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Season-Induced Variation in Water Table Depth and Selected Chemical Parameters of Groundwater in Lagos Coastal Plain Sand Aquifer, Nigeria

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ABSTRACT: In-situ measurement of depth to aquifer and water table was undertaken in 45 protected dug wells over two seasons. Samples were also analyzed for pH, EC, TDS, Ca, Cl, K, HCO_3, CO_3, SO_4, Mg, K, and Na using universally accepted laboratory techniques. The study was aimed at examining seasonal variations in the chemistry of groundwater in the Lagos Coastal Plain Sand aquifer and its potability using the WHO standards. The study area covered parts of the Lagos Metropolis and the entire settlements of Ikorodu, Epe, and Badagry. The sample locations were mapped with ArcMap 9.3 software while the data were analyzed using descriptive statistics, paired sample T-test, correlation and multivariate statistical techniques using SPSS software 17.0 version. The result shows that about 60% of the samples had pH below the WHO minimum standard of 6.5 in both the dry and wet seasons. Mean EC and TDS levels were excessively high at Igando in both seasons. Some major ions, calcium, magnesium, potassium and sodium, and chloride exceeded the WHO limit at Oko-Oba, Ilogbo, Shomolu and Shogunle in the dry season. They were also excessively high in the wet season at Igando, Oko-Oba, Odo-Onosa, Ilogbo, Shomolu, and Shogunle. Correlation analysis shows that a significant relationship exists between the parameters at $p<0.05$ with the exception of Mg^{2+} and K^+ in both seasons. The result of the paired sample T-test also shows significant variations among pH, Ca^{2+}, HCO_3^- and Mg^{2+} with higher mean values in the dry than the wet season except for pH. Factor analysis identified salinity and anthropogenic activities as the two major sources of pollution. These account for about 74.48% and 84.21% of the total variances in dry and wet seasons, respectively. Consequently, protection of the recharge areas of the aquifer from environmental pollution and formulation and enforcement of appropriate policies that will stem the rate of indiscriminate groundwater exploitation and prevention of saline water intrusion in the coastal settlements are recommended.

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Groundwater is a major source of water for human consumption worldwide (World Water Assessment Programme (WWAP, 2009). It is crucial for the livelihoods and food security of about 1.2 to 1.5 billion rural households in Africa and Asia (Comprehensive Assessment of Water Management in Agriculture, 2007). Groundwater also plays a vital role in the hydrological cycle by sustaining a wide range of terrestrial, aquatic and marine ecosystems (Morris *et al.,* 2003). According to AQUASTAT (2011), the rate of groundwater abstraction is estimated at about 1,000 km^3 per year comprising about 67% abstracted for irrigation, 22% for domestic, and 11% for industrial uses. In Nigeria, potential groundwater resource is estimated at about 51.9 billion m^3 per annum (Federal Ministry of Water Resources (MWR, 2007). However, its availability varies with rainfall, location, and geological formations. The nation's geology is dominated by the Basement Complex Rocks (BCR) covering the greater parts of the north while the Sedimentary rocks span the Lagos-Osse and the Niger-Delta Basins. Along the coastal zone of the south west, the geology is characterized by recent littoral sandy alluvium and coastal plain sands. The major aquifer in this basin occurs in sands and overburden with shales and clays forming impermeable horizons (Longe *et al.,* 1987). Though groundwater is reliable in terms of its quality, the increasing risks of anthropogenic activities have resulted into quality degradation which translates directly into socio-economic impacts that constitute a major global concern (United Nation Education Programmee, 2010). For instance, over-abstraction of groundwater has been implicated in the deterioration of water quality through increased concentrations of naturally occurring compounds as reported in India where fluorosis threatens millions of people (Esteller et *al.,* 2012; UNESCO, 2012). Increased saltwater intrusion into coastal aquifers was also reported in Cyprus and the Gaza strip (Stellar, 2010). Indiscriminate disposal of liquid and solid waste,

