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EVALUATION OF GROUNDWATER QUALITY USING WATER QUALITY INDICES IN PARTS OF LAGOS-NIGERIA

Isaiah S. Akoteyon

Department of Geography and Planning, Lagos State University,Ojo, P.M.B. 1087, Apapa, Lagos
e-mail: sewanuakot@gmail.com

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Abstract

Water samples collected from forty-five hand dug wells and thirteen boreholes using random sampling technique were measured for pH, electrical conductivity and total dissolved solids. Calcium, chloride, bicarbonate and carbonates were analyzed using titrimetry method. Magnesium, potassium and sodium by Atomic Absorption Spectrophotometer (AAS) and sulfate was analyzed using a spectrophotometer. The study aims to evaluate groundwater quality using water quality indices in parts of Lagos-Nigeria. The sample locations and spatial variations in the concentration of bicarbonates, Revelle and Water quality indices were mapped using surfer 6.0 software. The result shows that pH indicate extremely acidic to strongly alkaline condition, EC shows medium and high enrichment of salts from location 28 and 21 respectively. Spatially, about 31% and 29.3% of bicarbonate are under poor and moderate zones respectively. The computed Revelle index shows that 41.4% and 1.7% are slightly and strongly influenced by groundwater salinization respectively. Unlike the water quality index, about 12.1% and 1.7% indicate poor and water unfit for drinking respectively. The paper concludes that groundwater salinization is on the increase since over half of the samples are influenced by salinity. Unlike the water quality, it was concluded that the water is of good quality since about 86.2% is suitable for drinking purposes. Based on these findings, it was recommended that waste water treatment and disposal methods should be avoided and appropriate treatment methods to make it more potable and fit for human consumption should be employed in critical locations of the study area.

Keywords: groundwater, Lagos-Nigeria, water quality, Revelle Index, Water Quality Index

INTRODUCTION

Fresh water, as a valuable and finite resource, is a central issue of sustainable development, economic growth, social stability, and poverty alleviation. Fresh water quality has grown to become the major international issue in recent years (Rejith et al., 2009). Urban growth, increased industrial activities, intensive farming, and overuse of fertilizers in agricultural production have been identified as drivers responsible for these changes (Patwardhan, 2003). Studies have shown that the polluted environment has a detrimental influence on human health, fauna and flora species (Sujatha and Reddy, 2003). Contamination of groundwater (resulting from human activities or from inherent aquifer material) impairs water sources and poses threat to public health (Renji and Panda, 2007). Rapid population growth and increased anthropogenic activities result in huge discharge and diverse pollutants reaching sub-surface water. Excessive groundwater withdrawals have been reported to result in hydro-chemical changes in the physical, chemical and microbiological water quality, decline of the water table, reverse hydraulic gradient and consequently water quality deterioration in coastal areas (Esteller et al., 2012; Jamshidzadeh and Mirbagheri, 2011). Poor water quality results in incidences of water-borne diseases and consequently reduces the life expectancy (WHO, 2006). Thus, concern for clean and safe drinking water and protection from contamination is justified because a large proportion of the population in the study area depends on sub-surface sources e.g. dug wells and boreholes etc. for domestic and drinking uses.

Water quality evaluation is based on the physical, chemical and biological parameters ascertaining the suitability for various uses such as consumption, agricultural, recreational and industrial use (Boyacioglu, 2007; Sargaonkar and Deshpande, 2003). Traditional methods of assessing water quality are based on the comparison of experimentally determined parameter values with existing guidelines. This method allows proper identification of contamination sources essential for checking legal compliance (Boyacioglu, 2007). One of the advantages of water quality index (WQI) is that it serves as a useful and efficient method for assessing the suitability of water quality for various purposes. It also serves as a mean of communicating information on the overall quality of water using a single number both temporarily and spatially (Christiane et al., 2009; Boyacioglu, 2007).

Water quality indicators have been applied to assess the overall water quality in different parts of the globe efficiently (Bharti and Katyal, 2011). These indicators are based on the comparison of water quality parameters using regulatory standards to give a single value to the water quality of a source. WQI computation involves four steps: parameter selection, development of sub-indices, assignment of weights and aggregation of sub-indices to produce an overall index. WQI helps to reveal the temporal and spatial variation of water quality (Bharti and Katyal, 2011). It also serves as a useful tool for summarizing large amounts of water quality data into simple terms such as excellent, good, bad, etc. for easy communication to the public.

