and micas present in the formation liberating cations such as Ca and Mg into the water and leaving residues of clay minerals. A consequence of this incongruent dissolution is a rise in pH and in HCO_3 concentration of the water (Freeze and Cherry, 1979). The combination of pH with HCO_3 indicates alkaline nature and represents the role of dissolved CO_2 in the groundwater system. The result of the factor analysis obtained from this present study further corroborate the findings of the study carried out by Akoteyon et al., (2010).

Table 4: Rotated Factor Matrix of Groundwater Parameters

Variables	**Components**		
	Factor 1	**Factor II**	**Communality**
Electrical Conductivity	0.97	-0.04	0.95
Total Dissolve Solids	0.98	-0.05	0.97
Hydrogen ion Concentration	0.05	0.95	0.91
Calcium	0.92	0.19	0.89
Magnesium	0.48	-0.15	0.25
Total Hardness	0.94	0.17	0.90
Sodium	0.94	-0.02	0.88
Potassium	0.87	0.17	0.79
Chloride	0.93	-0.12	0.87

Bicarbonate	-0.01	0.94	0.88
Sulfate	0.72	0.05	0.52
Eigen Values	6.91	1.90	
% of Variance	62.73	17.43	
Cumulative % of Variance	62.73	80.16	

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

The computed WQI values range from 1.41 to 261.4. Thus, it is inferred that 10.62% of the groundwater sampled in parts of Lagos had excellent water quality. 7.67%, 44.6% and 37.11% had good water, poor water and very poor water quality, respectively (Table 5). It is thus concluded that none of the groundwater sampled is unsuitable for drinking in the study area (Table 6). The high value of WQI obtained in the study area has been found to be mainly from the relative high values of Total Hardness, pH, Total Dissolved Solids, Chloride and Calcium in the groundwater samples.

Table 5: Computed Relative Weight /WQI of Groundwater Parameters

Parameters	**Weight (wi)**	**Relative Weight (Wi)**	**Individual quality rating (qi)**	**Overall quality rating (qi x Wi)**	**% of water quality index**
TDS (mg/L)	4	0.16667	708.9	118.15	16.78
pH	4	0.16667	1568.82	261.48	37.11
Ca (mg/L)	2	0.08333	388.74	32.39	4.57
Mg (mg/L)	2	0.08333	16.97	1.41	0.20
TH (mg/L)	2	0.08333	2352.47	196.03	27.82
Cl (mg/L)	3	0.125	432.14	54.02	7.67
HCO_3 (mg/L)	3	0.125	281.06	35.13	5.0
SO_4 (mg/L)	4	0.16667	35.74	5.96	0.85
Total	∑ wi=24	∑ Wi = 1.000	∑ qi=5784.84	∑ Wi x qi=704.57	100

Table 6: Water quality Classification based on WQI value

WQI value	**Water quality**	**Percentage of water Samples**
<50	Excellent	10.62
50-100	Good water	7.67
100-200	Poor water	44.6
200-300	Very poor water	37.11
> 300	Water unsuitable for Drinking	-

Source: Asadi et al (2007)

CONCLUSION

Comparative physico-chemical characteristics of sampled water from selected boreholes in parts of Lagos state in respect of the regulatory the WHO and SON drinking water standards showed that all the parameters are within the maximum permissible limit of WHO while Mg and HCO_3 exceeded the SON limit of 0.2 and 3.0mg/L for drinking water, respectively. The co-efficient of variation (C.V) shows that all the groundwater parameters examined are heterogeneous in nature except pH.

Result of the multivariate statistical analysis using Factors I and II depicts intrusion of seawater into the aquifer system and the signatures of natural water recharge and water-soil/rock interaction.

The computed WQI was relatively high due to higher values of Total Hardness, pH, Total Dissolved Solids, Chloride and Calcium in the groundwater samples. Thus, this study demonstrates the usefulness of factor analysis and water quality index in evaluating the hydrochemical processes of groundwater and the determination of the suitability of groundwater for drinking purposes, respectively in the study area.

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