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inorganic and organic chemicals, manure from livestock, irrigation return flows, and mining residues have also been reported as potential sources of groundwater quality deterioration (UNESCO, 2012). The introduction of chemical pollutants such as heavy metals, toxic substances, and persistent organic products (POPs) has also been found to be responsible for groundwater quality degradation. Indeed, degraded water quality is responsible for the death of about 3.5 million people annually in developing countries (WHO, 2008). These arise from water-related diseases such as diarrhea, intestinal nematode infections, trachoma, schistosomiasis, malaria, onchocerciasis, dracunculiasis, lymphatic filariasis and dengue (UNESCO, 2012). Similarly, high levels of arsenic were also detected in a pond used for water supply in Bukuru, and high fluoride in parts of Kaltungo, Billiri, Gombe, Pindiga, Dass and Langtang, as well as in some boreholes in Abia, State, Nigeria (Ince *et al.,* 2010). The problem of saltwater intrusion was also reported to have threatened water supplies in coastal settlements around Uju, Guma and Songo areas of Benue state (Ince *et al*., 2010).

Methods used for water quality assessment include multivariate statistical techniques such as factor analyses, principal component analysis, cluster analysis, etc. Their uses have assisted in providing a solution to various environmental problems and a better understanding of the groundwater flow regime (Meng and Maynard, 2001; G¨uler *et al*., 2004 and Thyne *et al*., 2004).

The knowledge and understanding of chemical elements in groundwater and their health implications in humans, therefore, is very important for policy formulation and wellbeing of the populace tapping from the coastal plain sand aquifer. Therefore, this study seeks to contribute and fill this gap in knowledge with the aim of examining the seasonal variations in water table depth of major ions in groundwater from the Lagos coastal plain sand aquifer.

MATERIALS AND METHODS

Description of the study area: The study area covers the Coastal Plain Sands (CPS) Aquifers of Lagos, Nigeria. It lies approximately between Latitudes $6^{0}30^{|}$ N and 6^{0} $40^{|}$ N and Longitudes 3^{0} $00^{|}$ E and $4^{0}00^{|}$ E (Fig. 1). It covers parts of the Lagos Metropolis and the entire settlements of Ikorodu, Epe, and Badagry. Its area coverage is about 73.63km^{2}.

The climate is tropical with an average temperature of about 30^{0}C. Mean annual rainfall is about 1,532mm (Odumosu *et al.,* 1999). The vegetation is predominantly tropical type. The area is drained by Rivers Abesan, Berre, Ibu, Ore and Owo. Groundwater flows generally north to south with two small cones of depression in Apapa and Ikeja due to intense groundwater abstraction.

The geology is underlain by Benin Formation and is made up of unconsolidated sands and gravels (Adelana *et al.,* 2008). The hydrogeology is characterized by sand and clay from the underlying aquifer formation (Longe, 2011). The major aquifer formations in the area are the CPS categorized into four types namely the recent sediments/alluvium, the upper and lower CPS and the Abeokuta formation (Longe, 2011). Groundwater is found in semi-confined to unconfined aquifers consisting of sand and clay (Adelana *et al.,* 2008). Variation in the thickness between the first and third CPS aquifers ranges between 200m and 250m, respectively (Adelana *et al.,* 2008) while the mean groundwater storage of the first aquifer is estimated at about 2.87×10^{3} m^{3}.