Literature abounds on water quality assessment. Akoteyon et al. (2010), Yidana and Yidana (2010), Akoteyon and Soladoye (2011), Jamshidzadeh and Mirbagheri (2011), Partey et al. (2010), Celik and Yildirim (2006) Mishra et al. (2005), Edmunds et al. (2003) among others applied WQI in evaluating groundwater. For instance, Shah et al. (2008) compared groundwater quality in Gandhinagar Taluka in India and developped the water quality index for the area. Zaharin et al. (2009) classified salinization of groundwater in the shallow aquifer of a small tropical Island in Sabah, Malaysia using Revelle index (i.e. Cl / (HCO_3 + CO_3). Lobo-Ferreira et al. (2005), Chachadi and Lobo – Ferreira (2001) also adopted this index to evaluate seawater intrusion into the coastal aquifer in India. Thus, this study is aimed at evaluating groundwater quality using water quality indices in parts of Lagos-Nigeria as an alternative method for disseminating information on water quality status using indices for better understanding both by the public and relevant agencies.

STUDY AREA

The study area is located approximately between latitudes $6^o23'\ 30'^N$ and $6^o34'15^N$ and longitudes $3^o28'0^E$ and $3^o38'45^E$. It is bounded in the East by Ibeju-Lekki, in the North by the Lagos Lagoon and in the South by the Atlantic Ocean and parts of the metropolis in the West. The climate is tropical, hot and wet and the area is characterized by coastal wetlands, sandy barrier islands, beaches, low-lying tidal flats and estuaries (Adepelumi et al., 2009). The average temperature is about 27^0C with an annual average rainfall of about 1,532 mm (Adepelumi et al., 2009). The major seasons are the wet and dry seasons. The wet season lasts for 8 months (April to November) and the dry season covers a period of 4 months (December to March (Adepelumi et al., 2009). The dominant vegetation consists of tropical swamp forest (fresh waters and mangrove swamp forests and dry lowland rain forest).

The area is drained by Lagos Lagoon (Emmanuel and Chukwu, 2010). The geology is underlain by the Benin Formation and is made up of highly porous sand and gravel with thin shale/clay inter-beds (Oteri and Atolagbe, 2003). The groundwater flow direction shows a general North to South direction with two small cones of depression in Apapa and Ikeja because of intense groundwater extraction (Coode et al., 1997; Oteri and Atolagbe, 2003).

The hydrogeology is characterized by unfossiliferous sandstone and gravel weathered from underlying precambrian basement rock (Longe, 2011). It consists of Abeokuta and Ewekoro Formations, Coastal Plain Sands (CPS) and recent sediments. The CPS aquifer is the most productive and exploited aquifer in Lagos state. CPS is categorized into four types namely the recent sediments, the second and third aquifers also known as (upper and lower) CPS aquifer and the fourth aquifer is the Abeokuta formation (Longe, 2011).

The upper coastal plain sand aquifer (UCPS) is a water table aquifer and ranged from 0.4–21m below ground level with a relatively annual fluctuation below 5m (Asiwaju-Bello and Oladeji, 2001). This aquifer is usually tapped by hand dug well. The major limitation of this aquifer is that, it is prone to pollution because it is near to the ground surface. Unlike the lower coastal plain sand (LCPS) aquifer, it is tapped through boreholes.

MATERIALS AND METHODS

Fifty-eight samples including 45 hand dug wells (samples 1–45) and 13 boreholes (samples 46–58) were randomly selected for evaluation of groundwater salinization and quality assessment in the study area. Samples were collected in clean 150ml polyethylene bottles and preserved in ice chests for delivery to the chemistry department of the University of Lagos, Akoka for laboratory analyses using standard methods (APHA, 1998). In-situ parameters were measured for electrical conductivity (EC), pH and total dissolved solids (TDS) using a portable hand held (HI98303, Hanna model), (PH-102, RoHS model) and TDS/TEMP HM Digital model respectively. The *in-situ* measurements were necessary because these parameters are likely to change on transit to the laboratory. Chloride, calcium, carbonate and bicarbonate were determined using titrimetry method. Atomic Absorption Spectrophotometer (AAS) HI 98180 model was used to analyze magnesium, potassium and sodium, and sulfate was determined using spectrophotometer, HACH DR/2000 model. The individual sample co-ordinate and the computed Revelle and water quality indices were exported to the Surfer 6.0 software package for mapping the spatial variations of bicarbonate, the Revelle index and the water quality index using the Kriging method. The statistical analysis of the examined groundwater parameters were computed using SPSS software 17.0 version.

