Conceptualization of Pollution of Groundwater Resources in Ilaje Area, Nigeria, West Africa: Contribution From Hydrogeochemical and Numerical Index Techniques

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Abstract

Ilaje is a coastal settlement in Nigeria with a large number of its population depending on groundwater, through hand-dug wells, for domestic and irrigation use. Due to the vulnerability of coastal aquifers to contamination, for this study, 29 groundwater samples were analyzed for physicochemical parameters, major ions and trace elements to appraise the quality, pollution status and health risks of Ilaje water sources. Hydrogeochemical analysis revealed cationic, anionic and trace metals concentrations in these orders: Na^+>K^+>Mg^{2+}>Ca^{2+}, HCO_3^->Cl^->SO_4^{2-}>NO_3^-, and Fe^{2+}> Co^{2+}>Pb2$^+$> Ni^{2+}> Mn^{2+} respectively and prevalence of Na-Cl facies suggesting imprints of saline-water intrusion. The results from the pollution evaluation and irrigation index methods revealed that the groundwater has significant trace metal pollution and has low to no suitability for irrigation. Furthermore, in this study, the carcinogenic and non-carcinogenic health risks posed by ingestion of the water to adults and children were determined using Probability of Cancer Risk, Chronic Daily Intake, Health hazard Quotient and Indices. It was discovered that upon exposure to the water for a long period of time, residents are prone to illnesses such as kidney disfunction, brain damage, diabetes and cancer. The pollution of the shallow groundwater resources hinges on the highly porous and permeable nature of the alluvial aquifer system of the area. This work recommends solutions like proper monitoring system and treatment plants installation to control the problem of groundwater pollution in the area.

Introduction

The 40% distribution of the world's population in the coastal areas can be attributed to ocean navigation, coastal fisheries, tourism, and recreation. In spite of the suitability of the coastal environment, nature and human forces also drive negative impacts to groundwater resources. Subsurface freshwater in this environment is endangered due to saltwater encroachment into the coastal aquifers and human-caused pollution. The occurrence of potable water in coastal environments have been influenced by varying factors such geology, relief, saltwater intrusion, climate change, geogenic factors (water–rock interaction, and changes in space and time) and human activities (Manikandan et al., 2012, Todd and Larry 2005; Srinivasamoorthy et al., 2014; Bhattacharya and Bundschuh, 2015). Additional degradation to aquifers may be caused by fertilizer application, unsustainable farming techniques, improper sewage disposal, mining, oil exploration and exploitation (Rahman et al., 2017; Islam et al., 2016; Hossain et al., 2018; Bodrud-Doza et al., 2020; Idoko, 2010). Demand for water continues to soar alongside an annual rise in groundwater extraction due to population expansion (Ahmed et al., 2010; Rahman et al., 2017). This overexploitation, has led to reduction of water tables thereby promoting saline water encroachment causing degradation of water quality (Hoque et al., 2007; Akhter and Hossain, 2017; Hossain et al., 2018)

Understanding the quality and potability of groundwater in coastal areas has become an urgent issue. The adverse effect of drinking non-potable water from these areas has led to increased cardiovascular diseases, diarrhea, and abdominal pain (Chakraborty et al., 2019; Ohwoghere, 2012; Davraz et al., 2016; Sarvestani and Aghasi2019) Ignorance of the source of the contaminants has contributed to the increasing impact to communities from non-potable coastal groundwater (Liu et al., 2017). Most illness linked to water ingestion are common to coastal areas in developing countries (Ayeni et al; 2011, Aderibigbe et al; 2008). Studies on the water chemistry are scarce and reports of such do not receive wide attention. In-spite of these challenges, unguided digging of wells and drilling of boreholes continue to occur in coastal areas due to shallow water tables (Offodile, 2002).

Several studies of groundwater quality in coastal aquifers hinged on the accurate assessment of physicochemical parameters, major ions and heavy metals present in groundwater (Didar-Ul Islam et al., 2017; Asiwaju-Bello *et al*., 2021; Islam et al., 2017). Numerical indices such as Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Kelley Ratio (KR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Permeability Index (PI), Chloro Alkaline Index (CAI), Pollution Index of Groundwater (PIG), Potential Salinity (PS), Saltwater Intrusion parameter, Sulphate to Chloride ions concentration, Chronic Daily Intake (CDI), Health Hazard Quotient (HQ), Health Hazard Index (HI), Probability Cancer Risk (PCR) have been explored by researchers for qualitative evaluation of coastal groundwaters. Ionic ratios also have been used as guide to the sources of waters in the coastal environments. These assessments are made possible due to the concentration and dilution of ions in the waters. Results from these researches have been used to increase the resilience of coastal groundwater against carcinogenic and non-carcinogenic risks and to reduce health effects to the consumers (children and adults and possibly animals) and agricultural activities (USEPA, 2001; USEPA, 2009 USEPA, 2012; Giménez-Forcada et al., 2010, Singaraja et al., 2014; Zhang et al., 2016; Li et al., 2016; Schoeller 1967; Doneen, 1962).

Residents of Ilaje, a coastal region in Nigeria, have been reported to be prone to water borne diseases due to their consumption of unsafe water. Therefore, water quality monitoring is an urgent need in this area because it helps to better manage water resources with respect to public health. With this in mind, the aim of this work was to evaluate the groundwater quality of Ilaje and possible health risks associated with its consumption due to occurrence of some selected heavy metals and major ions. The work also determined the extent of saltwater encroachment, other possible sources of pollution and made recommendations that can be applied for better water resources management.

Geology And Hydrogeology

Ilaje is a coastal region of Ondo state, Southwest Nigeria between latitudes 6°16’0”N and 6°22’0”N and longitudes 4°26’0”E and 4°34’0”E (Fig. 1). It has 180 km of coastline and population of about 290,615 according to National Population Commission 2006 census. Due its proximity to the Atlantic Ocean, the most predominant occupations are fishing and salt mining while few other residents are either farmers or wood loggers. It is characterized by rainy and dry seasons with mean temperature of 22ºC during the rainy season and 28ºC during the dry season. Rain falls throughout the year, but the three months of November, December and January may be relatively dry. The mean annual rainfall exceeds 2000mm (Iloeje, 1981). The terrain is flat with gently undulating topography and is less than fifteen meters above sea level. The area is drained by many tributaries, streams and rivers, some of which are connected directly or indirectly to the Ocean and this can enable the degree and extent of saltwater intrusion. In recent times, incidents have been reported of sea surge and flooding that have submerged more than 200 houses, 500m of Ayetoro, a community in Ilaje, and rendered more than 2000 residents homeless, caused waterlogging of the area and saline-water encroachment (Ojolowo and Wahab, 2017).

Ilaje is a sedimentary terrain that falls within the Eastern portion of the Dahomey Basin and three chronostratigraphic geologic units are recognized. They are pre-lower Cretaceous folded sequence, Cretaceous sequence and Tertiary sequence (Omatsola and Adegoke, 1981; Billman, 1992). Since the 1960s, this basin has been explored and exploited for oil production (Bayode et al., 2011). Regardless of the positive economic impact contributed by the 60000 barrels per day oil produced, the associated environmental hazards cannot be overemphasized. There have been reported events of oil spillage (from the oils wells, illegal bunkering of pipelines and transportation of crude oil) and pipeline explosions.

Dahomey basin is a multi-aquifer system composed of recent alluvium deposits, Coastal Plain Sands, Ilaro and Ewekoro Formations (Okosun 1990; Longe et al., 1987). The aquifer units are sand, sandstone, clayey sand and dissolved/fractured limestone which are unconfined and confined in nature. The Recent Alluvial deposits are the most exploited for groundwater in Ilaje. This formation is exploited through hand-dug wells and shallow boreholes for domestic usage.

Materials And Methods

Twenty-nine hand dug well samples were collected in Araromi community and its environs in Ilaje area. The materials and methodology employed are both insitu and laboratory. Hand-dug wells (Fig. 1), well fetcher (plastic bucket used to draw water out of wells) and rubber bottles were used for collection of water samples and storage. A portable HANNA Combo EC/pH meter was used to obtain the insitu values of the physicochemical properties of the collected samples while two drops of concentrated HNO_3 were added to the samples for preservation of their ionic characteristics for laboratory determination. The concentrations of the anions (Cl^-, $NO_3^{2-,}$ HCO_3^-, SO_4^{2-}) were determined using titrimetric and spectrophotometric methods while those of the major ions (Ca^{2+}, Na^+, K^+, Mg^{2+}) and heavy metals (Pb^{2+}, Fe^{2+}, Co^{2+}, Ni^{2+}, Mn^{2+}) were determined using Atomic Absorption Spectrophotometry (AAS), as recommended by APHA 2012 standards. These tests were carried out in the Geochemistry and Marine Geochemistry laboratories of the Federal University of Technology, Akure, Ondo state, Nigeria, respectively. For analytical precision, ionic balancing of all the samples was done. Their ionic balance was within ± 10%, showing the reliability of the data. The obtained ppm and epm values of the cations, anions and heavy metals were then inputted in equations for analysis. The water quality (drinking, pollution and irrigation quality), saltwater ratio and human health hazards were determined using recommended equations and standards.

The drinking water quality was obtained by comparing the obtained results of the physicochemical characteristics to the recommended WHO drinking water limits, the irrigation quality was determined using (MAR, SSP, SAR, KR, PS, PI and RSC) and the chloro-alkaline indices was obtained with equations 1–9 (Schoeller 1967; Kelley, 1963; Todd 1980; Gupta and Deshpande, 2004; Doneen 1962; Richards 1954; Micheal 1992; Raghunath 1987)

$$\text{MAR} = \frac{(MgX100)}{(Ca+Mg)} \quad (1)$$

$$\text{SSP} = \frac{((Na+K)X100)}{(Ca+Mg+Na+K)} \quad (2)$$

$$\text{KR} = \frac{Na}{(Ca+Mg)} \quad (3)$$

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$$\text{SAR} = \frac{(Na)}{\sqrt{((Ca+Mg)/2)}} \quad (4)$$

$$\text{PI} = \frac{Na+\sqrt{(\text{HCO3}X100)}}{(Ca+Mg+Na} \quad (5)$$

PS = Cl + $\frac{SO4}{2}$ (6)

RSC = HCO_3^- – Ca^{2+} (7)

$$\text{CAI-1} = \frac{Cl-(Na+K)}{Cl} \quad (8)$$

$$\text{CAI-2} = \frac{Cl-(Na+K)}{\text{SO4}+\text{HCO3}+\text{CO3}} \quad (9)$$

Piper plots were produced to determine the hydrochemical facie of the water present using the hydrochemical data (Piper 1944). Pollution Index of Groundwater (PIG) uses the quantification of relative impact of individual chemical parameters (pH, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-) to determine overall groundwater quality. (Subba *et al.*, 2012). To get the PIG, five successive steps are required, starting with weightage assignment to each chemical parameter ranging from 1 to 5 in relation to their effect on human health. Computation of weight parameter (W_p) was achieved for all the chemical parameter content of each water sample by WHO standard for drinking water (D_s). Calculation of the overall water chemical quality (O_w) was achieved by multiplying W_p with S_c. Finally, of Pollution Index of Groundwater (PIG) values were obtained by summation of all the O_w values. Equations 10–13 were employed. PIG values < 1.5 show an insignificant to low pollution (Subba *et al.*, 2012).

