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Assessment of Groundwater Quality in the Lower Coastal Plain Sand Aquifer for Varied Uses

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Abstract

The study assessed the water quality of lower coastal plain sand (LCPS) aquifers for varied uses. 44 samples were collected from hand dug wells. pH, electrical conductivity, total dissolved solids, total hardness, alkalinity, calcium, magnesium, sodium, potassium, chloride, bicarbonate, carbonates and sulfate were determined using standard methods. Result shows that about 95.4% of the measured EC accounts for low enrichment of salts while 2.3% accounts for both medium and high enrichment of salts. The TDS values show that about 95.5% of the samples are fresh water while 4.5% are brackish. Factor Analysis extracted four factors and explained 91.71 % of total variance. The RSC value shows that about 18.2%, 13.6% and 15.9% of the samples represent suitable, marginal and unsuitable water, respectively, for irrigation purpose. Furthermore, computed MR values indicate that about 75% of the samples are suitable while the remaining 25% are not suitable for irrigation purpose. PI values also show that 63.6% of the samples are not suitable for irrigation while 34.1% and 2.3% are marginally suitable and suitable, respectively. For industrial water uses, 6.8% of the samples exceed the prescribed WHO HCO_3 limit while 2.3% and 11.4% exceed the SO_4 and TH limits, respectively. 93.2% of the samples exceed the prescribed pH limits, while TDS and Cl exceed the standard limit in about 4.5% and 2.3% of the samples, respectively. The WQI ranged between 21.59 to 550.97mg/L with about 31.8% representing excellent water quality while 50%, 15.9% and 2.3% indicate good, poor and water unfit for drinking purposes, respectively. The paper recommends adequate protection and thorough treatment of the water for human consumption.

Key words: Assessment, Groundwater quality, Lower Coastal Plain Sand, Water uses

Introduction

Monitoring of water resources quality is a major tool for sustainable development because it provides necessary information for water resources management. Groundwater quality assessment is usually based on the physical, chemical and biological parameters due to weathering from source rocks and anthropogenic activities. Assessment of groundwater quality is aimed at developing strategies to protect aquifers from contamination and it is, therefore, necessary for proper planning and management of water resources.

Groundwater plays a vital role in human life and development (Mukherjee, 2005). It serves as a vital natural resource for reliable and economic provision of safe water supplies to meet rural and urban domestic, industrial and agricultural water demand in Nigeria (NERC, 2003). According to FMWR (2007), Nigeria, is endowed with abundant groundwater resources estimated to be about 51.9 billion m^3 per annum.

The assessment of the suitability of groundwater for various purposes such as drinking, domestic, irrigation and industrial requires the determination of the concentrations of some important parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), Ca, Mg, K, Na, Cl, HCO_3 and SO_4 using appropriate guidelines stipulated by WHO (Srinivasamoorthy et al.2009). Evaluation of water quality prior to its use will assist in making the water free from water borne diseases. It will also guide farmers in preventing probable deleterious effect on plant productivity as well as protecting industrial equipment against incrustation and corrosion.

Morris et al. (2003) argued that about 2 billion people rely on groundwater for drinking water out of which 40% accounts for irrigated agriculture globally. Bear et al (1999) noted that about 70% of the world's population in coastal areas depends on groundwater for respective needs. Groundwater in coastal regions support irrigation, industrial production, sustains the flow of streams and rivers, and maintains riparian and wetland ecosystems (Balow, 2003). The USGS (2000) asserts that there have been large-scale withdrawals of groundwater by builders, hotels and other tourist establishments located in coastal areas in the last decade.

The characteristics of groundwater in coastal region vary both spatially and temporally and are influenced by many factors including rainfall, landform, soil, lithology, seawater intrusion and other anthropogenic activities (Manikandan et al 2012). The chemical composition of groundwater in coastal region varies depending on the nature of the hydrogeology, hydrometeorology, topography, drainage and other artificial conditions (Kim et al., 2005).

The continuous rise in population and the need for fresh water resources in coastal settlements is likely to create serious environmental consequences. This has resulted to pressure on coastal resources which requires rational exploitation of groundwater resources in coastal region. Indeed, groundwater withdrawal in the coastal region beyond its renewable capability is on the increase (Manikandan et al 2012). The extensive exploitation of groundwater results in groundwater storage depletion, lowering of the water-table (drawdown), seawater intrusion and associated freshwater problems in coastal region (Adelana and MacDonald, 2008; Bear et al., 1999).

Kumar (2007)and Balow, (2003) also assert that over-abstraction of groundwater in coastal aquifers can result in groundwater salinization, land subsidence, reduction in the amount of groundwater in storage and groundwater discharge to streams, wetlands, and coastal estuaries. Yuan and Yong (2009) infer that land use types may have significant effect on coastal aquifers especially when pollutant concentration is relatively high. Similarly, intensive groundwater withdrawal in coastal areas can result in hydrochemical changes in the chemical, physical, or microbiological water quality parameters with attendant undesirable effects such as social and economic problems (Esteller et al. 2011; Vrba, 2003).