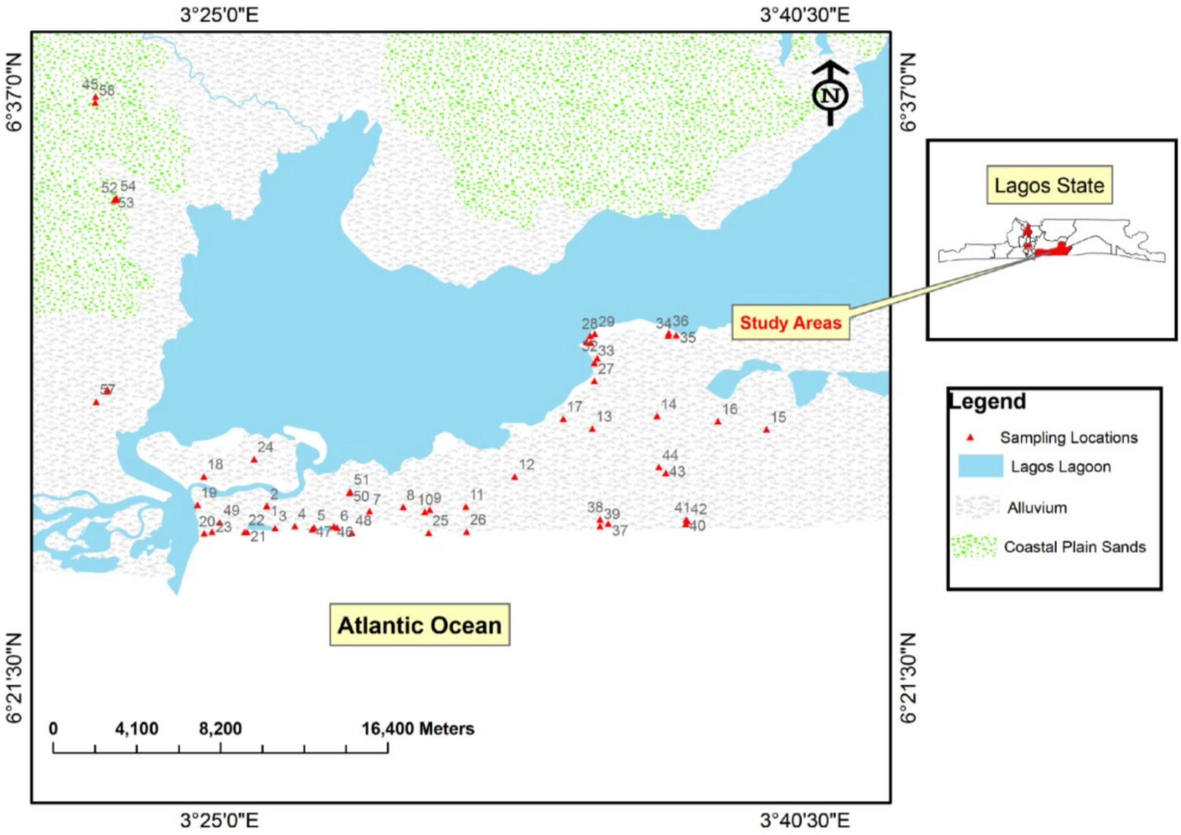

Fig.1 Sampling locations

Co-ordinates of the sampled wells were recorded using Global Positioning System (GPS) and thereafter were plotted using ArcMap 9.3 software on the geological map of Lagos, sheet 68 on 1:250,000 scale to generate a map of the sampling locations (*Fig.1*).