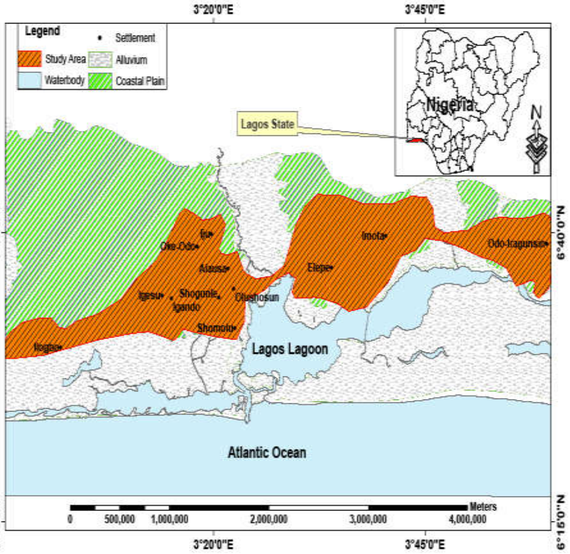

Fig. 1. The Study Area

Water table depth ranges between 0.4 and 21m with an annual fluctuation of less than 5m (Asiwaju-Bello and Oladeji, 2001). The water table of the upper coastal plain sand aquifer (UCPS) has an annual fluctuation that is less than 5m (Asiwaju-Bello and Oladeji, 2001). It is tapped by hand-dug wells and is usually prone to pollution because it is near the ground surface. In contrast, the lower coastal plain sand (LCPS) aquifer is tapped by boreholes and is not vulnerable to pollution. It is the most productive and exploited aquifer in Lagos State. Indeed, more than 30% of groundwater supply in Lagos and its environs tap from the CPS aquifer. This source complements the surface water from Adiyan, Iju, and Isashi.

The major challenge of groundwater resources in the LCPS is over-abstraction due to increasing demand resulting from high population growth and increased industrial production. According to Longe (2011), the surface water sources are also no longer reliable due to pollution and attendant high cost of treatment. Thus, groundwater has continued to serve as the major source of water supply in the state due to its relatively better quality and availability through the various mini and micro waterworks. The mini and micro waterworks have a total design capacity of about 53.2Mgd and 16.3Mgd, respectively. Corresponding total supplies are 2,797.38Mgd and 1,208.77Mgd (Lagos Water Corporation, 2012).

Sample collection and treatment: Data used for this study included those generated from a set of geological and topographical maps covering Sheet 68, the former having a scale of 1: 250,000 while the latter has 1:50,000. The maps cover Lagos NE1 & 2, Ibeju 280A, Ijebu-Ode 279 SE and SW. Groundwater samples were collected from forty-five (45) protected dug wells and stored in clean 150ml polyethylene bottles and preserved in ice chests for onward delivery to the Chemistry Department, University of Lagos, Akoka for analyses.

Depth to the water table and aquifer depth were measured using the sound meter and measuring tape with a plumb line, respectively. Some water quality parameters were also measured in-situ; pH was measured using a pocket pH-102 meter (RoHS) after being calibrated with a standard buffer solution; EC was measured using EC DiST-3 meter (HANNA, HI 98303) while TDS was measured with the TDS/TEMP (HM Digital) meter. The cations (Na^+ K^+, Ca^{2+} Mg^{2+}) and anions (Cl^-, HCO_3^-, CO_3^{2-} and $SO4^{2-}$ were determined in the laboratory using standard methods as suggested by the American Public Health Association (APHA, 1998).

Co-ordinates of the sample locations were recorded with a global positioning system (GPS) (Garmin map, 76CSX model) and thereafter were exported into ArcMap 9.3 software to produce the map of the sampling locations (Fig.2).

Sample analysis: The data were analyzed using descriptive statistics. Paired sample T-test and multivariate statistical techniques were also employed as contained in the SPSS software 17.0 version to test for variation in the concentrations of the parameters induced by season. The results of the groundwater parameters were compared with the World Health Organization Standard (WHO) for potable water use in the study area.