High salinity in groundwater poses great danger to human health as well as impairing the sustainability of groundwater resources. For instance, excess sodium in human body can result to hypertension, cardiac and renal diseases, hardening of the arteries, eye damage, cirrhosis of the liver and stroke (Ghassemi et al., 1995). Groundwater salinization also impacts seriously on coastal agriculture and can lead to changes in productivity, distribution of plant species, migration and consequently, extinction (Hanh and Furukawa, 2007).

The study assessed groundwater quality within the lower coastal plain sand aquifers for varied uses using multivariate and water quality indices.

The Study area

The study area lies within the Lower Coastal Plain Sand (LCPS) aquifer of Lagos area. It is a zone of coastal creeks and lagoons (Longe et al., 1987). It is located approximately between latitudes 6°24'N and 6° 33'N and longitudes 3°24'E and 3°39'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 by Lagos Island in the West. It occupies about 192.3km^2 land area (Fig.1).

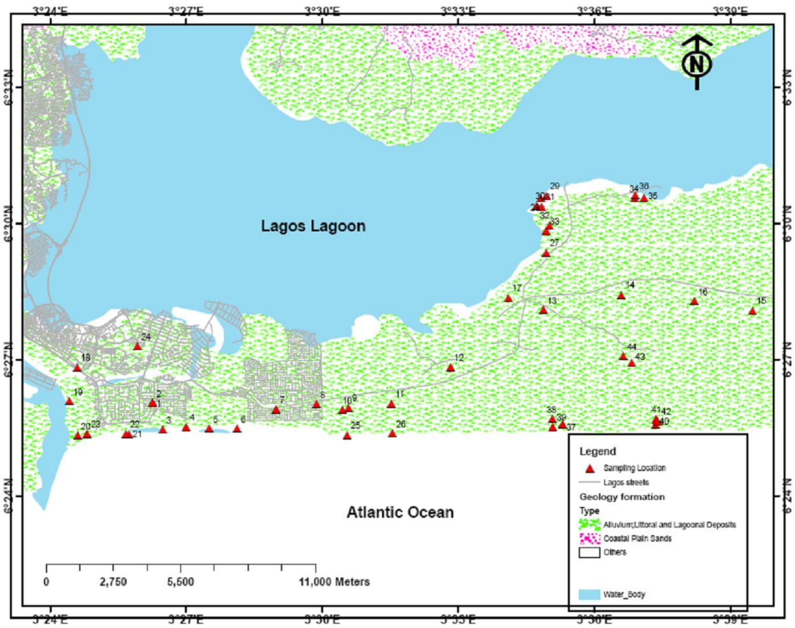

Fig. 1: Sampling Locations

The landform is characterized by coastal wetlands, sandy barrier islands, beaches, low-lying tidal flats and estuaries (Adepelumi, 2008). The climate is Tropical with annual average temperature and rainfall of about 27^{0}C and 1,532mm, respectively (Adepelumi, 2008). The area has two major rainfall seasons, the wet season between April to November while the dry season covers the months of December to March. The vegetation is dominated by brackish water swamp forests, freshwater swamp forests and riparian forests (FEPA, 1997).

The drainage system is characterized by Lagos and Lekki Lagoon fed by River Oni in the North Eastern part and by Rivers Oshun and River Saga in the north western parts of the lagoon (Emmanuel and Chukwu, 2010). The geology falls within the Benin formation. It is highly porous consisting of sands and gravels with thin shale/clay interbeds with lignite of Miocene to Recent age (Longe et al., 1987) which form a multi-aquifer system (Oteri & Atolagbe, 2003). The Benin formation comprises of 4 aquifer types namely; the Abeokuta group, Ewekoro formation, Coastal Plain Sands (CPS) and Recent sediment aquifers (Longe et al., 1987). The population is about 287,785 with a density of 1,496 people per km (NPC, 2006).

In Lagos state and its environs, the major aquifer is the Coastal Plain Sand (CPS). The CPS aquifer is categorized into four types, the first is the recent sediments usually less than 2m from the surface while the second (UCPS) is usually less than 30m. The third aquifer (lower CPS) is usually between 200 and 250m while the fourth aquifer type is the Abeokuta formation (Longe, 2011).

The aquifer formation of the present study falls under the UCPS and consists of alluvium material. It ranged between 0.4–21m below ground level. The UCPS aquifer is harnessed through hand dug well. One of the characteristics of the UCPS aquifer is that, it is prone to pollution due to its nearness to the ground surface.

Settlements within the study area comprise urban, peri-urban and riverine. Major human activities include, industrial, peri-urban agriculture, commercial and fishing. Sources of water supply for various uses include borehole, hand dug well and pipe borne water.

