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Full Length Research Paper

The impact of sea water intrusion on the spatial variability of the physical and chemical properties of ground water in Limbe-Cameroon

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A significant proportion of the population of Limbe, a coastal town in Cameroon, relies on ground water (gw) to satisfy their drinking water needs. The coastal aquifer is threatened by pollution from sea water intrusion and hence the aim of this study was to determine the suitability of the water. Physico-chemical analysis were carried out on samples collected from the study area and the Revelle Index was calculated and used to determine the extent of pollution from seawater intrusion. The water quality index (WQI) was calculated using values of the pH, bicarbonate, chloride, total dissolved solids and the electrical conductivity. The results showed that 23% of the groundwater in the study area is slightly polluted by seawater intrusion. Using the WQI, it was found that about 34.4% of the ground water resources in the study area is currently good for drinking while 65.6% is either poor, very poor or unsuitable for drinking. In order to reduce the intrusion of sea water into the aquifer, a halophyte plant like mangrove should be planted at the mouth of the main river in Limbe.

Key words: Coastal aquifer, pollution, salinity, water quality index, Revelle Index.

INTRODUCTION

In the last few decades, there has been a tremendous increase in the demand for fresh water in the world due to the rapid growth of the population and the accelerated pace of industrialization (Rejith et al., 2009). Limbe, a coastal town in Cameroon on the Atlantic Ocean has a demand for domestic water supply that the water utility company cannot satisfy and hence a significant proportion of the population relies on ground water (gw) to meet their domestic water demands.

Under natural conditions, coastal aquifers are recharged by rainfall, and the gwflows towards the ocean preventing saltwater from encroaching into the freshwater. The global mean sea level (GMSL) increased by an average rate of 1.8 mm/year during the 20th century

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(Douglas, 1997) and the IPCC reported with a high confidence that this rate has been increasing (Bates et al., 2008). The IPCC (2007) estimated that the GMSL increased by 3.1 mm/year from 1993 to 2003, but this change is not spatially uniform worldwide. Nicholls and Cazenave (2010) estimated a GMSL rise of approximately 3.3 mm/year for the period 1992 to 2010.

Motchemien (2015) estimated on the basis of data obtained from the tide gauge installed in Limbe, a rise in the mean sea level of the Atlantic Ocean in the lower part of the Gulf of Guinea of about 10 mm / year. One effect of such an increase is sea water intrusion into coastal aquifers (Werner and Simmons, 2009). Salt water intrusion is a serious problem because about 80% of the world's population lives along the coast and utilize coastal aquifers for their water supply. In addition, over exploitation of coastal aquifers has resulted in falling groundwater levels (gwl). Sea level rise and falling water gwl have resulted in increased pollution of gw due to sea water intrusion resulting in wells previously used to for domestic water supply being abandoned. For example, in New Jersey, more than 120 wells were abandoned because of saltwater contamination (Lacombe and Carleton, 1992).In the study area, about 250 wells has been abandoned because the water has become salty (Motchemien, 2015).

Variations in the sea level and the associated wedge movement can influence the near-shore and/or large-scale submarine discharge patterns and impact nutrient loading levels across the aquifer-ocean interface (Li and Jiao, 2003). While anthropogenic activities, such as over pumping and felling of trees in urbanized coastal areas, are the major causes of salt water intrusion, it is projected that increases in the sea level due to climate change would aggravate the problem (Li and Jiao, 2003). Feseker (2007) modelled the impacts of climate change and changes in land use patterns on the salt distribution in a coastal aquifer and concluded that rising sea level could induce rapid progression of salt water intrusion.

Excessive groundwater withdrawals have been reported to result in hydro-chemical changes in the physical, chemical and microbiological water quality; drop in the water table level; reverse hydraulic gradient and consequently water quality deterioration in coastal areas (Esteller et al., 2012). Poor water quality results in incidences of waterborne diseases and consequently reduces the life expectancy of the population (WHO, 2006). Thus, concern for clean and safe drinking water and protection from contamination is justified because a large proportion of the population in the study area depends on ground water for domestic purposes.

Water quality evaluation is based on the physical, chemical and biological parameters ascertaining the suitability for various uses such as domestic consumption, agricultural, recreational and industrial use (Sargaonkar and Deshpande, 2003). The traditional assessment of water quality consists of comparing the point values of water quality parameters levels with their guideline or standard values based on allocated water use or uses. This type of assessment does not provide an overall assessment of water quality of a water body which is important for managers and decision-makers. To resolve this decision-making problem, several water quality indices have been developed to transform point value water quality parameters into integrated indicator values. Many studies have demonstrated the usefulness of assessing the water quality of gw using a water quality index (WQI). Examples are presented by: Shah et al (2008); Zaharin et al. (2009); Chachadi and Lobo – Ferreira (2001); Akoteyon (2013); Vasanthavigar et al. (2010); Ramakrishnaiah et al. (2009); Rao and Nageswararao (2013), and Sahu and Sikdar (2008).