Wp = $\frac{(Rw)}{\sum Rw}$ (10)

Sc = $\frac{C}{Ds}$ (11)

Ow = Wp * Sc (12)

PIG = $\sum$Ow (13)

Simpson Ratio and SO_4^{2-}: Cl^- were used to obtain the extent of saltwater encroachment through equations 14&15 (Saou et al., 2012; Todd, 1959). The values are interpreted; good quality (< 0.5), slightly contaminated (0.5–1.3), moderately contaminated (1.3–2.8), injuriously contaminated (2.8–6.6) and highly contaminated (> 6.6) (El Moujabber et al., 2006; Korfali and Jurdi, 2010; Todd, 1959).

Simpson Ratio = $\frac{Cl}{(HCO3+CO3)}$ (14)

Where CO_3 = 0.000001

SO_4^{2-}: Cl^- = $\frac{SO4}{Cl}$ (15)

Human health hazard involves estimation of the probability of adverse effect water has on human health after exposure for a given period and it is expressed by carcinogenic and non-carcinogenic risks (Bortey-Sam et al., 2015; USEPA, 2009). For this study, five trace elements were employed; Fe^{2+}, Mn^{2+}, Pb^{2+}, Co^{2+} and Ni^{2+}. The Chronic Daily Intake (CDI) (mg/kg/day) through oral exposure pathway was calculated, for both adults and children, using the formula;

$$\text{CDI} = \frac{CWXIRWXEFXED}{BWXAT} \quad (16)$$

Where CW is the concentration of heavy metals in water sample (mg/l), IRW is ingestion rate of groundwater in L/day (2L for adults, 1L for children), EF is exposure frequency (365 days), ED is exposure duration (70 years for adults and 6 years for children), BW is body weight in Kg

(70kg for adults and 15kg for children) and AT is average exposure time (25,550 days for adults, 2190 days for children) (USEPA, 2009; Wu et al., 2009, Karim, 2011; Rahman et al., 2017; Yang et al., 2012).

The non-carcinogenic risk of the groundwater to humans was determined using Health hazard Quotient (HQ) and Health hazard Indices (HI) calculations as recommended by USEPA (1989). If the value of the HQ is below 1, it is considered that the risk is at an acceptable level but if it is beyond 1, it poses a non-carcinogenic risk to its consumers (USEPA, 2001; Giri and Singh, 2015).

$$HQ = \frac{CDI}{RfD} \quad (17)$$

Where RfD is reference dose of a specific contaminant (mg/kg/day) obtained from risk-based concentration table (USEPA, 1999). The RfD of the trace metals are 0.02, 0.7, 0.0035, 0.3 and 0.046 for Co^{2+}, Fe^{2+}, Pb^{2+}, Ni^{2+} and Mn^{2+} respectively (USEPA, 2012). To determine the overall potential carcinogenic risk posed by the five trace metals, the health index was calculated (USEPA, 1989)

$$HI = \sum HQ \quad (18)$$

If HI ≤ 1, it is assumed that the groundwater poses no non-carcinogenic threat to its consumers but if > 1, it implies that the groundwater poses threat to its consumers (USEPA, 1989; Yang et al., 2012).

Probability of Cancer Risk (PCR) is the incremental probability of a consumer's susceptibility to cancer over a lifetime as a result of exposure to this groundwater; Eq. 18 (Li et al., 2016)

$$PCR = CDI*SF \quad (19)$$

SF is the carcinogenic slope factor.

Results And Discussion

The twenty-nine samples collected from the hand dug wells were analyzed for physicochemical properties, cations; (sodium, potassium, magnesium and calcium), anions; (nitrate, sulphate, bicarbonate and chloride) and trace metals; (iron, lead, manganese, cobalt and nickel). Pollution and irrigation indices of these major ions and trace metals were calculated from their respective concentrations of occurrence. Piper plot was also produced to determine the types of water present in the study area and numerical indices were employed to determine health risks posed to consumers

Water Quality

The groundwater sampled has pH values that range from 7.58 (neutral) to 8.54 (slightly alkaline) and mean value of 8.02. These values show that the water has the ability to resist reactions that would tend to make it acidic. The pH of the wells falls within the 6.5–8.5 range recommended by WHO (2011) for drinking water. Electrical Conductivity (EC) of water is a measure of its nutrient enrichment (Srinvasamoorthy *et al.*, 2014; Zhang et al., 2019). The EC of Ilaje groundwater ranges from 34 to 1084 μs/cm and has an average of 346.03μs/cm (Table 1). All EC values of the wells fall within the 1500μs/cm recommendation of WHO (2011) for drinking water, making this water suitable for drinking by its consumers. Additionally, TDS ranges from 17 to 542 mg/l $CaCO_3$ with an average value of 174.10 mg/l $CaCO_3$ (Table 2). The number of dissolved solids present in water and duration of water residence in the subsurface accounts for its TDS. Of all the wells sampled, only the well in location 10, present in Enu-Amo, has TDS value of 542 mg/l which is above the recommended 500 mg/l by WHO (2011). This high TDS can be attributed to impact of anthropogenic sources such as domestic sewage, septic tanks and agricultural activities (Logeshkumaran et al., 2015). Consumers of water from well 10 are liable to suffer from kidney and heart diseases (Gupta and Deshpande,2004). Water containing TDS less than 500mg/l could be considered "fresh water" (Hem, 1970). This water is good enough for drinking and irrigational purposes because it will not affect the osmotic pressure of soil solution.

Table 1
Statistical summary of the physicochemical properties, major ions and trace metals of Ilaje groundwater

Parameter	Min	Max	Mean
pH	7.56	8.76	8.02
EC(ΩS/cm)	34	1084	333
TDS (ppm)	17	542	168
HCO_3 (ppm)	32	832	361
Cl(ppm)	5.1	745.3	213
NO_3(ppm)	0.04	0.9	0.26
SO_4(ppm)	0.48	41	12.4
Ca(ppm)	1.63	20.4	8.04
Mg(ppm)	0	44	8.94
K (ppm)	7.95	39.19	21.74
Na (ppm)	1.26	149.82	50.5
Pb(ppm)	0.05	0.54	0.27
Mn(ppm)	0	0.22	0.06
Co(ppm)	0.38	0.57	0.46
Fe(ppm)	0.4	1.02	0.62
Ni(ppm)	0.36	0.53	0.44

Table 2
Physicochemical parameters and pollution index of Ilaje groundwater

Location	Town	Lat6�N	Lon4�E	PIG (trace metals)	PIG (major ions)
L1	Obinehin	19.63333	33.06667	17.824	0.18365
L2	Obinehin	19.6	33.13333	18.46914	0.25833
L3	Obinehin	19.8	33.76667	15.74555	0.21251
L4	Enu-Amo	19.23333	30.86667	20.7494	0.32701
L5	Enu-Amo	19.46667	30.46667	19.33407	0.2481
L6	Enu-Amo	19.46667	30.43333	24.12638	0.32953
L7	Enu-Amo	19.5	30.46667	19.76722	0.2733
L8	Enu-Amo	19.43333	30.46667	19.22023	0.22992
L9	Enu-Amo	19.53333	30.46667	18.39016	0.30193
L10	Enu-Amo	19.6	30.36667	15.47781	0.36652
L11	Araromi	20.86667	30.66667	14.53653	0.19387
L12	Araromi	20.76667	30.8	16.46635	0.06009
L13	Araromi	20.86667	30.76667	17.4991	0.15012
L14	Araromi	19.9	29.86667	15.23422	0.18836
L15	Araromi	20.13333	29.73333	16.12119	0.17371
L16	Araromi	20.06667	29.8	22.36593	0.16143
L17	Araromi	20.03333	29.8	20.54842	0.15447
L18	Araromi	20	29.93333	20.21346	0.19318
L19	Araromi	20.6	30.56667	15.37809	0.15676
L20	Araromi	20.86667	30.13333	17.54669	0.17434
L21	Araromi	20.66667	30.16667	18.28271	0.19371
L22	Araromi	20.76667	30.16667	16.19485	0.19321
L23	Araromi	20.5	30.4	15.26256	0.21941
L24	Araromi	20.46667	30.6	14.83025	0.15829
L25	Araromi	20.4	30.66667	17.47067	0.1472
L26	Araromi	20.23333	30.83333	11.75107	0.15055
L27	Araromi	20.63333	30.76667	19.44218	0.18372
L28	Oke-Siri	19	32.4	16.14614	0.20499
L29	Araromi	19.95166	29.67333	16.14614	0.18599

The PIG values range from 11.90 to 24.46 with an average value of 17.83 (Table 3). These values suggest that the groundwater in the study area has been highly polluted, on comparison to set standard (Subba *et al.*, 2012). Therefore, this water poses health risks like lung cancer, organ damage, amongst others to its consumers (Obasi and Akudinobi, 2020). It is seen in Table 2 that OWPb and OWCo both have more than 80% contribution to this pollution and it hints at influences of anthropogenic activities on the groundwater. On exclusion of these heavy metals from the analysis, it is seen that the water is generally not polluted by the occurrence of major ions but that of heavy metals (Table 1).