Materials and Methods

A total of 44 hand dug wells (HDW) were sampled within the study area. The HDW are used for drinking and other domestic purposes. Samples were collected from the HDW after agitation for about 10 minutes in order to remove stored groundwater in the well (Todd & Mays, 2005).

Samples were collected in clean 1.5 litre polyethylene plastic bottles after being thoroughly rinsed using the groundwater to be sampled. The bottles were labeled and tightly packed, transported to the Chemistry laboratory of the University of Lagos for chemical analysis within 24 hours from the time of sampling to avoid errors that may result from environmental factors (Todd & Mays, 2005).

Depth to water table and depth of the HDW were measured using sound meter and graduated string, respectively (Todd & Mays, 2005). Co-ordinates of the sampling locations of the HDW were recorded using Global Positioning System (GPS) and thereafter were plotted using ArcMap 9.3 software to generate the map of the sampling locations (Fig.1)

The field measurement and laboratory analytical methods adopted is presented in (Table 1)

Table 1: Field measurement/ laboratory method and instrument

Parameter	Measurement/laboratory method/instrument and reagents
Electrical Conductivity	EC Dist 3(HI98303, Hanna model
pH	pHmeter(PH-102,RoHS model)
Total Dissolve Solids	TDS/TEMP TM Digital model.
Calcium,Total Alkalinity and Total Hardness	Titrimetry method (using Murexide and Sodium Hydroxide,HCl and EDTA reagents respectively.
Magnesium, Potassium and Sodium	Atomic Absorption Spectrophotometer (AAS) Hanna (HI 98180) model.
Chloride	Argentometry titrimetry method (using Potassium Chromate as indicator)
Sulpfate	Spectrophotometry (HACH DR/2000 meter)
Carbonate and Bicarbonate	Titration method (using standardized hydrochloric acid solution)

The following procedures were also adopted in determining certain parameters:

- Determination of Carbonate hardness (CH) - the lowest values among (TA and TH), Noncarbonated hardness (NCH) - (TH–TA).
- Excess alkalinity (EA)- the difference between (TA–TH) (Chow,1964).
- Determination of water quality for irrigation purpose: Application of - Residual sodium carbonate (RSC), Magnesium hazard (MR) and Permeability index (PI).
- Determination of water quality for industrial purpose: Application of HCO_3 of more than 400 mg/L, TH greater than 300 mg/L , SO4 above 100 mg/L, pH less than 7,TDS above 1,000 mg/L and Cl above 500 mg/L (Johnson, 1983).
- Determination of water quality for drinking purpose: Application of Water Quality Index

(WQI) using World Health Organization (2004) standard. The stages of calculating the WQI includes

$$qn = 100\,[Vn - Vio]\,/\,[Sn - Vn] \quad (1)$$

where

n = water quality parameters and quality rating or sub index (qn) corresponding to nth 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 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.

- $$W_n = K/S_n \quad (2)$$

where

W_n = unit weight for the nth parameters,

S_n = 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:

- $$WQI = \Sigma q_n W_n / \Sigma W_n \quad (3)$$

Multivariate statistical techniques adopted for this study include factor analysis, principal component analysis and cluster analysis. FA was used to explain the variances and relationships among the variables observed in the data and to explain the main processes that govern the distribution of hydrochemical variables of the study area (Ghrefat and Yusuf 2006, Deepulal et al., 2011) while PCA technique adopted helped in the extraction of different factors.

Factor analysis is given as:

$$Z_{ji} = a_{f1}f_{1i} + a_{f2}f_{2i} + a_{f3}f_{3i} + \ldots + a_{fm}f_{mi} + e_{fi} \quad (4)$$

where z is the measured variable, *a* is the factor loading, *f* is the factor score, *e* the residual term

accounting for errors or other source of variation, *i* the sample number and m the total number of factors (Shrestha & Kazama,2007;Suheyla,2010) while the principal component analysis is given as:

$$Z_{ij} = a_{i1} x_{1j} + a_{i2} x_{2j} + a_{i3} x_{i3} x_{13} + ... + a_{im} x_{mj} \quad (5)$$

where, z is the component score, a is the component loading, x the measured value of variable, i is the component number, j the sample number and m the total number of variables (Helena, 2000; Shrestha & Kazama, 2007; Suheyla,2010).

Results and Discussion

The measured well characteristics and groundwater quality of the sampled hand dug wells are presented in Table 2. Depth to water table (DWT) ranged between 0.45 and 3.7m while depth of the sampled wells was narrow in a range, between 1.4 and 5.25 m. The range of the water temperature was narrow, between 27.0 and 31.0^{o}C. The mean depth to water table, depth and water temperature of the sampled wells are in the order of 1.76m, 3.11m and 29.07^{o}C, respectively. Depth to water table represents the groundwater reservoir level and changes in its level represent changes in the groundwater in storage (Karanth, 1987).