The aim of this study was to assess the suitability of the gw in Limbe for domestic use. The specific objectives were to: Determine the spatial variation of the physical and chemical properties of the gw; evaluate the extent of sea water intrusion into the aquifer; determine the proportion of the gw suitable for drinking and finally a propose solution to reduce the impact of sea water intrusion on the gw quality.

MATERIALS AND METHODS

Description of the study area

Location

Limbe is located along the coastal area of Fako Division, South-West Region of Cameroon (Figure 1). The study area is located approximately between latitudes 3^o 90´ and 4^o 05 N and longitudes 9^o 29´ and 9^o 06´ E. It is bounded in the East by Bimbia, in the North by Bonadikombo, in the South by the Atlantic Ocean and in the West by Mukundange. The population of Limbe is about 130,000 inhabitants spread over a surface area of 596 km^2(INS, 2013).

The town is characterized by a low-lying coastal plain, rising up to a chain of horseshoe shaped hills towards the northeast and east, with the highest point at 362 m above sea level (Njabe and Fobang, 2006). Within the town, small streams flow into larger drainage channels that converge into the main river (Njenguele) that empties into the Atlantic Ocean (Figure 2). These rivers frequently overflow their banks in the rainy season causing floods in the low-lying areas that are only 1 to 2 m above sea level (Ndille and Belle, 2014). The hills that surround the town are made up of loose ferralitic and volcanic soils that easily disintegrate when the water content is high (Nwankiti, 1983).

Climate

The climate of Limbe is the sub-equatorial type with two distinct seasons: a dry season of two months from December to January and a rainy season of 10 months that runs from February to November with a mean annual rainfall of 3,100 mm, ±1,100 standard deviation (Suh et al., 2003). The monthly rainfall frequently exceeds 500 mm and sometimes is over 1,000 mm in June, July and August. The mean annual temperature is about 26°C while the relative humidity is generally above 85% (Fombe and Molombe, 2015).

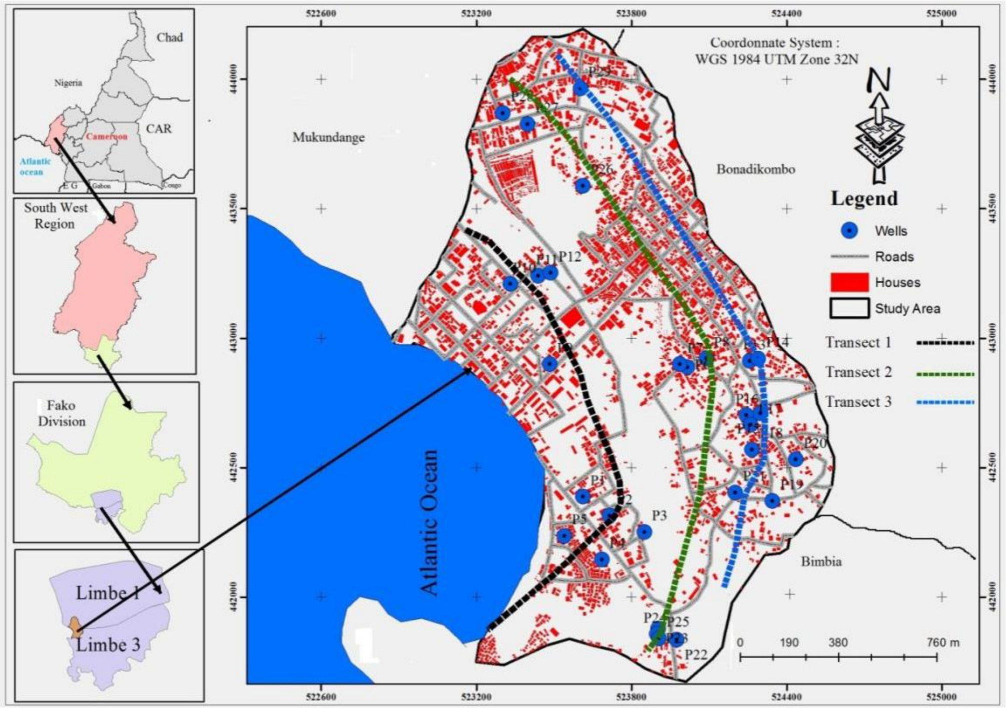

Figure 1. Location of the study area and location of sampling points in Limbe.