Evaluation of groundwater salinity and the drinking water quality assessment were executed applying:

Revelle Index (RI):

$$R = rCl^{-} / (rHCO_3^{-} + rCO_3^{2-}) \qquad (1)$$

where:

r = milliequivalents per litre (meq/l)

RI < 0.5 (unaffected), 0.5- 6.6 (slightly affected) > 6.6 (strongly affected) (Zaharin et al., 2009; Revelle, 1941)

The Water Quality Index (WQI) was evaluated using the World Health Organization (2004) standard. The stages of calculating the WQI include:

$$qn = 100\,[Vn - Vio\,] / [Sn - Vn] \qquad (2)$$

where:

n is the water quality parameter and quality rating or sub index (*qn*) corresponding to n^{th} parameter (i.e a number reflecting the relative value of this parameter with respect to its standard (maximum permissible value)

qn = Quality rating for the nth water quality parameter

Vn = Estimated value of the nth parameter at a given the sampling point

Sn = Standard permissible value of the nth parameter

Vio =Ideal value of nth parameter in pure water (i.e. 0 for all other parameters except pH and Dissolved Oxygen (7.0 and 14.6 mg/l respectively).

The Unit weight (Wn) is calculated by a value inversely proportional to the recommended standard value (Sn) of the corresponding parameter.

$$W_n = K/S_n \qquad (3)$$

where:

Wn= unit weight for the nth parameters

Sn = standard value for the nth parameters

K = constant for proportionality

The overall WQI is calculated by aggregating the quality rating with the overall WQI which is calculated by aggregating the quality rating with the unit weight linearly as:

$$WQI = \Sigma q_n W_n / \Sigma W_n \qquad (4)$$

RESULTS AND DISCUSSION

The measured parameters and the descriptive statistics of the groundwater characteristics of the study area are shown in *Table 1*. The pH of the sampled wells varied from 3.4 to 8.55 indicating an extremely acidic to strongly alkaline condition that may affect the taste (Todd and Mays, 2005).