Table 2: Descriptive statistics and varimax rotated factor loading of groundwater quality

Parameters	Unit	Min	Max	Mean	CV(%)	F1	F2	F3	F4
		Descriptive statistic				Varimax rotated factor loading matrix			
DWT	(m)	0.45	3.7	1.76	-				
Depth	(m)	1.4	5.25	3.11	-				
Temp	T0C	27	31	29.07	-	-0.135	0.113	-0.6	0.126
pH	-	3.4	8.55	6.04	14.4	0.084	-0.03	0.036	0.978
EC	(µ/scm)	40	4040	522.7	118.46	0.93	0.084	0.296	0.038
TDS	(mg/L)	30	6112	430.45	208.72	0.989	0.011	0.103	0.026
TA	(mg/L)	28	848	278.01	72.17	0.081	0.907	0.408	0.044
TH	(mg/L)	14	1780	198.98	135.13	0.955	0.049	0.263	0.001
CH	(mg/L)	14	520	149.55	74.02	0.333	0.343	0.719	-0.034
NCH	(mg/L)	0	1489.2	49.42	453.56	0.981	-0.11	-0.04	0.018
EA	(mg/L)	0	626	128.45	122.07	-0.132	0.919	0.015	0.08
Na	(mg/L)	0.63	1080.1	47.08	344.09	0.99	-0.052	0.079	0.036
K	(mg/L)	0.17	52.32	5.2	158.08	0.934	-0.057	0.288	0.061
Ca	(mg/L)	12	1200	147.84	127.45	0.919	0.029	0.303	-0.027
Mg	(mg/L)	2	580	51.14	171.53	0.952	0.088	0.154	0.062
Cl	(mg/L)	6	3400	169.61	299.66	0.992	-0.041	0.09	0.019
HCO_3	(mg/L)	0	621.6	123.62	123.81	0.091	0.008	0.91	0.297
CO_3	(mg/L)	0	848	154.39	127.19	0.012	0.921	-0.293	-0.187
SO_4	(mg/L)	2	1250	36.34	515.29	0.984	-0.046	-0.043	0.017
% of Variance						55.54	15.81	13.78	6.58
Cumulative %						55.54	71.35	85.13	91.71

The descriptive statistics of groundwater quality of the study area is also presented in Table 2. The result shows that pH varied between 3.4 and 8.55 with a mean of pH6.04, indicating a slightly acidic condition (Todd and Mays, 2005). The determination of pH of water is useful for water treatment to address probable issues of corrosiveness of iron pipe (Hem, 1991).
Electrical conductivity ranges between 40 and 4,040 (µ/scm) with a mean of 522.7µS/cm. Rao et al (2011) classified EC as type I, if the enrichments of salts are low (EC<1,500 µS/cm); type II, if the enrichment of salts are medium (EC: 1,500 and 3,000 µS/cm); and type

III, if the enrichments of salts are high (EC>3,000 µS/cm). Based on the measured EC of the study samples, 95.4% of the wells fall under the type I (low enrichment of salts) while 2.3% fall under the type II and type III (medium and high enrichment of salts), respectively. Kumar et al. (2009) have reported that concentration of EC in groundwater may be attributed to the high chloride content.

The measured TDS showed a wide variation between 30 and 6,112mg/L with a mean of 430.45mg/L. The TDS include the bicarbonates, sulpfates, and chlorides of calcium, magnesium, sodium, and silica (Karanth, 1987). The degree of TDS has been classified as fresh, if it is less than 1,000 mg/L; brackish, if it is between 1,000 and 10,000 mg/L; saline, if it is between 10,000 to 1,000,000 mg/L; and brine, if it is more than 1,000,000 mg/L (Carroll, 1962). Using this classification system, 95.5% of the sampled wells were classified as fresh water while the remaining 4.5% represents brackish type.

The value of TA, TH, CH, NCH and EA ranged between 28-848, 14-1, 780, 14-520, 0-1, 489.20 and 0-626mg/L, respectively. Corresponding means are 278.01, 198.98, 149.55, 49.42 and 128.45mg/L. (Table 2). The presence of Calcium and Magnesium ions water is responsible for total hardness in water. TH is an important criterion for determining the suitability of water for domestic, drinking, and industrial supplies (Karanth, 1987). According to Heath (1998), TH can be classified as soft, if the TH is between 0 and 60mg/L, moderately hard if it lies between 61 and 120 mg/L, hard if it is from 12 to 180 mg/L, very hard if it is higher than 180 mg/L. Thus, approximately 34.1%, 25%, 22.7% and 18.2% of the sampled wells are very hard, hard, moderately hard and soft, respectively.