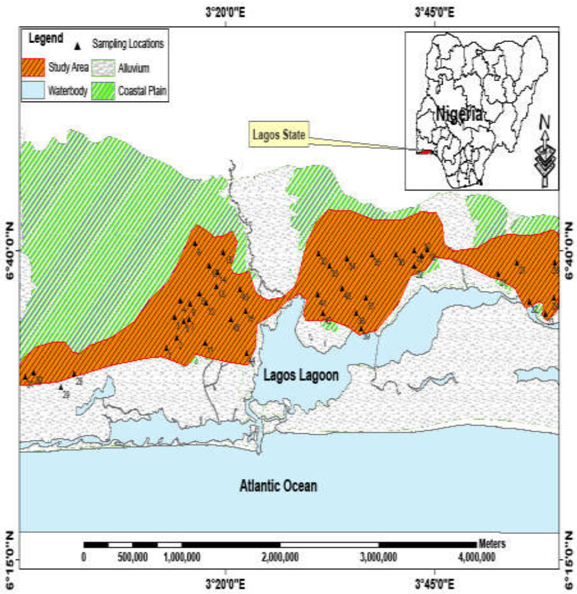

Fig. 2. Sampling Locations

RESULTS AND DISCUSSION

Well characteristics and physicochemical properties of groundwater: Depth to water table (DWT) ranged from 1.9 to 27.7m and 0.8 to 29.2m in the dry and wet seasons, respectively (Fig. 3). The corresponding mean was 14.84 and 15.16m. Aquifer depth was between 2.0 and 30.96m with a mean of 17.48m. pH varied between 3.02 and 7.3 in the dry season and from pH3.6 to 7.4 in the wet. The corresponding mean was pH5.14 and 5.99. It was observed that in dry season all the sampling locations with the exception of Igando and Alausa had pH6.5 which is lower (more acidic) than the minimum prescribed by WHO (2006) for potable water. In the wet season, only 27 locations representing 60% of the sampling locations had a pH that is lower than the WHO standard. Figure 4 depicts the pH statistics compared with the WHO potable water standard.

EC ranged between 13 and 9,779 µScm with an average of 343.8µScm^{-1} in the dry season while it was between 15 and 6,600µScm with a mean of 276.36µScm in the wet season. TDS varied from 10 to 4,890mg/L in the dry season and between 11 and 3,300mg/L in the wet season. The corresponding mean was 192.07 and 157.69mg/L respectively. It was observed that in all the sampling locations, EC and TDS values were within the WHO limits of 1,000µScm to 500mg/L respectively except at Igando in both seasons. High values of these parameters can result from the infiltration of leachates from dump sites in the area.