Table 3: Total Pollution Index of Groundwater values of Ilaje

LOC	Ow(pH)	Ow(TDS)	Ow(EC)	Ow(Ca2+)	Ow(Mg2+)	Ow(Na+)	Ow(K+)	Ow(HCO3	Ow(Cl-)	Ow(SO42-)	Ow(NO3-)	OWPb	OWMn	OWFe	OWCo	OWNi	PIG
1	0.123252	0.035366	0.016504	0.000212	0.00039	0.003178	0.001424	0.001491	0.001627	0.000192	1.52E-05	7.474212	0.060117	0.253866	8.76122	1.274585	18.00765
2	0.124228	0.106341	0.018537	0.000372	0.001041	0.002399	0.001184	0.001695	0.002469	4.16E-05	1.93E-05	8.472078	0.046676	0.235712	8.324246	1.390428	18.72747
3	0.130244	0.04122	0.027398	0.000239	0.001626	0.001904	0.000497	0.001839	0.007239	0.000297	2.12E-06	4.234952	0.096918	0.362616	9.930832	1.120231	15.95805
4	0.136911	0.106585	0.070813	0.000451	6.50E-05	0.00186	0.002228	0.001647	0.006173	0.000256	1.75E-05	8.472078	0.062945	0.350552	10.22215	1.641681	21.07641
5	0.142439	0.055366	0.036829	0.000504	0.002797	0.001853	0.00143	0.002399	0.004321	0.00012	3.93E-05	7.972058	0.04598	0.356584	9.491684	1.467761	19.58216
6	0.13252	0.112439	0.074959	0.000265	0.001496	0.000519	0.001544	0.002079	0.003591	0.000104	7.56E-06	11.71134	0.007091	0.368648	10.51346	1.525837	24.4559
7	0.136911	0.071463	0.048943	0.000557	0.003707	0.001865	0.0017	0.002191	0.00578	0.000172	1.02E-05	8.472078	0.035018	0.290116	9.637342	1.332662	20.04051
8	0.138862	0.047073	0.031382	0.000584	0.000846	0.00186	0.002378	0.002511	0.003704	0.000694	2.20E-05	8.222068	0.029363	0.290116	9.346026	1.332662	19.45015
9	0.127967	0.097317	0.064878	0.000106	0.002667	0.000719	0.001417	0.003231	0.003591	8.18E-06	2.92E-05	5.232818	0.00957	0.592296	10.95261	1.602859	18.69209
10	0.127317	0.132195	0.08813	0.000663	0.003382	0.001329	0.00155	0.003327	0.008193	0.000421	1.62E-05	2.98925	0.084521	0.253866	10.95261	1.197563	15.84434
11	0.13252	0.033659	0.022439	0.000292	0.001236	0.000662	0.001333	0.000128	0.001291	0.000302	4.67E-06	4.484962	0.006003	0.320334	8.469904	1.25533	14.7304
12	0.030976	0.02065	0.000398	0.00065	0.000916	0.005714	0.000101	0.000421	0.000245	0.00030634	1.69E-05	2.741414	0.044196	0.501642	11.53742	1.641681	16.52674
13	0.138862	0.004146	0.002764	0.000186	0.000455	0.000505	0.000943	0.001695	0.000505	4.91E-05	7.32E-06	4.484962	0.002132	0.368648	11.09827	1.545093	17.64922
14	0.134472	0.028537	0.019024	0.000398	0.00078	2.67E-05	0.00142	0.001775	0.001796	0.00012	5.80E-06	3.987116	0.007091	0.241744	9.491684	1.506582	15.42257
15	0.132683	0.021463	0.014228	0.000159	0.00052	0.000766	0.001324	0.000896	0.001347	0.000312	6.22E-06	2.98925	0.002828	0.447238	11.09827	1.583604	16.29489
16	0.138374	0.008537	0.005772	0.000186	0.00052	0.000343	0.000932	0.00088	0.00578	9.07E-05	1.07E-05	11.71134	0.004959	0.320334	9.05471	1.274585	22.52735
17	0.123577	0.01561	0.010325	0.000133	0.000715	0.000437	0.001462	0.0008	0.001122	0.00028	6.07E-06	6.22851	0.061205	0.435174	12.41354	1.409994	20.70289
18	0.124553	0.038293	0.025528	0.000637	0.00013	0.000369	0.001316	0.001663	0.000617	5.80E-05	1.34E-05	9.965616	0	0.41702	8.324246	1.506582	20.40664
19	0.127642	0.01439	0.009593	0.000106	0.001106	0.000806	0.001318	0.000992	0.000561	0.00023	1.15E-05	2.241394	0.004263	0.41702	11.53742	1.177997	15.53485
20	0.132683	0.022195	0.014878	7.96E-05	0.00065	0.000549	0.001485	0.001136	0.000337	0.000336	6.31E-06	5.480654	0.030059	0.34452	10.51346	1.177997	17.72103
21	0.124228	0.034634	0.023008	0.000133	0.001756	0.001002	0.00142	0.002271	0.00477	0.000471	1.74E-05	6.22851	0.060857	0.38077	10.22215	1.390428	18.47642
22	0.123415	0.04	0.026585	5.31E-05	0.000325	0.000694	0.0013	0.000496	0.000112	0.00022	1.11E-05	4.734972	0.019445	0.284084	9.785174	1.371173	16.38806
23	0.12813	0.052683	0.035122	0.000239	0.00013	0.000444	0.001294	0.000688	0.000564	0.000115	4.01E-06	3.987116	0.015225	0.386802	9.637342	1.236074	15.48197
24	0.134797	0.011951	0.007805	0.000239	0	0.000813	0.001296	0.00048	0.000617	0.000286	3.79E-06	2.741414	0.021228	0.356584	10.51346	1.197563	14.98854
25	0.129756	0.006585	0.006423	0.000212	0.000846	0.000479	0.001446	0.00112	0.000224	9.67E-05	1.52E-05	3.737106	0.008135	0.592296	11.97439	1.158742	17.61787
26	0.128618	0.010732	0.007073	0.000212	0.00039	0.001075	0.001379	0.000672	5.61E-05	0.000341	4.43E-06	0.995692	0.02088	0.33843	8.909052	1.487016	11.90162
27	0.122927	0.031463	0.022033	0.000186	0.001171	0.003029	0.00104	0.001503	0.000281	8.48E-05	5.16E-06	8.969924	0.012398	0.308212	8.76122	1.390428	19.6259
28	0.12374	0.039756	0.026423	0.000159	0.006049	0.000531	0.002451	0.002991	0.002694	0.000187	6.19E-06	4.734972	0.003524	0.356584	9.930832	1.120231	16.35113
29	0.129756	0.03122	0.020894	0.000159	0.00078	0.000505	0.001325	0.000896	0.000281	0.00017	5.98E-06	4.484962	0.000696	0.320334	9.930832	1.313407	16.23622

The Magnesium Adsorption Ratio (MAR) values of the groundwater sample range from 0 to 93.826% and have mean value of 56.86% (Table 4). Four wells (17%) have MAR values that are less than 50%. According to the MAR standard, this shows that they are suitable for irrigation uses while majority of the wells are not suitable for these purposes. The water is unsafe because presence of Mg^{2+} in irrigation water results in poor crop growth (Punmia and Lal 1981; Asaduzzaman, 1985). The Sodium Absorption Ratio (SAR) values of the groundwater sample range from 2.433 to 17.311 (Table 4). It has a mean value of 4.71 and all the wells fall within the good and excellent categories, for irrigation purpose. When water high in sodium and low in calcium is used for irrigation, the cation exchange complex can become saturated with sodium, which can destroy the soil structure owing to dispersion of clay particles (Singh 2002). Presence of Na^{+} in irrigation water reacts with soil to reduce permeability and its repeated use makes the soil impermeable. High Na^{+} saturation also directly causes Ca^{2+}deficiency; soil crusting, poor plant growth and development of alkali soil. Additionally, the Soluble Sodium Percentage (SSP) of the groundwater samples ranges from 34.55–92.61% with a mean value of 69.84% (Table 4). Twenty-seven (93%) wells have SSP values that are beyond the 50% standard SSP value and are unsuitable for irrigation. Excess SSP causes osmotic effect on soil-plant system owing to the restriction of air and water circulation during wet conditions and such soils are usually hard when they are dry. These methods have been applied in the appraisal of several coastal aquifer water (Edet, 2017; Asiwaju-Bello *et al.*, 2021; Aziane *et al.*, 2020; Didar-Ul Islam et al., 2017).

Table 4
Irrigation quality and saltwater intrusion ratio of Ilaje groundwater

Location	MAR	SAR	SSP	KR	PI	PS	RSC	SR	SO_4/Cl Ratio
L1	42.3729	17.3105	92.60974	11.50055	4.412522	4.6421	5.7884	0.681968	0.056593
L2	52.8402	8.93865	81.69098	4.06101	5.10336	6.4295	6.3796	0.910269	0.008092
L3	73.1422	6.67527	75.02254	2.854453	5.951542	19.2814	7.1738	2.459859	0.01972
L4	5.45256	8.90373	86.56453	5.197715	6.554659	16.4469	6.0605	2.34194	0.019889
L5	68.9324	4.81073	63.7389	1.52275	5.585931	11.3688	9.0609	1.12569	0.013385
L6	69.2771	1.84494	56.08782	0.800485	12.65555	9.459	8.1166	1.079581	0.013909
L7	72.6855	4.31714	59.03249	1.218772	4.855813	15.2355	8.1268	1.648682	0.014327
L8	36.6817	6.40655	77.15914	2.690401	6.862239	11.199	9.3975	0.921856	0.090005
L9	90.9494	2.19393	53.25115	0.816905	11.55835	9.2232	13.0827	0.694781	0.001097
L10	67.0968	3.09465	52.01194	0.878822	6.80862	22.0296	12.6193	1.539258	0.024654
L11	62.8723	2.46921	61.16342	1.122925	3.351395	4.0499	0.0758	6.30441	0.112267
L12	62.0347	9.3552	87.06927	5.825197	3.389788	2.1916	1.0011	1.154185	0.262031
L13	49.505	2.75416	71.54604	1.831068	17.11162	1.415	6.6652	0.186194	0.04667
L14	43.956	0.10485	36.84419	0.050167	23.57364	4.898	6.6667	0.632201	0.032206
L15	56.6572	4.17929	78.91072	2.780515	9.710013	4.2193	3.4273	0.939816	0.111298
L16	52.8402	1.80907	64.20191	1.16234	15.03991	15.0343	3.321	4.106664	0.007535
L17	68.323	2.23108	69.88738	1.390089	12.3455	3.5637	3.0747	0.877146	0.11958
L18	7.55287	1.46931	55.02173	0.713828	14.80242	1.7244	5.8405	0.231946	0.045075
L19	80.6452	3.59754	72.21869	1.958894	8.74373	2.005	3.9024	0.353699	0.197149
L20	76.5697	3.11482	76.85416	2.154771	13.77549	1.6896	4.5333	0.185321	0.479138
L21	84.1122	3.62595	67.24804	1.599959	9.756053	13.3824	9.1075	1.312656	0.047436
L22	71.0227	5.36002	87.41047	5.050333	9.202983	0.829	1.9512	0.14148	0.941238
L23	17.8891	2.72418	76.32073	2.036828	13.03529	1.7271	2.4525	0.512643	0.097406
L24	0	5.50321	85.68878	4.540826	7.713138	2.2842	1.6	0.804087	0.222026
L25	61.4367	2.13327	65.03375	1.159386	12.25913	0.813	4.2638	0.12531	0.206711
L26	42.3729	5.85683	83.01934	3.891089	6.786018	0.9816	2.4277	0.052213	2.913074
L27	71.5991	12.3828	86.83878	6.174121	4.302	0.9276	5.8783	0.116647	0.145063
L28	93.8257	1.09264	34.54762	0.274371	7.145867	7.3633	12.0175	0.562888	0.033395
L29	66.2252	2.43296	68.54021	1.42888	11.4734	1.136	3.4273	0.195801	0.289986

Kelley's ratio indicates the balance between Na^+, Ca^{2+}, and Mg^{2+} ions in the water samples. Its values in the samples range from 0.0502 to 11.50 (Table 4) with a mean value of 2.644. Twenty-four wells (83%) have values above the < 1 standard of groundwater suitable for irrigation. This shows occurrence of high amount of sodium which will affect the permeability and infiltration property of the soil when employed for agricultural purposes. Some of the problems caused to plants when this type of water is used are poor seedling emergence, lack of aeration for plants and, plant and root diseases (Ayers and Westcot, 1985). The Potential Salinity (PS) values range from 0.35 to 21.25 with an average of 6.63 (Table 4). These show that the PS in the groundwater of Ilaje is high, thus making the water not suitable for irrigation purposes. This is because high values mean the salts present in the groundwater are highly soluble and increase the salinity of the soil such that it is unable to support the growth of crops (Doneen, 1962; Siamak and Srikantaswamy, 2009).