The cations (Ca, Mg, Na and K) varied between 12 and 1,200, 2 and 580, 0.63 and 1,080.10 and 0.17 and 52.32mg/L, respectively. The dominant cations are in the order of: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. The anions ($CO_3$, Cl, HCO_3 and SO_4) varied from 0 to 848, 6 to 3,400, 0 to 621.60 and 2 to 1,250mg/L, respectively. The dominant anions are in the order of: $Cl^{-} > CO_3^{2-} > HCO_3^{-} > SO_4$ (Table 2)

On the pattern of relative variation, the Coefficient of variation (C.V %) shows that all the examined groundwater variables with the exception of pH are heterogeneous. For instance, SO_4 tops the list followed by NCH, Na and Cl in that order. Based on the wide variability of the groundwater parameters of the study area, there is the need for proper treatment and routine monitoring of water quality (both surface and groundwater) for a sustainable water resources management

Result of the FA indicates four factors (Table 2) that can be related to the various processes controlling groundwater characteristics in the study area. The rotated factor matrix statistics show that the four factors extracted explain 91.71 % of total variance.

Factor I, which explains 55.54% of the total variance, has strong positive loading on TDS, Cl, Na, NCH, SO_4, TH, Mg, K, EC and Ca. The chemical constituents of Mg^{2+}, Cl^{-}, Na^{+}, K^{+}, and SO_4 represents the dominant components of seawater (Lu et al., 2011). It also reflects the contribution of evaporation, recharge and anthropogenic sources of the groundwater system (Aiman and Mohamed, 2010).

Factor II accounts for 15.81% of the total variance and is characterized by strong positive loading of EA, CO_3 and TA. The rest of the variables show very low loadings. The negative loading of pH, NCH, Na, K, Cl, and SO_4 on factor II confirms that the concentration of these parameters in the groundwater does not contribute significantly to factor II.

Factor III accounts for 13.78% of the total variance and is characterized by strong positive loading of HCO_3, and CH. The rest of the variables show very low loadings. Temperature, NCH, CO_3 and SO_4 indicate negative loading on the factor. Factor IV accounts for 6.58% of the total variance and is characterized by strong positive loading of pH. The remaining variables show very low loadings. Ca, CH and CO_3 indicate negative loading on the factor .
The CA technique was used to classify the parameters of groundwater into categories or clusters based on their similarities (Richard and Dean, 2002; Alvin, 2002). CA is given as**:**

$$d^2_{ij} = \sum_{k=1}^{m} (Z_{ik} - Z_{jk})^2 \qquad (6)$$

where $d^2 ij$ indicate the Euclidean distance, ^{Z}ik and ^{Z}jk are the values of variable k for object i and j, respectively, and m is the number of variables (Thyne et al., 2004 and Anita and Gita, 2011).

The Ward's method was used to carry out CA (Lu et al., 2011) while the hierarchical agglomerative clustering with standardized Square Euclidean distance was used as a dissimilarity measure (Maria et al., 2011; Stephen and Brian, 2005).
The dendrogram of the sampling locations model resulting from the CA of the measured parameters is shown in Figure 2. The CA grouped 44 sampling locations into 4 clusters under the similarity of groundwater quality parameters.