Table 1 Detected parameters of groundwater and their descriptive statistics

Sample No.	pH	EC (µS/cm)	TDS (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	CO_3^{2-} (mg/l)
1	6.84	630	424	13.4	4.16	69	45	38	176	9	153
2	7.33	285	200	10.11	2.05	96	30	40	169	7	148.4
3	6.8	380	264	7.61	1.54	160	16	38	UDL	11	445.2
4	5.96	748	515	13.65	2.28	316	26	82	50.4	17	339.2
5	5.92	204	141	3.7	0.45	86	30	18	UDL	5	339.2
6	6.02	375	257	6.95	1.8	72	44	34	UDL	9	275.6
7	6.52	222	153	6.33	2.12	90	22	20	UDL	5	254.4
8	6.4	182	128	3.85	0.74	102	15	14	67.2	4	148.4
9	4.54	206	143	4.27	1.89	82	74	80	UDL	6	314.4
10	5.58	763	533	32.3	5.12	110	112	176	UDL	19	826.8
11	6.01	310	219	7.22	3.51	12	2	36	100.8	8	127.2
12	5.31	348	240	6.99	4.2	64	56	48	UDL	8	402.8
13	5.48	174	124	4.16	1.89	30	26	32	117.8	5	84.8
14	5.5	360	250	5.59	2.34	150	20	44	369.6	8	106
15	5.32	40	30	0.63	0.19	16	2	8	UDL	2	106
16	3.79	659	453	16.52	4.88	234	22	142	UDL	14	360
17	3.4	213	150	2.79	0.87	92	16	30	UDL	5	233.2
18	6.09	658	440	29.64	4.52	190	32	116	UDL	8	848
19	6.86	327	223	9.2	1.76	94	28	36	252	6	63.6
20	6.61	145	99	4.09	0.36	44	16	16	50.4	4	84.8
21	6.57	4040	6112	1080.1	52.32	1200	580	3400	184.8	1250	106
22	6.7	442	302	17.89	2.72	52	74	70	67.2	7	275.6
23	7.14	648	449	25.56	3.97	114	96	100	621.6	12	127.2
24	6.41	490	341	15.89	2.71	76	94	62	218.4	7	190.8
25	6.8	738	492	69.7	10.58	118	106	246	210	10	UDL
26	6.43	438	296	47.38	6.42	50	34	166	110	8	UDL
27	5.48	648	442	41.53	5.65	138	54	140	120	9	UDL
28	6.29	1575	1020	122.51	15.75	414	106	448	570	16	40
29	6.1	1053	705	112.42	14.63	328	86	374	456	14	26
30	6.67	806	537	104	16.3	406	92	356	380	12	38.5
31	5.48	318	202	5.27	3.12	138	26	40	104	8	29.7
32	5.89	369	242	3.4	2.42	140	24	16	86	6	UDL
33	6.03	611	400	32.69	4.78	142	74	114	140	9	UDL
34	6.39	790	541	38.24	5.17	184	16	130	240	12	UDL
35	5.34	425	290	22.6	4.15	144	8	75	128	4	UDL
36	5.61	490	305	10.46	5.2	100	12	114	104	6	UDL
37	6.5	472	296	31.88	4.58	108	26	120	70	9	UDL
38	5.09	68	47	1.3	0.5	12	2	8	UDL	2	84
39	6.03	191	125	9.8	1.35	22	6	6	UDL	2	96
40	6.3	115	81	6.2	0.17	14	4	10	UDL	4	42
41	6.22	63	44	2.6	0.48	38	12	32	UDL	4	48.4
42	8.55	103	72	3.6	4.8	60	10	46	UDL	8	28
43	5.9	676	479	52.7	8.12	202	26	176	130	10	UDL
44	5.64	201	134	24.6	6.18	196	48	166	146	10	UDL
45	8	116	59	4.31	0.28	46	UDL	16	0.08	4	UDL
46	6.2	312	240	5.21	2.7	88	34	20	30.4	5	276.4
47	6.02	289	154	6.53	1.9	76	38	26	26.4	4	344.8
48	6	403	301	8.35	3.5	81	42	31	28	6	398.2
49	6.8	175	137.5	8	2.15	6.4	2.3	17.1	149.05	11.7	UDL
50	7.1	210	147.4	26.3	12.25	22	10	11	48.23	5.4	UDL
51	5.9	185	132.8	20.2	10.5	3.1	1.1	25.8	43.4	12.3	UDL
52	6	70	23	30	5.2	UDL	UDL	23	31.2	45	UDL
53	6	72	22	30	4.8	UDL	UDL	25	30	43	UDL
54	6	70	23	31	4	UDL	UDL	22	33.1	44	UDL
55	5.4	66	66.9	2.2	1.2	2.1	0.77	11.6	29.5	1.2	UDL
56	5.3	50	46.9	2.2	1	2.1	0.77	8.4	29.15	0.2	UDL
57	5.4	66	66.9	2	1.6	2.1	0.77	11.6	25.2	0.6	UDL
58	6	52	23	1.3	UDL	24	UDL	5	UDL	1	UDL

UDL-Under detection limit.

Table 1 (cont.) Detected parameters of groundwater and their descriptive statistics

	pH	**EC (µS/cm)**	**TDS (mg/l)**	**Na^+ (mg/l)**	**K^+ (mg/l)**	**Ca^{2+} (mg/l)**	**Mg^{2+} (mg/l)**	**Cl^- (mg/l)**	**HCO_3^- (mg/l)**	**SO_4^{2-} (mg/l)**	**CO_3^{2-} (mg/l)**
Min	3.40	40.00	22.00	0.60	UDL	UDL	UDL	5.00	UDL	0.20	UDL
Max	8.60	4040.00	6112.00	1080.10	52.30	1200.00	580.00	3400.00	621.60	1250.00	848.00
Mean	6.07	433.36	351.40	38.80	4.80	118.24	41.03	133.04	102.50	30.70	134.70
Std. Dev	0.80	563.66	794.12	141.60	7.38	172.73	78.67	446.28	139.20	163.20	187.71
Skewness	-0.27	4.88	6.93	7.23	4.99	4.63	5.86	7.13	2.11	7.58	2.08
WHO Std.	8.5	1000	500	200	10	75	30	200	300	200	300

Min-minimum, Max-maximum, Std. Dev-standard deviation; WHO-World Health Organization; Std-standard