Permeability Index (PI) is used to know the influence of water quality on physical properties of soil (Doneen, 1962. The PI values fall within the range 0.45–23.57% with a mean value of 9.25% (Table 4). The water in Ilaje falls within the class III category implying that the water sample is not suitable for irrigation usage by its consumers. This water, if used over a long period of time, could potentially impair the permeability of the soil (Dhirendra et al., 2009). Residual Sodium Carbonate (RSC) is used to calculate the tendency for Ca^{2+} and Mg^{2+} to precipitate from water having high concentrations of bicarbonates thus increasing the relative proportion of sodium in the water in the form of sodium bicarbonate (Sadashivaiah*et al*., 2008). The water samples have RSC values that range from − 0.16 to 12.62 and a mean value of 5.38 (Table 4). Three (10%) of the wells sampled fall within the safe and excellent category with less than 1.25 values, two (7%) wells fall within the marginal category with values between 1.25–2.5 and the remaining wells (83%) fall in the unsatisfactory category. These wells within the satisfactory and marginal categories are suitable for irrigation because their continuous usage will not lead to salt build up that can hinder air and water movement due to clogging of soil pores, leading to degradation of the soil unlike the ones in the unsatisfactory category. Singh et al. also successfully reported the irrigation quality of groundwater present in Udham Singh Nagar, a city in India, by employing these aforementioned numerical indices. Overall, it can be said that the groundwater of the sampled communities has low to no irrigation suitability and are heavily polluted by heavy metals.

Chemical Indicators of Seawater Intrusion

Simpson Ratio (Cl/HCO_3) was used to know the extent of saltwater pollution in the study area. The values range from 0.05 to 6.30 and have an average value of 1.24 (Table 5). Eleven (38%) of the sampled hand-dug wells have values below 0.5 thus suggesting that the water has no saline water contamination while the remaining eighteen wells exhibit slight to high contamination (Todd, 1959; Sudaryanto and Naily, 2018). Water taken from L11 shows the most imprints of saltwater encroachment, with a value of about 6.3, which could have been caused by over-exploitation, sea level rise and tidal influences (Prakash et al., 2018b; Srinivasamoorthy et al., 2011). Several coastal aquifer researchers have effectively employed this ratio in the study of salinization of coastal groundwater; Papazotos et al., 2019; Sudaryanto and Naily, 2018; Abu Risha and Sturchio, 2018, Aladejana *et al*., 2021.

Table 5
Summary of groundwater quality compared to recommended standards

Quality Parameter	Standard	Interpretation	Study Area Character
PIG	< 1	Insignificant Pollution	100% (PIG without trace metals)
	1.0-1.5	Low pollution	Nil
	1.5-2.0	moderate pollution	Nil
	2.0-2.5	High pollution	Nil
	> 2.5	Very high pollution	100% (PIG with trace metals)
pH	6.5–8.5 (WHO,2011)	Safe for drinking	100%
EC	≤ 1500 (WHO,2011)	Safe for drinking	100%
TDS	≤ 500 (WHO,2011)	Safe for drinking	97%
MAR	≤ 50%	Good	17%
	> 50%	Bad	83%
SAR	< 10	Excellent	97%
	10–18	Good	3%
	18–26	Doubtful	Nil
	> 26	Poor	Nil
SSP	≤ 50%	Suitable	7%
	> 50%	Unsuitable	93%
KR	< 1	Suitable	17%
	> 1	Unsuitable	83%
Cl/HCO3	< 0.5	Good	38%
	0.5–13	Slightly contaminated	38%
	1.3–2.8	Moderately contaminated	21%
	2.8–6.6	Injuriously contaminated	3%
	> 6.6	Highly contaminated	Nil

PIG: Pollution Index of Groundwater EC: Electric Conductivity TDS: Total Dissolved Solids MAR: Magnesium Adsorption SAR: Sodium Adsorption Ratio SSP: Soluble Sodium Percentage KR: Kelley's Ratio

So_4^{2-}/Cl^- ratio had values ranging from 0.0011to 2.913 and an average of 0.306 (Table 5). Generally, this ratio decreases with an increase in salinity but from the results obtained, it is observed that the values are increasing thereby depicting occurrence to absence of saline water encroachment (Saou et al., 2012). L26 has water with the highest So_4^{2-}/Cl^- ratio, showing that the water present here has not experienced incidences of saline water intrusion; this is also corroborated by the 0.05 Simpson ratio of the well.

Hydrogeochemical Processes

Chloro-alkaline index is used to indicate ion exchange between the groundwater and its host environment during residence or travel (Schoeller, 1967). The values of CAI-1 of the samples collected range from − 18.257 to 0.926669 and mean value of -1.50626 while CAI-2 ranges from 0.312311 and 3.05347 with an average of 1.682891 (Table 6). Eleven (38%) wells have negative CAI-1 values exemplifying the softening process where calcium and magnesium are absorbed into the alluvial deposits' aquifer causing sodium and potassium exchange and this exchange is referred to as indirect. All the wells have positive CAI-2 values while eighteen (62%) wells have positive CAI-1 which implies the presence of strong direct ion exchange of sodium and potassium from water with magnesium and calcium in the aquifer leading to hardening (Asiwaju-Bello et al., 2013, Asiwaju-Bello *et al.*, 2020).

Table 6
Chloro-Alkaline Indices (CAI) of Ilaje groundwater

Location	CAI-1	CAI-2
1	-0.7021	3.05347
2	0.14588	5.556085
3	0.77862	18.03049
4	0.70119	15.14964
5	0.60388	10.63375
6	0.81569	9.007028
7	0.69482	14.31977
8	0.49541	9.061394
9	0.77681	9.048177
10	0.83996	20.75716
11	0.42439	1.186392
12	-2.0193	-1.2273
13	-0.0989	1.091435
14	0.86156	4.515847
15	0.38763	2.930381
16	0.92667	14.5193
17	0.48029	2.463563
18	0.18086	1.393906
19	-0.5243	0.934501
20	-1.0104	0.520766
21	0.78431	11.95644
22	-5.7983	-0.55968
23	0.00286	0.958879
24	-0.39	0.634038
25	-1.7368	0.241304
26	-18.257	-0.72849
27	-8.2281	-0.3392
28	0.69681	6.734816
29	-1.1962	0.312311

Where CAI = Chloro-Alkaline Index

Four hydrochemical facies in the order: Na-Cl > Ca-Na-HCO_3 > Na-HCO_3 > Ca-HCO_3 were revealed by piper plot (Fig. 6). NaCl, the most dominant facies, observed in sixteen (55%) wells, indicates occurrence of high salinity caused by overexploitation of groundwater by consumers, seawater encroachment, domestic wastewater and septic tank infiltration (Appelo and Postma, 1996; Asiwaju *et al.*, 2021). This NaCl dominance is an expected outcome for coastal groundwater as reported by Asiwaju *et al.*, 2021 and Badmus et al., 2020 in their reports of various hydrogeochemical studies of some coastal aquifers in Nigeria. Six (21%) wells fall within the $CaNaHCO_3$ facies and their formation

 minerals along their flow pathway (Batabyal, 2018; Senthilkumar et al., 2014). Five

(18%) wells are of $NaHCO_3$ facies and their occurrence can be attributed to the exchange of Na with Ca in $CaHCO_3$. $CaHCO_3$ is the least dominant facie, represented by two (7%) wells, which depicts silicate mineral dissolution from reaction between rock and water and recharge of rainfall (Mondal and Singh, 2012, Asiwaju-Bello *et al*., 2020). This also indicates the dominance of alkaline earths and weak acid anions (Badmus et al., 2020). The $NaHCO_3$ and $CaHCO_3$ facies occurrence show that there was dissolution of silicates and carbonates and a simultaneous ion exchange (Oyedele et al., 2019).

Human Health Risk Assessment

The Chronic Daily Intake (CDI) values for consumption of drinking water in Ilaje were obtained, for both adults and children. The CDI values for adults range from 0.0013 to 0.0154, 0 to 0.0064, 0.0116 to 0.0292, 0.0109 to 0.0163 and 0.0131 to 0.0151 as obtained for Pb, Mn, Fe, Co and Ni respectively. They also had averages of 0.0077, 0.0019, 0.018, 0.0132 and 0.0126 respectively (Table 7). The CDI values range for children are as follow 0.0031 to 0.04, 0 to 0.015, 0.0271 to 0.0681, 0.0255 to 0.0381 and 0.024 to 0.0352 as obtained for Pb, Mn, Fe, Co and Ni respectively. They also had averages of 0.0179, 0.0045, 0.042, 0.031 and 0.0293 respectively. For this work, exposure and risk assessments were carried out based on USEPA methodology. The health risks of the heavy metals, to both adults and children, in the study area were found in the order of Fe > Co > Ni > Pb > Mn. Fe is the highest contributor to these values in both adults and children. Presence of Fe in water can be beneficial to the consumer with iron deficiency; however, excessive body Fe has been linked to chronic diseases like heart disease and diabetes (Ghosh et al., 2020).