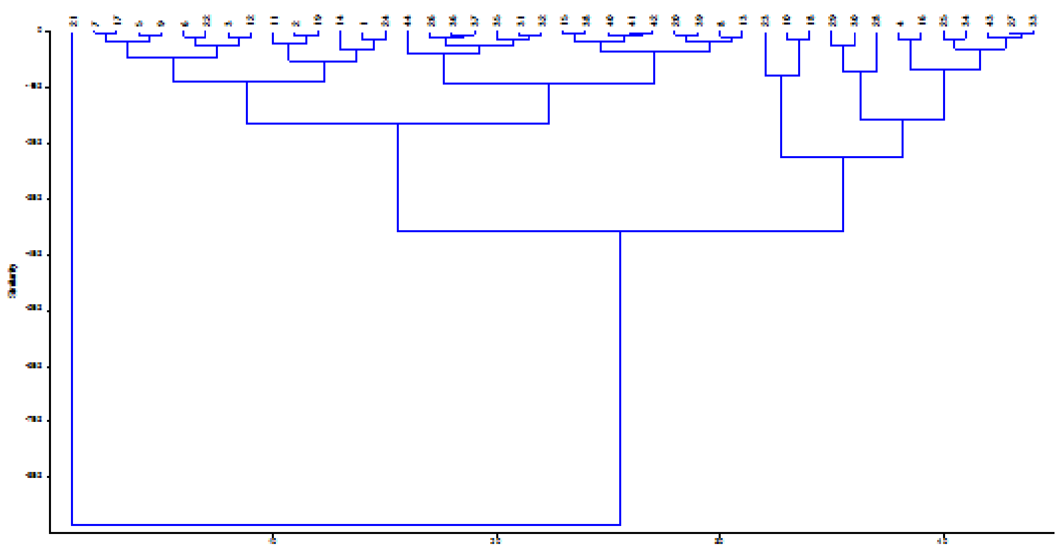

Fig.2: Cluster analysis dendrogram of the sampling locations

Cluster I corresponds to 14 sampling locations (1, 2, 3, 5-7, 9-11, 12, 14, 17, 19, 22 and 24. Cluster II corresponds to 13 sampling locations (4, 10, 16, 18, 23, 25, 27-30, 33-34 and 43. Cluster III corresponds to 16 sampling locations (8, 13, 15, 20, 26, 31, 32, 35-42 and 44) while Cluster IV has location 21.
The result of the adopted CA indicates that for any rapid assessment of groundwater quality within the study area, only one sampling location in each cluster will be required to

represent a fairly accurate spatial assessment of ground water quality for the entire study area. Thus, CA technique reduces the need for a large number of sampling locations.

Irrigation Purpose

Excessive concentrations of dissolved ions in the water used for irrigation affect plants and the physical and chemical parameters of agricultural soil by lowering the osmotic pressure in the plant structural cells (Rao et al.2011). This process prevents water from reaching the branches and leaves, thus reducing the agricultural productivity. Residual sodium carbonate (RSC), Magnesium hazard (MR) and Permeability index (PI) were adopted for the assessment of the suitability of water quality for irrigation purpose in the study area.

Residual Sodium Carbonate

The relation between carbonates concentration and alkaline earths (Ca^{2+}+Mg^{2+}) concentration can be used to explain the suitability of water for irrigation purpose (Rao et al.2011). It is given as:

(Eq.7) $$RSC = [(HCO3 + CO3) – (Ca + Mg)] \qquad (7)$$

where all ionic concentrations are expressed in milliequivalents per liter (meq/L).

Groundwater can be classified as suitable, if the RSC value is less than 1.25 meq/L; marginally suitable, if the RSC value is between 1.25 and 2.50 meq/L; and unsuitable, if the RSC value is more than 2.50 meq/L. High RSC value leads to increase of adsorption of Na^{+} in soil, which reduces the soil permeability and hence do not support plant growth (Rao et al.2011).

The computed RSC value ranged between -101.05 and 16.15meq/L in this study (Table 3). It is observed that approximately 15.9% of the groundwater samples (3, 5, 10 to 12, 15 and 18) have RSC values greater than 2.50meq/L and hence unsuitable for irrigation. About 13.6% of the groundwater samples (6, 7, 15, 17, 22 and 38) fall under the category of marginally suitable (1.25 to 2.50 meq/L) for irrigation. Approximately 18.2% (1, 2,9,13,14,20,23 and 40) were classified as suitable (>1.25meq/L) while the remaining 52.3% (4, 8, 16, 19, 21, 24 to 37, 41 to 44) show negative values of RSC, as the carbonates are less than the alkaline earths.

Magnesium Hazard

Szaboles and Darab (1964) proposed a magnesium hazard classification system for assessing the suitability of water quality for irrigation purpose. They argued that Magnesium damages soil structure, when water contains high Na and high salinity which consequently affects crop yields (Rao et al.2011). Magnesium hazard (MR) is expressed as a ratio of Mg ion concentration to combination of Ca and Mg ions concentration, multiplied by 100 (Eq. 8).

$$MR = \left[\frac{Mg}{Ca + Mg}\right] X\ 100 \qquad (8)$$

where all ionic concentrations are expressed in milliequivalents per liter (meq/L).