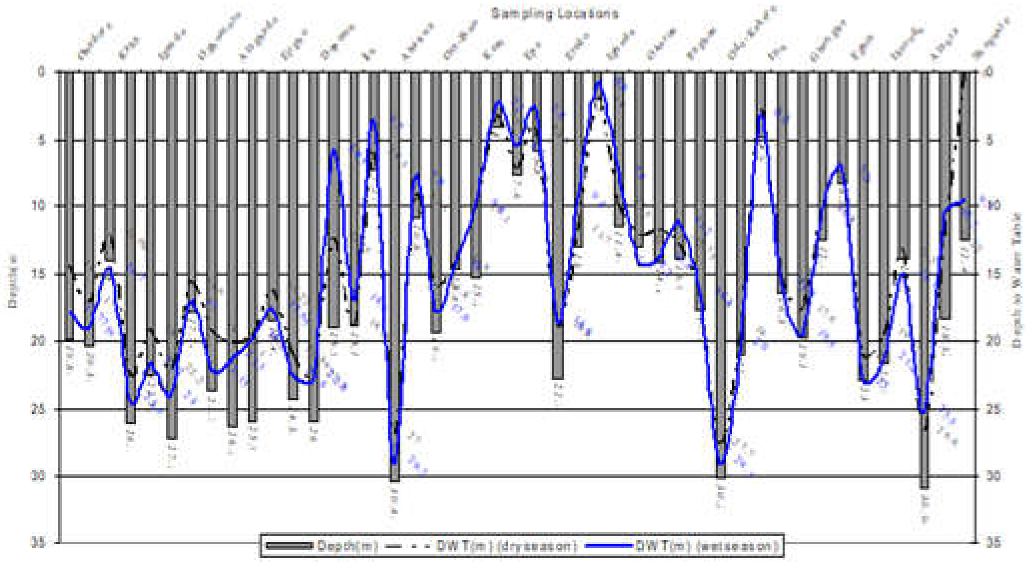

Fig. 3. Depth of Aquifer and Water Table Depth (DWT) in Dry and Wet Seasons

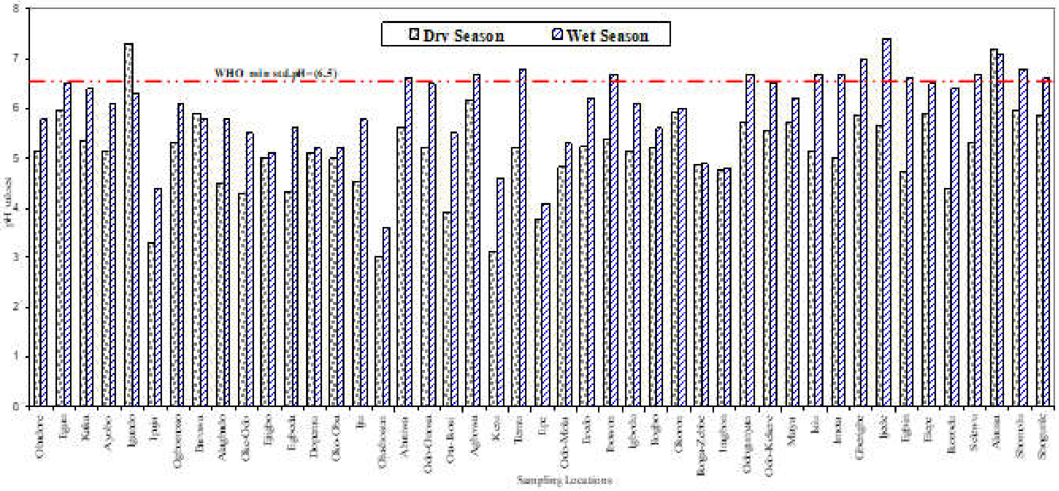

Fig. 4. Groundwater pH and WHO Potable Water pH Standard in Dry and Wet Seasons

Na and Ca varied between 1.87 and 1,350, 0.77 and 90mg/L, respectively. Both Mg and K were from 0.00 to 222 and 0.00 to 51.69 mg/L, respectively. The corresponding means are 39.68, 25.56, 12.61 and 3.62mg/L in the dry season. In all samples, the WHO limit of 30mg/L was exceeded. In the wet season, Na fluctuated between 1.96 and 1,142mg/L; K was from 0.08 to 1,102mg/L; Ca varied between 11.00 and 43.1mg/L while Mg was from 0.04 to 6.8mg/L. Na, K, Ca and Mg had a respective mean of 47.45, 28.63, 10.25 and 1.0mg/L. The high concentration of Ca^{2+} and Mg^{2+} can be attributed to the geology of the area (Todd & Mays, 2005).

Chloride, bicarbonate, and sulfate ranged between 4 and 2,800, 10 and 286.6 and 1.2 to 82mg/L with the corresponding mean of 92.24, 85.34 and 5.8mg/L respectively in the dry season. In the wet season, chloride, bicarbonate, sulfate, and carbonates varied between 2.00 and 2,250, 8.00 and 228, 1.00 and 46.00 and under detection limit to 0.1mg/L, respectively. Correspondingly, these parameters were 77.2, 60.36, 4.71 and 0.03mg/L on the average.

The high concentration of these parameters can be linked to infiltration of leachates from dump sites, sewage, and wastewater. In addition, K^{2+} exceeded WHO limit of 10mg/L at Oko-Oba, Ilogbo, Shomolu and Shogunle in a dry season whereas in the wet season, it exceeded the WHO limits at Igando, Oko-Oba, Odo-Onosa, Ilogbo, Shomolu, and Shogunle. The observed high concentration of K^{2+} in these locations can also be linked with the geology of the area (Todd and Mays, 2005). Calcium is present in all natural waters although its level depends on the rock types through which the water flows. Ca^{2+} is usually present in the form of carbonates, bicarbonates, sulfate, chloride, and nitrate. Ca^{2+} plays a vital role in bone structure, muscle contraction, nerve impulse transmission, and blood clotting. About 99% of Ca^{2+} is found in bone and teeth while the remainder is in soft tissue. Low intake of Ca^{2+} has been reported to cause osteoporosis, rickets, and hypertension (Kurtz and Morris, 1993). Magnesium is one of the earth's most common elements and forms highly soluble salts. The high concentration of Mg^{2+} is undesirable in potable water because it causes scale formation, cathartic and diuretic effects. Though magnesium is an essential co-factor for more than 350 enzyme systems, it is also responsible for energy metabolism, nucleic acid synthesis, and cellular balance, cardiovascular and hormonal functions (Tuthill and Calabrese, 1991). Low magnesium intake is responsible for osteoporosis, increased calcium balance, insulin resistance, metabolic syndrome, increased oxidant stress and increased risk of cardiovascular disease (Tuthill and Calabrese, 1991).