Table 7
Chronic Daily Intake (CDI) of Ilaje groundwater

Location	Pb-A	Pb-C	Mn-A	Mn-C	Fe-A	Fe-C	Co-A	Co-C	Ni-A	Ni-C
L1	0.009823	0.02292	0.003949	0.009213	0.012506	0.02918	0.011514	0.026867	0.011726	0.02736
L2	0.011134	0.02598	0.003066	0.007153	0.011611	0.027093	0.01094	0.025527	0.012791	0.029847
L3	0.005566	0.012987	0.006366	0.014853	0.017863	0.04168	0.013051	0.030453	0.010306	0.024047
L4	0.011134	0.02598	0.004134	0.009647	0.017269	0.040293	0.013434	0.031347	0.015103	0.03524
L5	0.010477	0.024447	0.00302	0.007047	0.017566	0.040987	0.012474	0.029107	0.013503	0.031507
L6	0.015391	0.035913	0.000466	0.001087	0.01816	0.042373	0.013817	0.03224	0.014037	0.032753
L7	0.011134	0.02598	0.0023	0.005367	0.014291	0.033347	0.012666	0.029553	0.01226	0.028607
L8	0.010806	0.025213	0.001929	0.0045	0.014291	0.033347	0.012283	0.02866	0.01226	0.028607
L9	0.006877	0.016047	0.000629	0.001467	0.029177	0.06808	0.014394	0.033587	0.014746	0.034407
L10	0.003929	0.009167	0.005551	0.012953	0.012506	0.02918	0.014394	0.033587	0.011017	0.025707
L11	0.005894	0.013753	0.000394	0.00092	0.01578	0.03682	0.011131	0.025973	0.011549	0.026947
L12	0.003603	0.008407	0.002903	0.006773	0.024711	0.05766	0.015163	0.03538	0.015103	0.03524
L13	0.005894	0.013753	0.00014	0.000327	0.01816	0.042373	0.014586	0.034033	0.014214	0.033167
L14	0.00524	0.012227	0.000466	0.001087	0.011909	0.027787	0.012474	0.029107	0.01386	0.03234
L15	0.003929	0.009167	0.000186	0.000433	0.022031	0.051407	0.014586	0.034033	0.014569	0.033993
L16	0.015391	0.035913	0.000326	0.00076	0.01578	0.03682	0.0119	0.027767	0.011726	0.02736
L17	0.008186	0.0191	0.00402	0.00938	0.021437	0.05002	0.016314	0.038067	0.012971	0.030267
L18	0.013097	0.03056	0	0	0.020543	0.047933	0.01094	0.025527	0.01386	0.03234
L19	0.002946	0.006873	0.00028	0.000653	0.020543	0.047933	0.015163	0.03538	0.010837	0.025287
L20	0.007203	0.016807	0.001974	0.004607	0.016971	0.0396	0.013817	0.03224	0.010837	0.025287
L21	0.008186	0.0191	0.003997	0.009327	0.018757	0.043767	0.013434	0.031347	0.012791	0.029847
L22	0.006223	0.01452	0.001277	0.00298	0.013994	0.032653	0.01286	0.030007	0.012614	0.029433
L23	0.00524	0.012227	0.001	0.002333	0.019054	0.04446	0.012666	0.029553	0.011371	0.026533
L24	0.003603	0.008407	0.001394	0.003253	0.017566	0.040987	0.013817	0.03224	0.011017	0.025707
L25	0.004911	0.01146	0.000534	0.001247	0.029177	0.06808	0.015737	0.03672	0.01066	0.024873
L26	0.001309	0.003053	0.001371	0.0032	0.016671	0.0389	0.011709	0.02732	0.01368	0.03192
L27	0.011789	0.027507	0.000814	0.0019	0.015183	0.035427	0.011514	0.026867	0.012791	0.029847
L28	0.006223	0.01452	0.000231	0.00054	0.017566	0.040987	0.013051	0.030453	0.010306	0.024047
L29	0.005894	0.013753	4.57E-05	0.000107	0.01578	0.03682	0.013051	0.030453	0.012083	0.028193
Where A = Adult and C = Children										

The HI for adults and children had values that range from 1.69 to 5.83 and 3.96 to 13.59 respectively (Table 8). The average values are also 3.54 and 8.21 respectively. All the water samples have values > 1 thereby suggesting that the water poses non-carcinogenic health risks to the lives of its consumers. For children, all the wells have a tendency of causing varying non-cancerous diseases to them on ingestion. From the obtained values, it was observed that Pb, for both adults and children, is the highest contributor to the values obtained. Continuous exposure to lead, at elevated levels, can lead to anemia, permanent brain damage, dysfunctional kidney, reproductive problems and eventual death (Engwa et al., 2018; Obasi and Akudinobi, 2020).

Table 8
Probability of Cancer Risk (PCR) due to Pb and Ni contamination and Health Index (HI) of Ilaje groundwater.

Location	PCRadult (Pb)	PCRchild (Pb)	PCRadult (Ni)	PCRchild (Ni)	HI (adult)	HI (child)
L1	8.35E-05	0.000195	0.01067	0.0249	4.072234	9.50188
L2	9.46E-05	0.000221	0.01164	0.02716	4.45103	10.38574
L3	4.73E-05	0.00011	0.009378	0.02188	2.921965	6.817918
L4	9.46E-05	0.000221	0.013744	0.03207	4.722627	11.01946
L5	8.91E-05	0.000208	0.012288	0.02867	4.383073	10.22717
L6	0.000131	0.000305	0.012774	0.02981	5.826332	13.59478
L7	9.46E-05	0.000221	0.011157	0.02603	4.497927	10.49516
L8	9.18E-05	0.000214	0.011157	0.02603	4.376832	10.21261
L9	5.85E-05	0.000136	0.013419	0.03131	3.477244	8.11357
L10	3.34E-05	7.79E-05	0.010026	0.02339	2.531569	5.906994
L11	5.01E-05	0.000117	0.010509	0.02452	2.849196	6.648124
L12	3.06E-05	7.15E-05	0.013744	0.03207	2.641081	6.162523
L13	5.01E-05	0.000117	0.012935	0.03018	3.153068	7.357159
L14	4.45E-05	0.000104	0.012613	0.02943	2.840994	6.628985
L15	3.34E-05	7.79E-05	0.013257	0.03093	2.615674	6.103239
L16	0.000131	0.000305	0.01067	0.0249	5.60846	13.08641
L17	6.96E-05	0.000162	0.011804	0.02754	3.921077	9.14918
L18	0.000111	0.00026	0.012613	0.02943	5.011388	11.69324
L19	2.5E-05	5.84E-05	0.009862	0.02301	2.177067	5.079822
L20	6.12E-05	0.000143	0.009862	0.02301	3.357838	7.834954
L21	6.96E-05	0.000162	0.01164	0.02716	3.763752	8.782087
L22	5.29E-05	0.000123	0.011479	0.02678	3.099429	7.232002
L23	4.45E-05	0.000104	0.010348	0.02415	2.74796	6.411906
L24	3.06E-05	7.15E-05	0.010026	0.02339	2.326506	5.428515
L25	4.17E-05	9.74E-05	0.009701	0.02263	2.776419	6.478311
L26	1.11E-05	2.6E-05	0.012449	0.02905	1.696936	3.959518
L27	0.0001	0.000234	0.01164	0.02716	4.622841	10.78663
L28	5.29E-05	0.000123	0.009378	0.02188	2.975941	6.943863
L29	5.01E-05	0.000117	0.010995	0.02566	2.964333	6.916776

Table 9
Summary of Health Index (HI) of Ilaje groundwater (USEPA, 1989).

Quality Parameter	Standard	Interpretation	Study Area Character	
			Adult	Children
HI	< 0.1	Negligible	Nil	Nil
	0.1-1	Low risk	Nil	Nil
	1–4	Medium risk	66%	Nil
	> 4	High risk	34%	100%

In calculating the carcinogenic risks, for both adults and children, of trace metals in the groundwater of Ilaje, the Probability of Cancer Risk (PCR) of Pb and Ni were considered. From results obtained, it was observed that about 7% and more than 70% of the wells have Pb values beyond the $\leq 1\text{x}10^{-6}$ to $1\text{x}10^{-4}$ standard, thereby posing carcinogenic risks to adults and children respectively (Table 8) (US-EPA 1999; Lim et al. 2008; Adamu et al. 2014; Rahman et al. 2017, Olabode et al., 2020). Additionally, all the wells in the study area have Ni values beyond the standard for both adults and children.

These results show that consumers of water drawn from these wells are susceptibility to cancer and other non-cancerous health risks through ingestion in form of drinking water.

Conceptualisation

The results obtained from the present study were synthesized to conceptualize the various processes and scenarios that are responsible to the non-potability of groundwater resources in Ilaje area.

The unconsolidated nature of the recent alluvial deposit of Ilaje makes the aquifer materials highly porous and permeable. These characteristics engender high infiltration rates; such that during rainfall events, the aquifer is easily recharges favoring the shallow depth of water table and increased availability of water for supply. This shallow water table depth coupled with approximately flat topography facilitates easy movement of surface water towards landward direction by sea surge. This landward movement induce strong interaction with the shallow groundwater, thereby polluting it. This potential interaction best accounts for the observed occurrence of saline water encroachment presented in the results.

Another scenario established by the observed occurrence of heavy metals in the subsurface water can be attributed to past oil exploitation activities in this area and fuel leakages from boats. In time past, Ilaje was actively explored and exploited for crude oil, these activities resulted in incidences of oil bunkering and spillage. It is highly possible that remnant heavy metals from these events mixed with the groundwater during the process of groundwater-surface water interaction. During the sampling, it was also observed that some households used metal casing for their wells (Fig. 4). Metal leaching from these casings can also significantly contribute to elevated levels of heavy metals and possible pollution of groundwater.

Conclusion

This work studied not only the conventional physicochemical characteristics and major ions of groundwater from hand-dug wells in Ilaje area, but also carried out a novel study of the carcinogenic and non-carcinogenic health risks this water poses to its consumers. This study corroborated the detrimental health risks of consuming coastal groundwater highlighted by past works on coastal aquifers. From the results obtained, the wells exhibit an expected saline water encroachment associated with coastal groundwater which can be attributed to tidal waves and over exploitation of groundwater. Also, the water has low to no irrigation usability due to its ability to cause clogging of soils. Despite the occurrence of the physicochemical parameters and major ions in unharmful concentrations, the anomalous occurrence of trace metals makes this water unfit for consumption. Health Index (HI) and Chronic Daily Intake (CDI) served as tools to study the non-carcinogenic health hazards of this water to both adults and children. This result showed that Fe is the major contributor of risk and all the wells in Ilaje constitute varying types of health risks to its consumers. Consumption of water with toxic concentrations of heavy metals causes illnesses like diabetes, heart diseases, dysfunctional kidney and reproductive challenges. Furthermore, to assess the carcinogenic health risks of this water, Probability of Cancer Risk (PCR), lead and nickel enrichment, was employed. It was observed that these trace metals, when ingested over a period of time, pose significant cancer risk to both adults and children of the study area. The pollution of the shallow groundwater resources hinges of the highly porous and permeable nature of alluvial aquifer system of the area.

Recommendations

In lieu of the obtained results, the following recommendations are suggested, to better safeguard the health of Ilaje residents.