The Electrical Conductivity (EC) varied between 40 and 4,040µScm^{-1} with a mean value of 433.36µScm^{-1}. According to the classification in Rao et al. (2012), samples from locations 1 to 20, 22 to 27 and 29 to 58 are of low enrichment of salts while location 21 and 28 depict medium and high enrichment of salts respectively. TDS varied between 22 and 6,112 mg/l with a mean value of 351.44mg/l. According to Todd and Mays (2005), the samples from locations 1 to 20, 22 to 27 and 29 to 58 are of the fresh water type while locations 21 and 28 depict the brackish water type. Calcium, Magnesium, Sodium and Potassium varied between under the detection limit to 1, 200, under detection limit to 580, 0.63 to 1,080.10 and under detection limit to 52.32 mg/l with a mean value of 118.24, 41.03, 38.77 and 4.82 mg/l, respectively (*Table 1*).

Carbonate, chloride, bicarbonate and sulfate varied between under the detection limit and 848, under the detection limit to 621.6, 5 and 3,400 and 0.2 to 1,250mg/l with mean values of 134.70, 133.04, 102.46 and 30.73 mg/l respectively. According to Stuyfzand (1989), the classification of chloride shows that about 46.6% of Cl in the samples accounts for fresh water while 37.9%, 8.6%, 5.2%, and 1.7% accounted for oligohaline, fresh-brackish, brackish and brackish-salt respectively (*Table 2*). The spatial variation of bicarbonate in the study area is presented in (*Fig. 2*). According to the WHO (2004) classification, the variation in HCO_3 concentration revealed that about 31% of the samples are under poor zone, 29.3% moderate zone and 10.3% good zone respectively.

Evaluation of groundwater salinization

The computed Revelle index varied from 0.05 and 14.62meq/l. The relationship between the ratios of $Cl/HCO_3 + CO_3$ indicates a strong positive linear relation with Cl concentrations ($r = 0.94$, $p < 0.01$). This linear relationship indicates the mixing of saline water and fresh groundwater (Zaharin et al., 2009). *Figure 3* shows the spatial variation of the extent of the groundwater salinization in the study area. About 56.9% of the samples (n = 33) were unaffected by salinity, 41.4% (n = 24) were slightly influenced and the remaining 1.7% (n = 1) was strongly influenced by salinity. Areas of critical concern include locations 21, 25-30, 33-37, 41-44, and 51-58 in the study area. Thus, effort must be made to curtail the current groundwater salinization in the area in order to ensure groundwater sustainability.

Assessment of drinking water quality

The suitability of groundwater quality for drinking purpose in the study area was determined using World Health Organization (WHO, 2004) guidelines. According to Sahu and Sikdar (2008), the computed water quality index (WQI) ranged from 15.27 to 550.97mg/l. The spatial variations in the samples revealed that about 37.9% of the sampled wells had excellent water quality and 48.3%, 12.1% and 1.7% indicate good, poor and water unfit for drinking respectively (*Fig.4*). Critical areas that require urgent attention include locations 9-10, 16-17, 21 and 28. Others are 12, 23, 25 27, 33 and 43-44. These locations pose a threat to human health and water resources management in the study area.

Table 2 Classification of Chloride in the study area (Source: Stuyfzand (1989))

Chloride Type	**Chloride (mg/l)**	**Sample Numbers**
Very Oligohaline	< 5	-
Oligohaline	30.0-150	(n=23) 5, 7–8, 15, 17, 20, 32, 38–40, 45–47, 49–58
Fresh	30-150	(n=26) 1–4, 6, 9, 11–14,16, 18, 19, 22–24, 27, 31, 33–37, 41–42, 48
Fresh-Brackish	150-300	(n=5) 10, 25–26, 43–44
Brackish	300-1,000	(n=3) 28–30
Brackish-Salt	1,000-10,000	(n=1) 21
Salt	10,000-20,000	-
Hypersaline	>20,000	-