Table 1. Paired sample statistics and correlation of groundwater parameters

Parameters		Mean	S.D	Std. Error Mean	Correlation	p- value
Pair 1	pH	5.148	0.882	0.131	0.736	0.000
	pH*	5.989	0.841	0.125		
Pair 2	EC	343.80	1444.980	215.405	0.999	0.000
	EC*	276.36	973.214	145.078		
Pair 3	TDS	192.07	721.246	107.517	0.998	0.000
	TDS*	157.69	485.805	72.420		
Pair 4	Ca^{2+}	25.56	20.223	3.015	0.777	0.000
	Ca^{2+}*	10.245	10.172	1.5163		
Pair 5	Mg^{2+}	12.61	32.775	4.886	0.161	0.291
	Mg^{2+}*	1.000	1.369	0.204		
Pair 6	Na^{+}	39.676	200.106	29.830	0.991	0.000
	Na^{+}*	47.450	169.037	25.199		
Pair 7	K^{+}	3.624	7.962	1.1869	0.085	0.578
	K^{+}*	28.629	163.847	24.425		
Pair 8	Cl^{-}	92.24	414.202	61.746	0999	0.000
	Cl^{-}*	77.20	333.001	49.641		
Pair 9	HCO_3^{-}	84.451	57.627	8.591	0.883	0.000
	HCO_3^{-}*	60.36	42.896	6.395		
Pair 10	SO_4^{2-}	5.80	11.785	1.757	0.989	0.000
	SO_4^{2-}	4.71	6.518	0.972		

Wet season parameters are in asterisk

Table 2. Seasonal paired samples T-test of groundwater parameters

Variables		Paired Differences					t	df	p-value
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	pH – pH*	-0.841	0.627	0.093	-1.02951	-0.652	-8.998	44	0.000
Pair 2	EC – EC*	67.444	475.211	70.840	-75.325	210.214	0.952	44	0.346
Pair 3	TDS – TDS*	34.378	238.035	35.484	-37.136	105.891	0.969	44	0.338
Pair 4	Ca^{2+} – Ca^{2+}*	15.3167	13.890	2.071	11.14364	19.489	7.397	44	0.000
Pair 5	Mg^{2+} – Mg^{2+}*	11.613	32.583	4.857	1.8237	21.402	2.391	44	0.021
Pair 6	Na^{+} – Na^{+}*	-7.774	39.486	5.886	-19.63666	4.089	-1.321	44	0.193
Pair 7	K^{+} – K^{+}*	-25.005	163.361	24.352	-74.08424	24.074	-1.027	44	0.310
Pair 8	Cl^{-} – Cl^{-}*	15.040	83.241	12.409	-9.968	40.048	1.212	44	0.232
Pair 9	HCO_3^{-} - HCO_3^{-}*	24.096	28.213	4.206	15.6195	32.572	5.729	44	0.000
Pair 10	SO_4^{2-} - SO_4^{2-}*	1.093	5.426	0.809	-0.537	2.723	1.352	44	0.183

The presence of calcium and magnesium ions in water is responsible for total hardness (TH) in water. TH is an important criterion for determining the suitability of water for various uses e.g. domestic, drinking, and industrial (Karanth, 1987). Sodium in the drinking water supply is a major health concern for most people with heart disease, hypertension, kidney disease, and circulatory illness. According to Baron (1997) increased intake of Na^{+} is responsible for hypertension while the acute effect of high levels of Na^{+} in drinking water may result to nausea, vomiting, convulsion, muscular twitching and rigidity and cerebral and pulmonary oedema (Baron, 1997). High intake of Na^{+} can also result in heart failure, gastrointestinal infections, loss of fluid leading to dehydration and permanent neurological damage in infants (Amjad *et al.,* 2010). Low potassium can also result in excessive loss of extracellular fluid, excessive dieresis or prolonged malnutrition (Amjad *et al.,* 2010).