1. Proper monitoring system and treatment plants should be put in place to remove these heavy metals, techniques like filtration, adsorption, chemical precipitation and ion exchange and control pollution of these wells.
2. Wells should be properly grouted (to prevent infiltration), covered and cased downwards with appropriate casing materials.
3. Alternative and safe sources of water should be made available to consumers because the observed wells are in very bad states. Boreholes are most preferable because they give room to explore greater depths for freshwater and possible delineation of the saltwater-freshwater interface.
4. As a result of the nutrients exchange that exists between groundwater and surface water, there is need to study the interaction between Ilaje groundwater and the surface water bodies present here. This research would give a better insight into the roles played by this interaction in the pollution of groundwater.
5. Seeing as residents of the community have been exposed to this water for a long period of time, it is advised that both adults and children be subjected to comprehensive medical investigations. These will, especially for children, lead to early detection of sicknesses and care; to prevent long-term challenges while for adults with health challenges, mitigating care and recommendations can be made.

Declarations

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Ethical Approval

This research article follows all the acknowledged principles of ethical and professional behavior accordingly.

Consent to participate

All the authors supported the need to carry out this research

Consent to publish

All the authors supported the need to publish the results of the research

Authors Contribution

OF Erukubami, AT Adelakun and OF Olabode were involved in the groundwater sampling. AT Adelakun also assisted with laboratory analysis of samples. OF Erukubami interpreted the data while both OF Erukubami and OF Olabode wrote the manuscript. OF Olabode provided all the maps. YA Asiwaju-Bello was involved in the design of the research work and provided relevant contributions during analysis and data interpretation.

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Competing interests

The authors declare that they have no conflict of interest

Availability of data and material

The data for the study is available upon request.

References

1. Abu Risha UA, Sturchio N. The impact of hydrogeological setting on the protection of coastal groundwater aquifers, El Dabaa, Northwestern Coast, Egypt. Research Journal of Env. Sci. 6(3) pp. 174–186

2. Adamu CI, Nganje TN, And Edet A (2014) Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, southeastern Nigeria. Environment Nanotechnology Monitoring Management. https://doi.org/10.1016/j.enmm.2014.11.001
3. Aderibigbe SA, Awoyemi AO, And Osagbemi GK (2008) Availability, adequacy and quality of water supply in Ilorin metropolis. NigeriaEurJ Scientific Res 23:528–536
4. Adewuyi GO, Oputu OU, And Opasina MA (2010) Assessment of groundwater quality and saline intrusions in coastal aquifers of Lagos Metropolis, Nigeria. J Water Resour Prot 2:849–853. http://dx.doi.org/10.4236/jwarp.2010.210100
5. Ahmed KM, Islam MS, Sultana S, Ahmed SU, Rabbani G (2010) Changes in the groundwater regime of Dhaka city: a historical perspective. In: Book Chapter: Celebration of 400 Years of Capital Dhaka: Plants, Wildlife, Garden and Environment of Capital Dhaka. Asiatic Society of Bangladesh, Publisher, pp 383–400
6. Akhter S, Hossain MS (2017) Groundwater modelling of Dhaka City and surrounding areas and evaluation of the effect of artificial recharge to aquifers. World J Res Rev 5(3):54–60
7. Aladejana JA, Kalin RM, Sentenac P, Hassan I, Groundwater Quality Index as a Hydrochemical Tool for Monitoring Saltwater Intrusion into Coastal Freshwater Aquifer of Eastern Dahomey Basin, Southwestern Nigeria, *Groundwater for Sustainable Development*, https://doi.org/10.1016/j.gsd.2021.100568
8. Appelo C, Postma D (1996) Geochemistry, groundwater and pollution. Balkema Rotterdam
9. Asaduzzaman M (1985)). Handbook of groundwater and wells. BRAC Prokashana, Dhaka
10. Asiwaju-Bello YA, Olabode OF, Duvbiama OA, Iyamu OI, Adeyemo AA, Onigbinde MT (2013)). Hydrochemical evaluation of groundwater in Akure Area, South-western Nigeria, for irrigation purpose. Eur Int J Sci Technol 2:8, 235–249
11. Asiwaju–Bello YA, Olabode OF, Ogunsuyi MT (2020) Pollution potential and causative hydrogeochemical processes in unconfined aquifer systems in a typical urban setting: emphasis on recharge and discharge areas. Applied Water Science 52:1–23. https://doi.org/10.1007/s13201-019-1131-5
12. Asiwaju–Bello YA, Olabode OF, Owoseni JO, Daramola SO, Ogunsuyi MT, Yusuf LA, Utulu BS, Adiele T, Shodeinde R (2021) Imprints of sea surge and municipal activities on non-potability of groundwater in shallow coastal sandy aquifer system of Lagos State, southwestern Nigeria. https://doi.org/10.1016/j.gsd.2021.100613
13. Ayeni AO, Balogun II, Soneyea SO (2011)). Seasonal assessment of physicochemical concentration of polluted urban river: A case of Ala River in Southwestern Nigeria. Research Journal of Environmental Science 5(1):22–33. https://dx.doi.org/10.3923/rjes.2011.22.35
14. Ayers RS, Westcot DW (1985)). Water quality for agriculture, irrigation and drainage. Paper No. 29. FAO, Rome
15. Azaine N, Khaddari A, IbenTouhami M, Zouahri A, Nassali H, Elyoubi M (2020) Evaluation of groundwater suitability for irrigation in the coastal aquifer of Mnasra (Gharb, Morocco). Mediterranean Journal of Chemistry 10:197. http://10.197.10.13171/mjc1020200222997
16. Badmus GO, Akinyemi OD, Gbadebo AM, Oyedepo JA (2020) Hydrochemical analysis of groundwater quality along the coastal aquifers in part of Ogun state, Southwestern Nigeria. http://doi.org.10.1016/j.heliyon.2020.e05661
17. Batabyal AK (2018) Hydrogeochemistry and quality of groundwater in a part of Damodar Valley, Eastern India: an integrated geochemical and statistical approach, Stoch Environ Res Risk Assess Vol.32 pp. 2351–2368 https://link.springer.com/article/10.1007/s00477-018-1552-y
18. Bayode OJA, Adewumi EA, Odunwole S (2011)). Environmental implications of oil exploration and exploitation in the coastal region of Ondo State, Nigeria: A regional planning appraisal. Journal of Geography Regional Planning 4(3):110–121
19. Bhattacharya P, And Bundschuh J (2015) Groundwater for sustainable development cross cutting the UN sustainable development goals —editorial. Groundwater Sustainable Dev 1:vol.1, No 2, pp. 155–157. https://doi.org/10.1016/j.gsd.2016.04.004
20. Billman HG (1992)). Offshore stratigraphy and paleontology of the Dahomey embayment, West Africa. Nigerian Association of Petroleum Explorationists (NAPE) 7:121–130
21. Bodrud-Doza MD, Didar-Ul Islam SM, Tanjena Rume, Quraishi SB, Rahman MS, Bhuiyan MAH (2020).Groundwater quality and human health risk assessment for safe and sustainable water supply of Dhaka City dwellers in Bangladesh. Groundwater for sustainable development Vol. 10 pp. 1–12 https://dx.doi.org/10.1016/j.gsd.2020.100374
22. Bortey-Sam N, Nakayama SMM, Ikenaka Y, Akoto O, Yohannes YB, Baidoo E, Mizukawa H, And Ishizuka M (2015) Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa, Ghana: estimation of the daily intakes and target hazard quotients (THQs). Ecotoxicol Environ Saf 111:160–167. https://doi.org/10.1016/j.ecoenv.2014.09.008
23. Chakraborty R, Khan Km D, Dt K, Ma, Ahmed A, Islam M (2019) Health Implications of Drinking Water Salinity in Coastal Areas of Bangladesh. Int J Environ Res Pub Health 16(9):3746

24. Choudhury K, Saha D, And Chakraborty P (2001) Geophysical study for saline water intrusion in coastal alluvial terrain. J Appl Geophysvol 46:189–200. https://doi:10.1016/S0926-9851(01)00038-6
25. Davraz A, Afşin M, Aksever F, Karataş Z, Hinis M (2016) The interference of a deep thermal system with a shallow aquifer and health risk assessment: the case of sandikli (afyonkarahisar). Environ Earth Sci 75:332. https://doi.org/10.1007/s12665-015-5144-6
26. Dhirendra MJ, Kumar A, Agrawal N (2009) Assessment of the irrigation water quality of river ganga in Haridwar District, Rasayan. J Chem 2:285–292
27. Didar-Ul Islam SM, Bhuiyan MAH, Rume T, Azam G (2017) Hydrogeochemical investigation of groundwater in shallow coastal aquifer of Khulna District, Bangladesh. http://doil.org.10.1007/s13201-017-0533-5
28. Doneen LD (1962) The influence of crop and soil on percolating water. In: Proceedings of the biennial conference on groundwater recharge pp. 156–163
29. Edet A (2017) Hydrogeology and groundwater evaluation of a shallow coastal aquifer, southern Akwa Ibom sate. Nigeria Appl Water Sci Vol. 7 2397–2412. http://doi.org/10.1007/s13201-016-04321-1
30. El Moujabber M, Bou Samra B, Darwish T, Atallah T (2006) Comparison of different indicators of groundwater contamination by seawater intrusion at Lebanese coast. Water Resour Manag Vol 20:161–180
31. Engwa GA, Ferdinand PU, Nwalo FN, Unachukwu MN (2018) Mechanism and effects of heavy metals toxicity in humans, poisoning in the modern world- new tricks for an old dog? Ozgor Karcioglu and banu Arslan IntechOpen. http://doi,org/10.5772/intechopen.82511
32. Ghosh GC, Khan MJH, Chakraborty TK (2020) Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore, Bangladesh. Sci. Eep 10, 5206. http://doi.org.10.1038/s41598-020-62187-5
33. Giménez-Forcada E, Bencini A, Pranzini G (2010) Hydrogeochemical considerations about the origin of groundwater salinization in some coastal plains of Elba Island (Tuscany, Italy). Environ Geochem Health 32:243–257
34. Giri S, Singh AK (2015) Human health risk assessment via drinking water pathway due to metal contamination in the groundwater of Subarnarekha River Basin, India. Environ Monit Assess 187:63. https://doi.org/10.1007/s10661-015-4265-4
35. Gupta SK, Deshpande RD (2004). Water for India in 2050: first-order assessment of available options, Current Sciences, vol. 86,No. 9, pp.1216–1224
36. Hossain HA, Hussain S, Khaliq A, Ashraf U, Anjum SA, Men S, Wang L (2018) Chilling and drought stresses in crop plants: Implications, cross talk, and potential management opportunities. Front Plant Sci 9:393
37. Hoque MA, Hoque MM, Ahmed KM (2007) Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: causes and quantification. Hydrogeol J 15:1523–1534
38. Idoko MA (2010). Seasonal variation in iron in rural groundwater of Benue state, middle belt Nigeria. Pakistan Journal of Nutrition 9(9):892–895. https://dx.doi.org/10.3923/pjn.2010.892.895
39. Iloeje NP (1981) A new geography of Nigeria. New revised edition, Longman, Great Britain
40. Islam Ma, Zahid A, Rahman Mm R, Ms I, Mj, Akter Y, Shammi M, Bodrud-Doza M, Roy B (2016) Investigation of groundwater quality and its suitability for drinking and agricultural use in the south central part of the coastal region in Bangladesh. Expo Health. https://doi.org/10.1007/s12403-016-0220-z
41. Islam SMD, Majumder RK, Uddin MJ, Khalil MI, And Alam MF (2017) Hydrochemical characteristics and quality assessment of groundwater in Patuakhali district, southern coastal region of Bangladesh. Expo. Health 9, 43–60. https://link.springer.com/article/10.1007/s12403-016-0221-y
42. Karim Z (2011) Risk assessment of dissolved trace metals in drinking water of Karachi, Pakistan. Bull Environ Contam Toxicol 86:676–678. https://doi.org/10.1007/s00128-011-0261-8
43. Kelley WP (1963) Use of saline irrigation water. Soil Sci Vol 95:355–391
44. Korfali SI, Jurdi M (2010) Deterioration of coastal water aquifers: causes and impacts. European Water 29:3–10
45. Li P, Li X, Meng X, Li M, Zhang Y (2016) Appraising groundwater quality and health risks from contamination in a semiarid region of northwest China. Expo Health 8(3):361–379. https://doi.org/10.1007/s12403-016-0205-y
46. Liu Y, Jiao JJ, Liang W, Kuang X (2017) Hydrogeochmical characteristics in coastal groundwater mixing zone. Appl Geochem 85:49–60
47. Lim HS, Lee JS, Chon HT, Et Al (2008) Heavy metal contamination and health risk assessment in the vicinity of the abandoned Songcheon Au–Ag mine in Korea. Journal of Geochemical Exploration Vo 96:223–230. http://doi:10.1016/j.gexplo.2007.04.008
48. Logeshkumaran A, Magesh NS, Godson PS, Chandrasekar N (2015) Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City. Tamil Nadu India Appl Water Sci 5(4):335–343. https://doi.org/10.1007/s13201-014-0196-4