Table 3: Computed values of RSC, MR, PI, WQI and WQR of the study area

Code	RSC	MR	PI	WQI	WQR
HW1	0.83	51.82	29.4	42.84	Excellent
HW2	0.46	34.02	27.27	35.54	Excellent
HW3	5.54	14.19	3.43	29.31	Excellent
HW4	-5.78	11.95	8.11	68.95	Good
HW5	4.54	36.54	2.31	49.48	Excellent
HW6	1.98	50.21	3.99	56.16	Good
HW7	2.18	28.73	4.26	35.86	Excellent
HW8	-0.27	19.46	18.8	32.12	Excellent
HW9	0.3	59.82	1.83	109.23	Poor
HW10	12.85	62.68	8.75	112.17	Poor
HW11	5.14	21.33	150	42.28	Excellent
HW12	5.62	59.1	3.7	88.49	Good
HW13	1.13	58.95	40.94	61.08	Good
HW14	0.45	18.05	28.78	68.51	Good
HW15	2.58	16.84	3.06	48.67	Excellent
HW16	-1.49	13.42	5.07	130.78	Poor
HW17	1.86	22.34	1.99	114.25	Poor
HW18	16.15	21.72	9.63	69.57	Good
HW19	-0.74	32.9	32.88	28.45	Excellent
HW20	0.18	37.93	29.78	21.59	Excellent
HW21	-101.05	44.35	31.52	550.97	Water Unfit for drinking
HW22	1.61	70.16	19.34	51.9	Good
HW23	0.84	58.13	29.25	66.2	Good
HW24	-1.59	67.13	21.11	69.15	Good
HW25	-11.17	59.69	27.66	94.74	Good
HW26	-3.48	52.84	46.32	56.82	Good
HW27	-9.36	39.19	24.43	93.16	Good
HW28	-18.71	29.68	24.17	149.42	Poor
HW29	-15.15	30.19	26.89	135.91	Poor
HW30	-20.32	27.2	21.67	132.53	Poor
HW31	-6.67	26.39	15.95	72.02	Good
HW32	-7.55	21.99	14.71	57.44	Good
HW33	-10.89	46.21	20.07	82.83	Good
HW34	-6.57	12.57	29.93	55.41	Good
HW35	-5.76	8.41	27.41	73.4	Good
HW36	-4.28	16.56	27.33	68.74	Good
HW37	-6.71	31.42	26.59	48.37	Excellent
HW38	2.05	21.33	7.41	55.71	Good
HW39	1.62	31.01	21.39	35.47	Excellent
HW40	0.38	32.35	20.93	22.51	Excellent
HW41	-1.27	34.38	3.68	30.46	Excellent
HW42	-2.88	21.52	4.03	67.14	Good
HW43	-10.42	19.68	25.27	83.98	Good
HW44	-11.34	28.77	17.7	91.53	Good

If MR exceeds 50mg/L, such water is considered to be harmful and hence is unsuitable for irrigation.
In this study, MR varied from 8.41 to 70.16mg/L (Table 3). It exceeds 50mg/L in about 25% of the groundwater samples (1, 6, 9, 10, 12, 13 and 22 to 26), hence are not suitable for irrigation purpose. The remaining 75% (2, 3 to 5, 7, 8, 11, 14 to 21 and 27 to 44), have MR less than 50mg/L, hence they are suitable for irrigation purpose.

Permeability Index

Doneen (1964) proposed a method of classifying irrigation water quality using permeability index (PI). PI is a ratio of the combination of Na and the square root of HCO_3 ions concentration to the combination of Ca, Mg, and Na ions concentration, multiplied by 100 (Eq.9).
where all ionic concentrations are expressed in milliequivalents per liter (meq/L).The equation is given as:

$$PI = \left[\frac{Na + \sqrt{HCO3}}{Ca + Mg + Na}\right] X\ 100 \qquad (9)$$

Using PI, water quality can be classified into three classes, i.e., Classes I, II, and III. Class I has 100% maximum permeability and is suitable for irrigation. Class II has 75% permeability and is marginally suitable for irrigation while class III, is associated with 25% permeability and is unsuitable for irrigation purposes (Rao et al.2011).
The computed PI varied from 1.8 to 150.0% in the study area (Table 3). Consequently, approximately 63.6% of the groundwater samples (3 to10, 12, 15, to 18, 22 to 24, 27to 28, 30 to 34, 38 to 42 and 44) are in Class I (unsuitable), 34.1% (1, 2, 13, 14, 19 to 21, 23, 25, 26, 29, 35 to 37, and 43) fall under Class II and are marginally suitable for irrigation purpose while only 2.3% (location 21) is in Class III and is suitable for irrigation purpose.

Industrial Purpose

The water quality requirements for industrial supplies are very broad and virtually almost every industrial sector has its own criteria. The major water quality problems often encountered in industrial operations arise from incrustation and corrosion, which results from the chemical reactions caused by low/ poor water quality (Rao et al.2011).
Johnson (1983) adopted the water quality criteria for determining the incrustation and corrosion properties of water in an area. According to Jacob (1983), water with HCO_3 of more than 400mg/L or TH content greater than 300 mg/L or SO_4 above 100 mg/L, may cause incrustation. Similarly, water with pH less than 7 or TDS value more than 1,000mg/L or Cl above 500mg/L, may cause corrosion.
HCO_3 exceeds the limit of 400mg/L in approximately 6.8% of the groundwater samples (23, 28, 29); SO_4 was found to be above 100mg/L in approximately 2.3% of the groundwater samples (location 1) while TH exceeded 300 mg/L in approximately 11.4% of the groundwater samples (4, 21 and 28 to 30). Based on these statistics, groundwater in these locations can cause incrustation on metal surfaces and hence it is not suitable for industrial use.

Similarly, groundwater is free from corrosion, if the pH is more than 7. In addition, highly mineralized water, with TDS above 1,000mg/L or Cl above 500mg/L may result in corrosion. Based on the measured pH of the samples, approximately 93.2% had less than pH7. The only exceptions are samples from locations 2, 23 and 42. TDS exceeded the limit of 1,000mg/L in only about 4.5% of the samples, i.e., locations, i.e., 21 and 28 while the concentration of Cl exceeded the limit of 500 mg/L in only about 2.3% of the samples. Consequently, it is inferred that corrosion of metals surfaces can arise from the use of these waters for industrial purposes.