Table 3. Correlations Matrix of Parameters in the Dry Season

Variable		**pH**	**EC**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Cl^{-}**	**HCO_3-**	**SO_4^{2-}**
pH	Correlation	1									
	p-value										
EC	Correlation	0.361*	1								
	p-value	0.015									
TDS	Correlation	0.351*	**1.00****	1							
	p-value	0.018	0.00								
Ca^{2+}	Correlation	0.218	0.237	0.249	1						
	p-value	0.150	0.116	0.099							
Mg^{2+}	Correlation	**0.421****	**0.977****	**0.976****	**0.381****	1					
	p-value	0.004	0.00	0.00	0.010						
Na^{+}	Correlation	0.362*	**0.998****	**0.997****	0.208	**0.973****	1				
	p-value	0.015	0.00	0.00	0.170	0.00					
K^{+}	Correlation	0.018	0.089	0.099	-0.067	0.032	0.084	1			
	p-value	0.905	0.561	0.517	0.662	0.836	0.583				
Cl.	Correlation	0.352*	**0.999****	**0.998****	0.213	**0.971****	**1.000****	0.097	1		
	p-value	0.018	0.00	0.00	0.160	0.00	0.00	0.527			
HCO_3^-	Correlation	0.036	0.022	0.019	0.078	0.059	0.022	-0.064	0.018	1	
	p-value	0.813	0.884	0.900	0.610	0.701	0.886	0.675	0.909		
SO_4^{2-}	Correlation	0.327*	**0.991****	**0.992****	0.242	**0.965****	**0.989****	0.069	**0.990****	0.012	1
	p-value	0.028	0.00	0.00	0.109	0.00	0.00	0.652	0.00	0.935	

Table 4. Correlations Matrix of Parameters in the Wet Season

Variable		pH	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^-	SO_4^{2-}	CO_3^{2-}
pH	Correlation	1										
	p-value											
EC	Correlation	0.014	1									
	p-value	0.928										
TDS	Correlation	-0.012	**0.999****	1								
	p-value	0.936	0.00									
Ca^{2+}	Correlation	-0.084	-0.010	0.012	1							
	p-value	0.582	0.949	0.936								
Mg^{2+}	Correlation	-0.222	0.176	0.186	0.297*	1						
	p-value	0.142	0.248	0.220	0.048							
Na^{+}	Correlation	0.009	**0.994****	**0.994****	-0.029	0.124	1					
	p-value	0.953	0.00	0.00	0.850	0.416						
K^{+}	Correlation	0.051	**0.994****	0.990**	-0.070	0.115	**0.989****	1				
	p-value	0.738	0.00	0.00	0.649	0.452	0.00					
Cl^{-}	Correlation	0.018	**0.996****	**0.995****	-0.053	0.139	**0.995****	**0.997****	1			
	p-value	0.906	0.00	0.00	0.731	0.362	0.00	0.00				
HCO_3^-	Correlation	**0.476****	**0.545****	**0.529****	-0.154	-0.211	**0.542****	**0.586****	**0.564****	1		
	p-value	0.001	0.00	0.00	0.313	0.165	0.00	0.00	0.00			
SO_4^{2-}	Correlation	-0.037	**0.974****	**0.976****	0.022	0.176	**0.979****	**0.967****	**0.974****	**0.525****	1	
	p-value	0.809	0.00	0.000	0.885	0.248	0.00	0.00	0.00	0.00		
CO_3^{2-}	Correlation	-0.035	**0.436****	**0.435****	0.062	0.259	**0.418****	**0.449****	**0.440****	0.293	**0.448****	1
	p-value	0.822	0.003	0.003	0.685	0.086	0.004	0.002	0.002	0.050	0.002	

** significant at $p<0.01$; *significant at $p<0.05$

Chloride in drinking water is generally not harmful to humans except at high concentrations. Chloride may impart a salty taste to drinking water and can also exert a significant effect on the rate of corrosion of steel and aluminum or metals used in water handling systems. It can also result in gastrointestinal problems, irritation, diarrhea and dehydration (WHO, 1999).

Seasonal variations of groundwater parameters: The paired sample statistics and correlation of the examined parameters is presented in Table 1. The result shows that there are significant correlations at $p<0.05$ among most of the examined parameters with the exception of Mg^{2+} and K^{+} in both seasons. Similarly, the seasonal paired sample T-test shows significant variations among pH, Ca^{2+}, HCO_3^{-} and Mg^{2+} in the study area (Table 2).