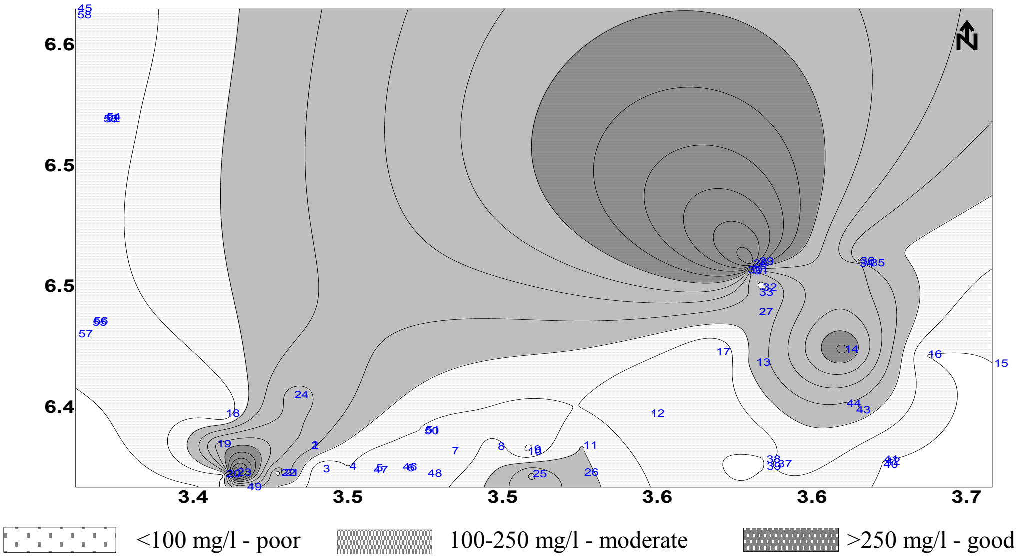

Fig.2 Spatial variation of bicarbonate

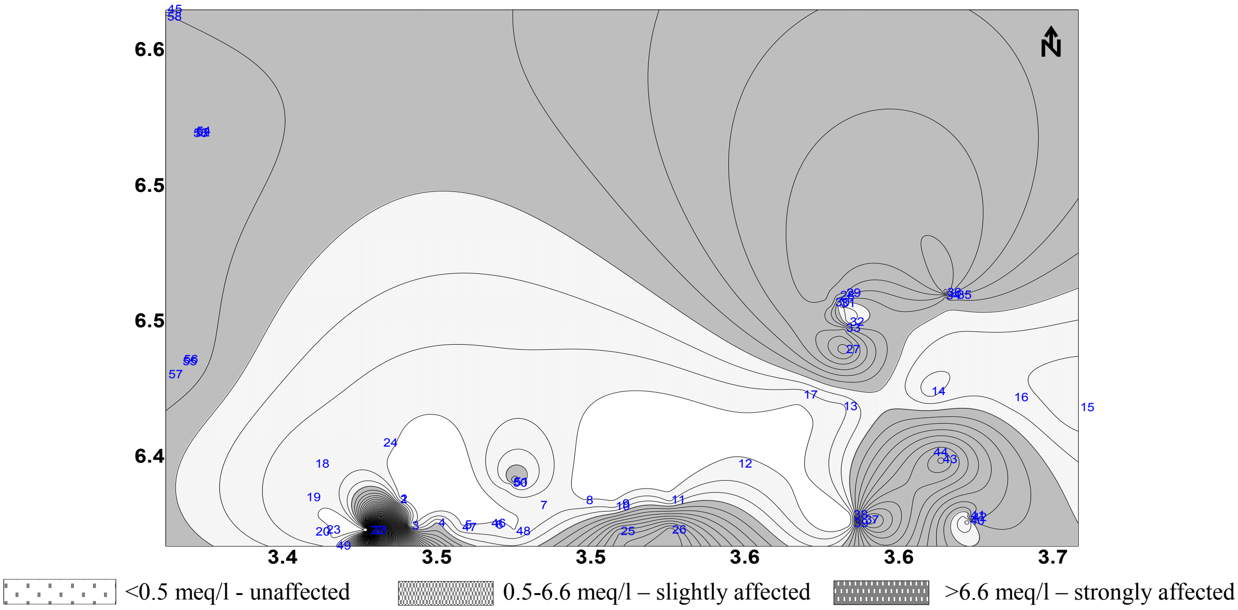

Fig.3 Spatial variation of Revelle index

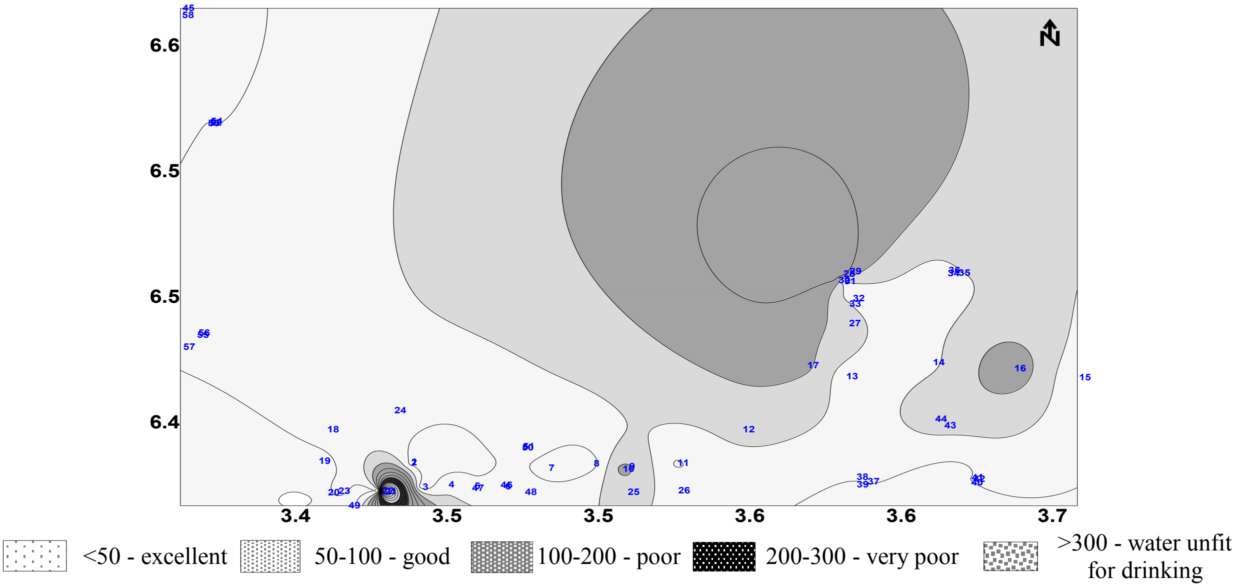

Fig.4 Spatial variation of Water quality Index

CONCLUSION

Groundwater is increasingly gaining significance as the main solution to the water supply problems in Nigeria, especially in the sub-urban and rural areas. The pH indicates extremely acidic to strongly alkaline conditions. About 96.6% of the EC values are characterized by low enrichment of salts, 12.1% medium enrichment of salts, and 1.7% high enrichment of salts. Major cations are in the order of: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and the major anions are in the order of: $CO_3^{2-} > Cl^{-} > HCO_3^{-} > SO_4^{2-}$. 46.6% of the samples accounts for fresh water and 37.9%, 8.6%, 5.2%, and 1.7% accounts for oligohaline, fresh-brackish, brackish and brackish-salt based on Chloride. Similarly, the classification of bicarbonate show that 31% of the samples fall under poor zone, 29.3% moderate zone and 10.3% good zone.

Groundwater salinization shows that 56.9% of the samples are unaffected, 41.4% are slightly influenced and 1.7% of groundwater was strongly affected. This infers that fresh groundwater contamination by salinity is a major concern for the fresh water supply in the study area especially around locations 21, 25-30, 33-37, 41-44 and 51-58. Thus, the need for the regulating groundwater exploitation through monitoring by concerned agencies for sustainable groundwater resource management. The suitability of groundwater for drinking purpose shows that about 37.9% of the samples had excellent water quality and 48.3%, 12.1% and 1.7% indicate good, poor and water unfit for drinking respectively. It is deduced that locations around 9-10, 16-17, 21 and 28 pose a great threat to water quality in the study area. However, the study concluded that the water quality of the study area is of good quality, since about 86.2% is suitable for drinking purposes. However, appropriate treatment methods to make it more potable and fit for human consumption should be employed in areas with poor quality. The study has contributed to knowledge by proffering methods of disseminating information on water quality status using indices for better understanding by the public and relevant agencies as well.

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