Drinking Water Purpose

Water Quality Index (WQI) reflects the composite influence of different water quality parameters. WQI is a very useful and efficient method of assessing the suitability of drinking water quality. The suitability of groundwater for drinking water purpose in the present study was determined based on the method proposed by Brown et al while the World Health Organization (WHO, 2006) guidelines were adopted as the permissible limit.

The computed WQI show that, the WQI ranged between 21.59 and 550.97 within the study area (Table 3). According to the classification system proposed by Sahu and Sikdar (2008), approximately 31.8% of the sampled wells had excellent water quality. These are from locations 1 to 3, 5, 7 to 8, 11, 15, 19 to 20, 37, and 39 to 41). 50%, (4, 6, 12 to 14, 18, 22 to 27, 31 to 36, 38, 42 to 44), 15.9% (9 to 10, 16 to 17, 28 to 30) and 2.3% (21) indicate good, poor and water unfit for drinking, respectively. None of the sampled wells falls under the very poor category (Table 4).

Table 4: Water Quality Index Categories

WQI	Description	Percentage of water samples/Sample locations
< 50	Excellent	31.8% (1 to 3,5,7 to 8,11,15,19 20,37,39 to 41)
50-100	Good	50% (4,6,13 to 14,18,22 to 27,31 to 36,38,42 to 44
100-200	Poor	15.9% (9-10, 16-17 and 28-30)
200-300	Very poor	Nil
>300	Water unfit for drinking	2.3% (21)

Source: Sahu and Sikdar, 2008

Summary, Conclusion and Recommendation

Results of the various analysis conducted show that depth to water table and depth of the sampled wells ranged between 0.45 and 3.7m and 1.4 and 5.25m, respectively with corresponding mean being 1.76 and 3.11m.

pH varied between 3.4 and 8.55 with a mean 6.04, indicating a slightly acidic condition. 95.4% of the measured EC fall under the Type I (low enrichment of salts) while 2.3% are in Types II and III (medium and high enrichment of salts).

TDS posted a wide variation between 30 and 6,112mg/L with mean value of 430.45mg/L. Based on the classification of TDS, 95.5% of the sampled wells are classified as fresh water while 4.5% are brackish. Similarly, TH level in the samples suggests that 34.1%, 25%, 22.7% and 18.2% are very hard, hard, moderately hard and soft waters, respectively.

Both cations (Ca, Mg, Na and K) and anions (CO_3, Cl, HCO_3 and SO_4) had wide variation. The C.V shows that all the examined groundwater variables with the exception of pH are heterogeneous.

FA extracted four factors which explained 91.71 % of total variance. Factor I explains 55.54% of the total variance, with strong positive loading on TDS, Cl, Na, NCH, SO_4, TH, Mg, K , EC and Ca. Factor II accounts for 15.81% of the total variance, and is characterized by strong positive loading of EA, CO3 and TA. Factors III and IV account for 13.78%, 6.58% of the total variance, respectively and are characterized by strong positive loading of HCO3 and CH; and pH respectively.

The dendrogram of the sampling locations using CA of the measured parameters grouped the 44 sampling locations into 4 clusters under the similarity of groundwater quality parameters. This implies that one sample each from a cluster is representative of the group for sample collection within the study area.

RSC ranged between -101.05 and 16.15meq/L; approximately 15.9% of the groundwater samples being unsuitable for irrigation while 13.6%, 18.2% are marginally suitable and suitable, respectively. MR varied from 8.41 to 70.16meq/L; about 75% is suitable for irrigation purposes while the remaining 25% are not. Similarly, PI varied from 1.8 to 150meq/L; approximately 63.6% of the samples are unsuitable while 34.1% and 2.3% fall under marginal and suitable uses for irrigation, respectively in the study area.

6.8% of the groundwater samples exceeded the limit of HCO_3 while 2.3% and 11.4% of the samples exceeded the limits of SO_4 and TH; hence are not suitable for industrial uses. pH, TDS and Cl in the waters also largely precludes their industrial use.

WQI ranged between 21.59 and 550.97mg/L. Approximately 31.8% had excellent water quality while 50%, 15.9% and 2.3% indicate good, poor and water unfit for drinking purposes, respectively.

Based on the computed WQI, it is concluded that though waters of the HDW within the LCPS are suitable for drinking purposes, appropriate treatment methods to make it more potable and fit for human consumption should be employed. On the suitability for irrigation purpose, it is concluded that the water is not suitable for irrigation purpose due to the high computed RSC and PI.

Routine monitoring and periodic water quality testing coupled with appropriate treatment for agricultural activity in the study area are also recommended.

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