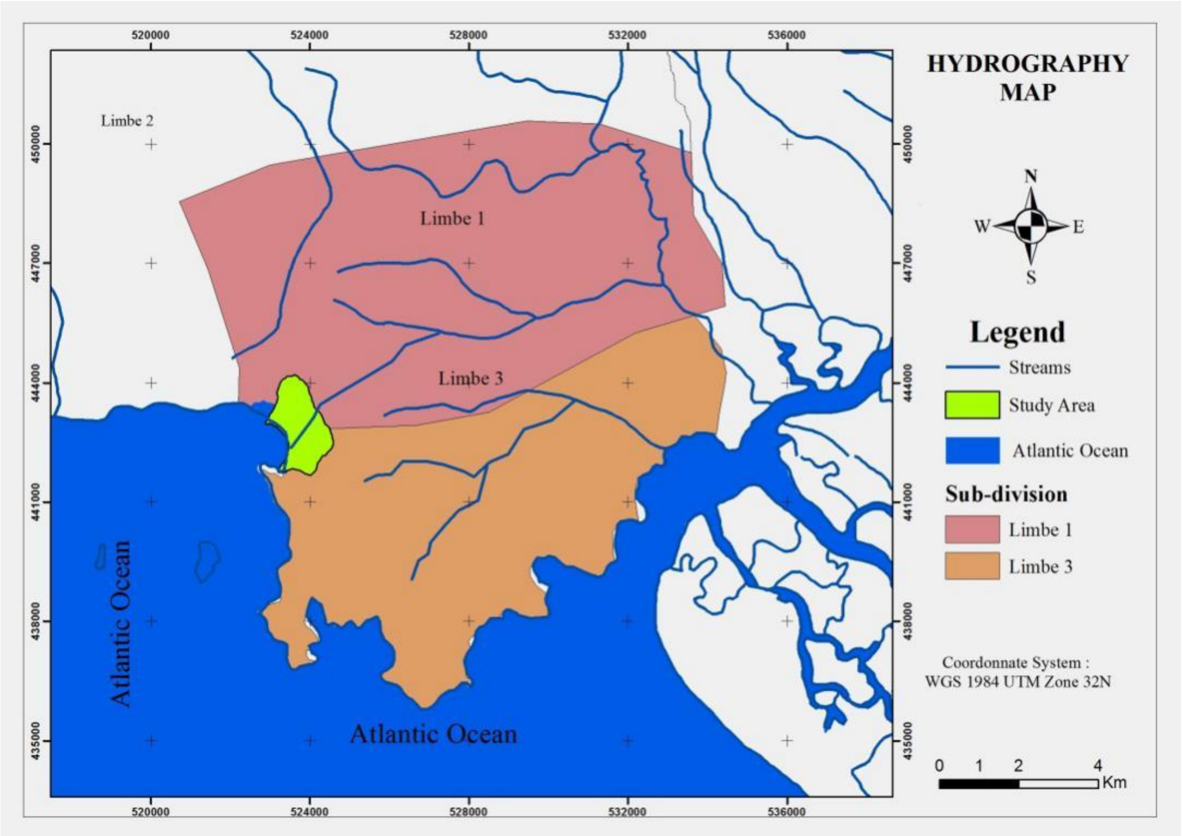

Figure 2. Hydrography of the study area.
Source: Buh(2009).