49. Longe EO, Malomo S, And Olorunniwo MA (1987) Hydrogeology of Lagos metropolis. journal of African Earth Sciences 6(2):106–174. https://doi.org/10.1016/0899-5362(87)90058-3
50. Manikandan S, Chidambaram S, Ramanathan Al P, Mv, Karmegam U, Singaraja C, Paramaguru P, Jainab I (2012) A study on the high fluoride concentration in the magnesium-rich water of hard rock aquifer in Krishnagiri district, Tamilnadu, India. Arab J Geosci. http://doi:10.1007/s12517-012-0752-x
51. Mondal NC, And Singh VP (2012). Chloride migration in groundwater for a tannery belt in groundwater for a tannery belt in southern India. Environ Monit Assess 184:2857–2879. https://doi.org/10.1007/s10661-011-2156-x
52. Obasi PN, Akudinobi BB (2020) Potential health risk and levels of heavy metals in water resources of lead-zinc mining communities of Abakaliki, southeast Nigeria. Appl Water Sci 10:184. http://doi.org/10.1007/s13201-020-01233-z
53. Offodile ME (2002) Groundwater study and development in Nigeria. Mecon Geology and Engineering Services, Jos, p 453
54. Ohwoghere AO (2012) Heavy metals distribution in degraded land forms in Delta state of Niger Delta. Journal of Mineral Resources vol 4(3):43–50
55. Ojolowo S, Wahab B (2017) Municipal solid waste and flooding in Lagos metropolis, Nigeria: Deconstructing the evil nexus. J Geogr Reg Plan Full 10:174–185
56. Okosun EA (1990) A review of the Cretaceous stratigraphy of the Dahomey embayment, West Africa
57. Olabode OF, Ajala TF, Asowata TI (2020) An assessment of the potential health risks associated with the use of spring waters in crystalline basement rocks in OkeIgbo in south-western Nigeria. Environ Earth Sci 79:411. https://doi.org/10.1007/s12665-020-09149-2
58. Omatsola ME, And Adegoke OS (1981) Tectonic evolution and Createaceous stratigraphy of the Dahomey basin, Nigeria. Journal of Mining Geology 18(1):130–137
59. Oyedele AA, Ayodele OS, Olabode OF (2019) Groundwater quality assessment and characterization of shallow basement aquifers in parts of Ado Ekiti Metropolis, southwestern Nigeria. SN Appl Sci. https://doi.org/10.1007/s4245 2-019-0683-1
60. Papazotos P, Koumantakis I, Vasileiou E (2019) Hydrogeochemical assessment and suitability of groundwater in a typical Mediterranean coastal area: A case study of the Marathon basin NE Attica, Greece. HydroResearch 2. http://doi.org/10.1016/j.hydres.2019.11.002
61. Piper AM (1944) A graphic procedure in geochemical interpretation of water analysis. Am Geophysical Union Trans 25:914–923
62. Prakash R, Srinivasamoorthy K, Gopinath S, Saravanan K, Vinnarasi F, Ponnuman G, Chidambaram s, Anandhan P (2018b) Radon isotope assessment of submarine groundwater discharge (SGD) in Coleroon River Estuary, Tamil Nadu India. J Radioanal Nucl Chem 317:25–36. http://doi.org/10.1007/s10967-018-5677-2
63. Punmia BC, And Lal PBB (1981) Irrigation and water power engineering. Standard Publishers Distributors, New Delhi
64. Raghunath HM (1987) Groundwater. Wiley Eastern, New Delhi
65. Rahman MM, Islam MA, Bodrud-Doza M, Muhib MI, Zahid A, Shammi M, Tareq SM, And Kurasaki M (2017)). Spatio-temporal assessment of groundwater quality and human health risk: a case study in Gopalganj. Bangladesh Expo Health 10:167–188. https://doi.org/10.1007/s12403-017-0253-y
66. Richards LA (US Salinity Laboratory) (1954) Diagnosis and improvement of saline and alkaline soils, US Department of Agriculture hand book pp 60
67. Saou A, Maza M, And Luc Seidel J (2012)). Hydrochemical processes associated with double salinization of water in an Algerian, carbonated and evaportic. Pol J Environ Stud 21 No(4):1013–1024
68. Sarvestani Ra, Aghasi M (2019) Health risk assessment of heavy metals exposure (lead, cadmium, and copper) through drinking water consumption in Kerman city. Iran Environ Earth Sci 78:714. https://doi.org/10.1186/s12199-019-0812-x
69. Schoeller H (1967) Qualitative evaluation of groundwater resources, methods and techniques of groundwater investigation and development. Water research, series 33 UNESCO, pp 44–52
70. Senthilkumar S, Balasubramanian N, Gowtham B, And Lawrence J,F (2014) Geochemical signatures of groundwater in the coastal aquifers of Thiruvallur district, south India. Appl Water Sci 7:263–274. https://doi.org/10.1007/s13201-014-0242-2
71. Siamak G, Srikantaswamy S (2009) Analysis of agricultural impact on the Cauvery river water around KRM dam. World Appl Sci J 6(8):1157–1169
72. Singaraja C, Chidambaram S, Prasanna MV, Thivya C, Thilagavathi R (2014) Statistical analysis of the hydrogeochemical evolution of groundwater in hard rock coastal aquifers of Thoothukudi district in Tamil Nadu, India. Environ Earth Sci 71:451–464
73. Singh AK (2002) Quality assessment of surface and sub-surface water of Damodar river basin, India. J Environ Health 44:41–49
74. Singh KK, Tewari G, Kumar S (2020) Evaluation of groundwater quality for suitability of of irrigation purposes: A case study in the Udham Singh Nagar, Uttaekhand. Journal of Chemistry. http://doi.org/10.1155/2020/6924026

75. Srinivasamoorthy K, Vasanthavigar M, Chidambaram s, Anandan P, Sharma VS (2011) Characterization of groundwater chemistry in an eastern coastal area of Cuddalore district, Tamil Nadu. J Geol Soc India 78:549–558. http://doi.org/10.1007/s1294-011-0122-4
76. Srinivasamoorthy K, Gopinath M, Chidambaram S, Vasanthavigar M, And Sarma VS (2014) Hydrochemical characterization and quality appraisal of groundwater from Pungar sub basin, Tamil Nadu, India. J King Saud Univ Sci 26(1):37–52. https://doi.org/10.1016/j.jksus.2013.08.001
77. Subba-Rao S-R, Nagamani VRG, Vidyasagar M, And Satyanarayan G N. L. V. V (2012).Chemical characteristics of groundwater and assessment of groundwater quality in Varha River Basin, Visakhapatnam district, Andhra Pradesh, India. Environ Mon Assess, vol. 184, pp. 5189–5214 http://doi:10.1007/s10661-011-2333-y
78. Sudaryanto, Naily W (2018) Ratio of major ions in groundwater to determine saltwater intrusion in coastal areas. Im IOP conference series: earth and environmental science Vol. 118. Institute of Physics Publication. http://doi.org/10.1088/1755-1315/118/1/012021
79. Todd DK (1959) Groundwater hydrology. United States. John Wiley and Sons. Inc, pp 277–294
80. Todd DK (1980) Groundwater hydrology. Published by John Wiley & Sons, New York Chichester, 2nd Edition
81. Todd DK, And Larry WM (2005) Groundwater hydrology, 3rd edn. Wiley, Hoboken
82. USEPA (1989) Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)
83. USEPA (US Environmental Protection Agency) (1999) A risk assessment–multi way exposure spread sheet calculation tool. United States Environmental Protection Agency, Washington,DC
84. USEPA (2001) Baseline Human Health Risk Assessment Vasquez Boulevard and I-70 Superfund Site. Denver CO. U.S. Environmental Protection Agency
85. USEPA (2004)). Risk Assessment Guidance for Superfund Volume I. Human Health Evaluation Manual(Part E).U.S. Environmental Protection Agency
86. USEPA (2009) National Primary and Secondary Drinking Water Standards. U.S. Environmental Protection Agency. Assessed from. http://www.epa.gov/safewater/consumer/pdf/mcl.pdf. (Accessed 20 September 2017)
87. USEPA (2012) Integrated Risk Information System of the US Environmental Protection Agency
88. World Health Organization (WHO) (2011) Guidelines for drinking-water quality. World Health Organization, Geneva
89. Wu B, Zhao DY, Jia HY, Zhang Y, Zhang XX, And Cheng SP (2009) Preliminary risk assessment of trace metal pollution in surface water from Yangtze River in Nanjing Section, China. Bull Environ Contam Toxicol Vol 82:405–409. https://doi.org/10.1007/s00128-008-9497-3
90. Yang M, Fei Y, Ju YMZ, And Li H (2012) Health risk assessment of groundwater pollution-a case study of typical city in north China. Plain J Earth Sci Vol 23 Ed:3, pp. 335–348. https://doi.org/10.1007/s12583-012-0260-7
91. Zhang S, Liua G, Suna R, And Wua D (2016) Health risk assessment of heavy metals in groundwater of coal mining area: a case study in Dingji coal mine, Huainan coalfield, China. Human Ecol Risk Assess 22 Ed. 7 1469–1479 https://doi.org/10.1080/10807039.2016.1185689
92. Zhang Q, Xu P, Qian H (2019) Assessment of groundwater quality and human health risk (HHR) evaluation of nitrate in the central-western Guanzhong basin, China. Int. J Environ Res Public Health 16:4246. http://doi.org.10.3390/ijerph16214246