Seasonal relationship of groundwater parameters: The seasonal relationships of groundwater parameters for both dry and wet seasons are presented in Tables 3 and 4, respectively. The results show that there is a significant correlation at *$p < 0.05$* among EC and TDS in most of the parameters. The strong correlations among these parameters suggest anthropogenic impacts and marine influence on the groundwater system (Aiman and Mohamed, 2010; Rao *et al.,* 2012).

Table 5. Rotated factor analysis in dry season

Parameters	**Factor Components**	
	F_1	**F_2**
pH	0.40	0.32
EC	0.99	0.02
TDS	0.99	0.02
Ca^{2+}	0.26	0.62
Mg^{2+}	0.98	0.17
Na^{+}	0.99	0.01
K^{+}	0.14	-0.60
Cl^{-}	0.99	0.00
HCO_3^{-}	-0.01	0.57
SO_4^{2-}	0.99	0.02
% of variance	61.84	11.64
Cumulative %	61.84	73.48

Table 6. Wet Season Rotated Factor Analysis.

Parameters	Factor components		
	F1	F2	F3
pH	-0.06	0.92	-0.05
EC	0.99	0.06	0.07
TDS	0.99	0.04	0.08
Ca^{2+}	-0.09	0.04	0.82
Mg^{2+}	0.15	-0.32	0.72
Na^{+}	0.99	0.05	0.02
K^{+}	0.99	0.10	0.00
Cl^{-}	0.99	0.07	0.02
HCO_3^{-}	0.55	0.69	-0.15
SO_4^{2-}	0.98	0.02	0.09
CO_3^{2-}	0.47	0.10	0.39
% of variance	59.36	15.58	9.27
Cumulative %	59.36	74.94	84.21

Multivariate statistics of the seasonal variations of groundwater parameters: The results of the factor analysis (FA) in dry season indicate that two factors explain 74.48% of the total variances (Table 5). Factor I accounts for 61.84% of the total variance with strong loading on EC, TDS, Na^{+}, Cl^{-}, SO_4^{2-}, and Mg^{2+}. These parameters represent seawater constituents (Lu et al., 2012). Factor II accounts for 11.64% of the total variance and is characterized by medium loadings of Ca^{2+}, K^{+} and HCO_3^{-}. In the wet season, the rotated factor matrix accounted for 84.21% of the total variance (Table 6).

The wet season FA shows that factor I accounts for 59.36% of the total variance, with high loadings on Cl^{-}, EC, Na^{+}, K^{+}, TDS, and SO_4^{2-}. These parameters (Cl^{-}, Na^{+}, K^{+}, and SO_4^{2-}) represent the dominant components of salinity and anthropogenic impacts on the groundwater system (Aiman and Mohamed, 2010; Lu *et al.,* 2012). Factor II accounts for 15.58% of the total variance and is characterized by high to medium positive loading of pH and HCO_3^{-}. While factor III accounts for 9.27% of the total variance and is characterized by strong and medium positive loading of Ca^{2+} and Mg^{2+} respectively (Table 6). The application of FA to reduce the number of parameters needed to explain the groundwater data in the study area is medium because eight out of the parameters were needed to explain 73.48% of the variance in the data set across two factors comprising of ten parameters in the dry season. In the wet season, eight out of the parameters were needed to explain 84.21% of the variance in the data set across the three factors comprising eleven parameters. It is to be noted that the application of FA in this study successfully identified the most significant sources of pollution in the groundwater of the study area.

Conclusion: The findings of this study revealed that DWT is relatively high in the wet season compared to the dry season. The degree of the seasonal relationship between the examined parameters shows significant correlations at $p<0.05$ with the exception of Mg^{2+} and K^{+} in both seasons. Furthermore, the seasonal paired sample T-test also shows significant variations among four parameters, pH, Ca^{2+}, HCO_3^{-} and Mg^{2+} while Factor analysis also suggests that the two major factors responsible for pollution are salinity and anthropogenic activities undertaken in the study area. Consequently, it is recommended that protection of recharge areas of the aquifer from environmental pollution resulting from various human activities is essential.

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