Figures

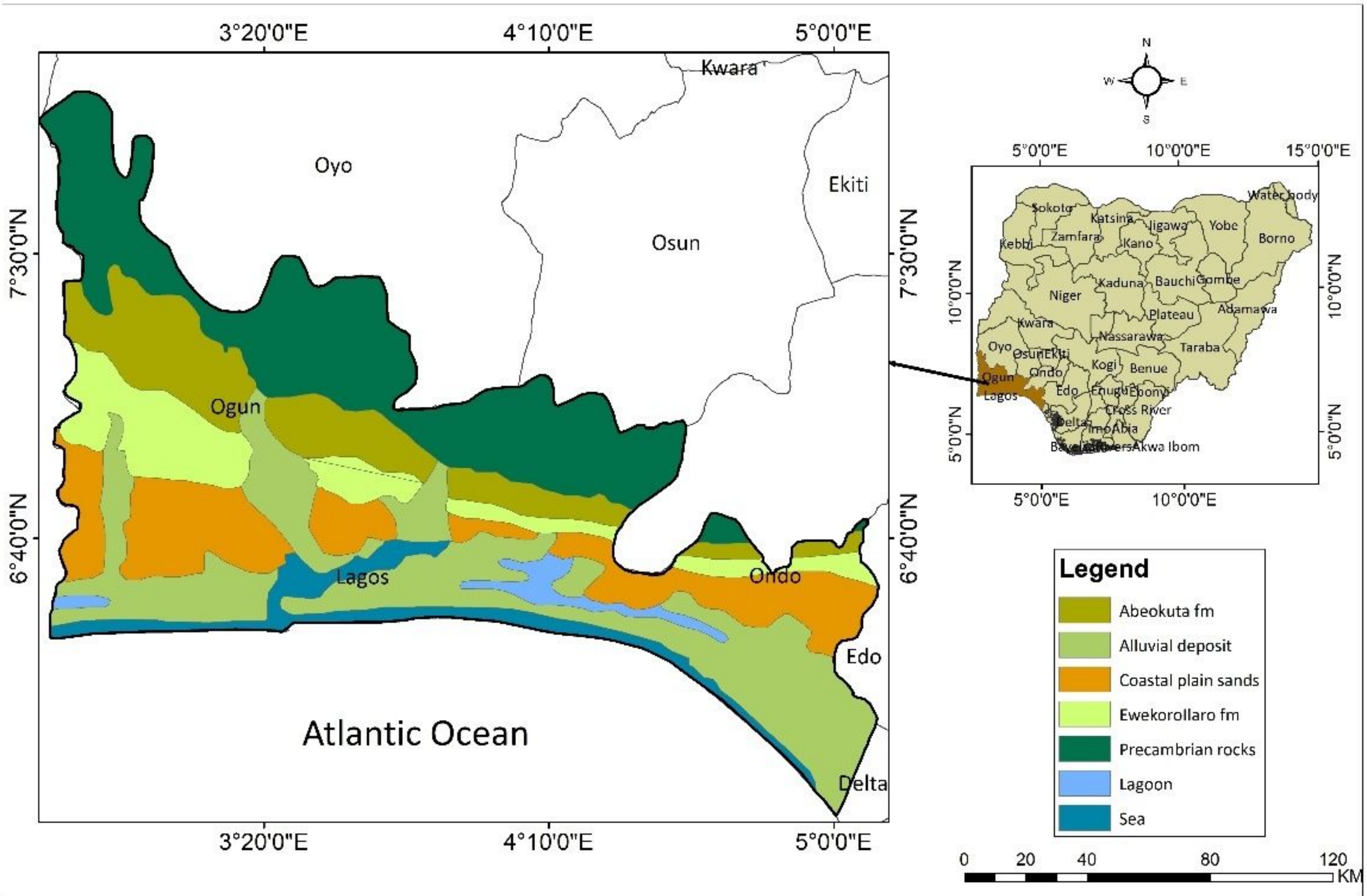

Figure 1

Geological map of Dahomey Basin

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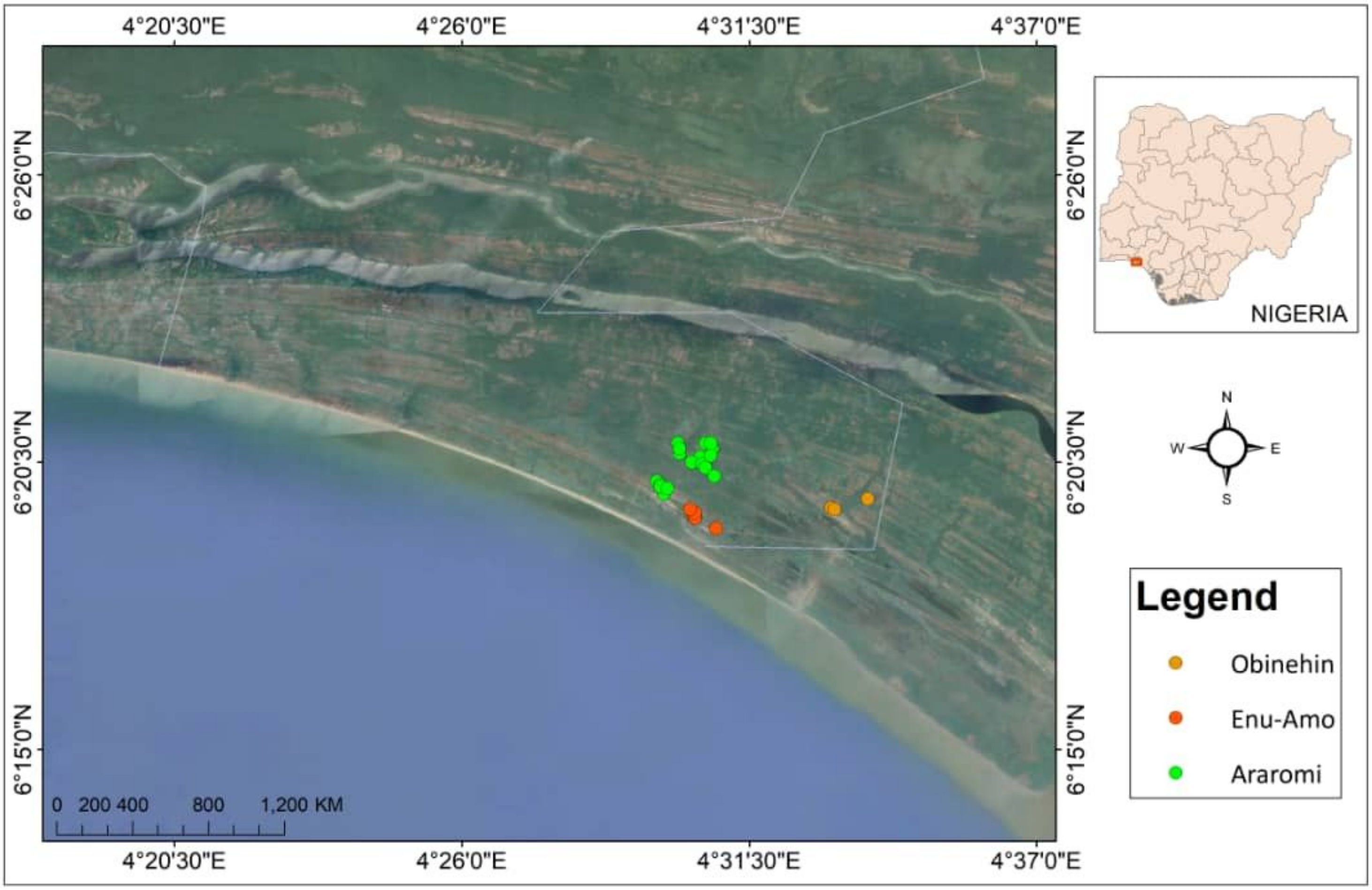

Figure 2

Location map of sampling points

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Collection of groundwater sample from well present in Obinehin

Figure 4

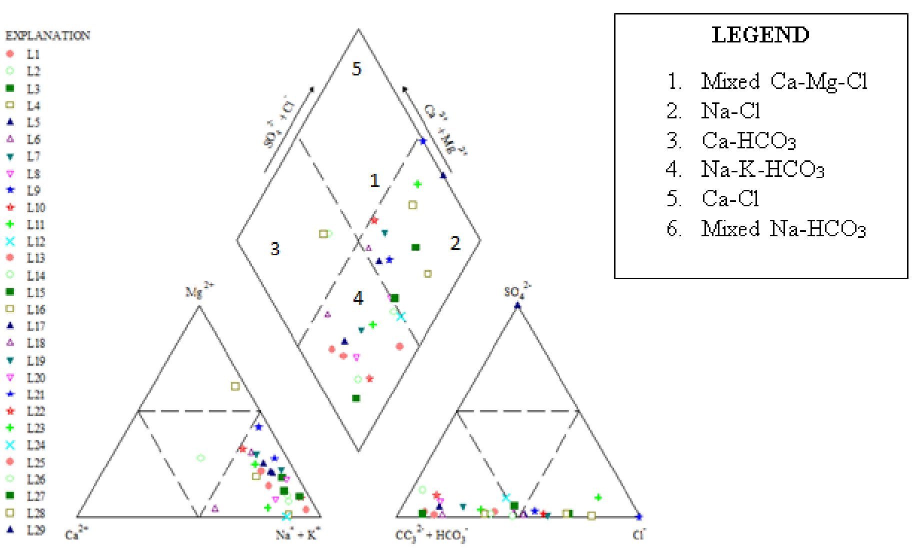
Observation of a sampled well found in Obinehin

Figure 5

A picture showing an iron cased well present in Enu-Amo

Figure 6

A picture showing a sampled well found in Araromi



Piper plots for llaje groundwater

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