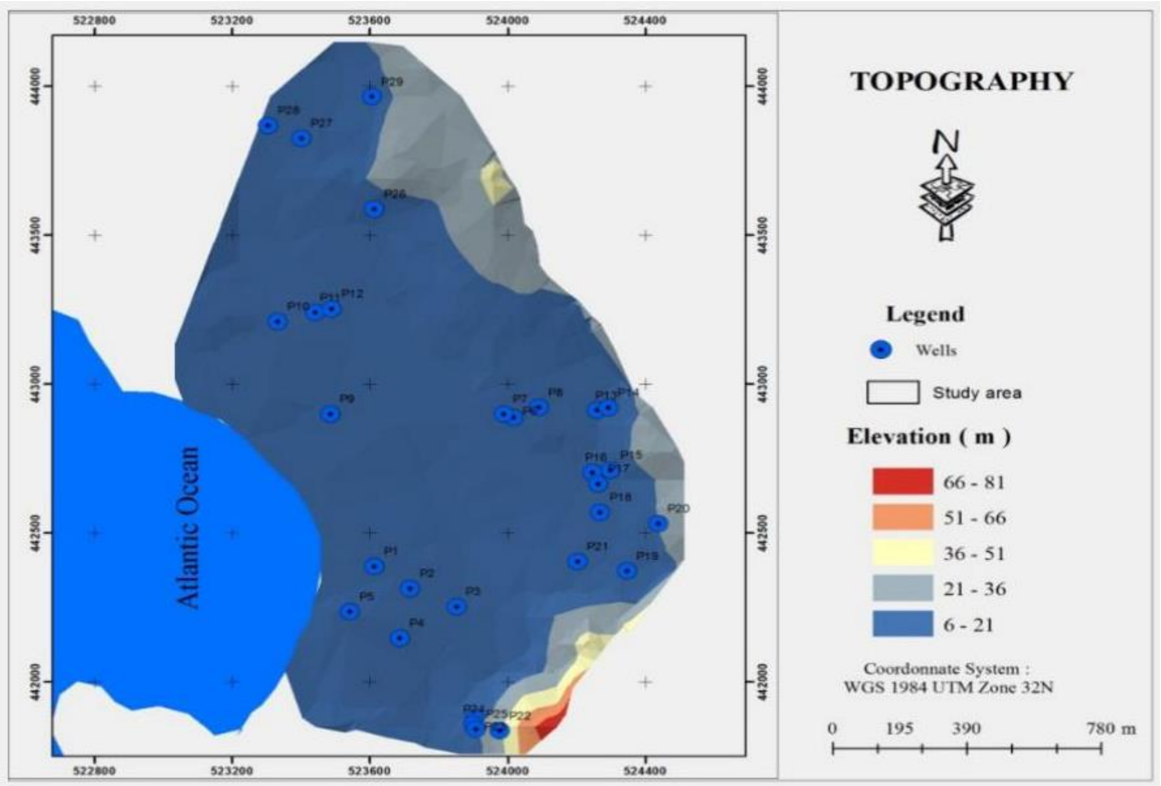

Figure 3. Topographic map of the study area.

Geomorphology and hydrogeology

Geomorphologically, the study area is made up of ridges and deeply incised ravines with a W–E orientation at a high angle to the general NE–SW orientation of Mount Cameroon (Suh et al., 2003). The elevations in the study area range from 0 to about 90 m above sea level with slopes ranging from 0 to 43° (Figure 3). The slopes on the foot of Mount Cameroon are composed of multiple porphyritic basaltic lava flows, punctuated by several strombolian pyroclastic cones to the W and NW and lahar deposit to the east of the study area (Diko et al., 2012). These ridges form part of the Limbe-Mabeta Volcanic Massif, made up of degraded and deeply weathered tertiary basaltic lava flows (Suh et al., 2003). The main rock types within this area include basalts (Figure 4), basanites, lahar deposits, and pyroclastic materials (Buh, 2009).

The hydrogeology is characterized by unfossiliferous sandstone and gravel, weathered from underlying Precambrian basement rock (Longe, 2011). It consists of coastal plain sands (CPS) and recent sediments. The CPS aquifer is the most productive and exploited aquifer in Limbe.

Data

Water samples were collected monthly between July 2017 and June 2018 from thirty hand dug wells located along three transects as shown on Figure 1. The sample size was determined using the formulae presented in Equations 1 and 2 (Howell, 1999):

$$m = \frac{z^2}{\varepsilon^2} * p * (1 - p) \quad (1)$$

$$n = \frac{m}{1 + \frac{m-1}{N}} \quad (2)$$

Where: m = the sample size. n = the correction sample size for a limited population. N = the population. z= the value related with confidence level (1.96 for 95% confidence level). p= the degree of variance between the elements of population (0.5). ε= the maximum error (0.07).

The electrical conductivity (EC), the pH and the total dissolved solids (TDS) were measured *in situ*using a portable hand held, pH-028 six in one monitor. Water samplesfor laboratory analysis were collected in clean 150 ml polyethylene bottles and preserved in ice chests for analyses of chloride and bicarbonate using standard methods (APHA, 1998).

The co-ordinates of the sampled wells were recorded using a Global Positioning System (GPS) and thereafter were plotted using ArcGIS software on the geomorphological map of Limbe. To get a comprehensive picture of the overall quality of groundwater, the WQI was used. WQI is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. Revelle (1941) proposed the following equation for calculating the Revelle Index (RI) which is used to assess groundwater pollution from seawater:

$$RI = \frac{[Cl^-]}{[HCO_3^-] + [CO_3^{2-}]} \quad (3)$$

Where: $[Cl^-]$ = the concentration of chloride in the sample; $[HCO_3^-]$ = the concentration of bicarbonate in the sample; $[CO_3^{2-}]$ = the concentration of carbonate in the sample.

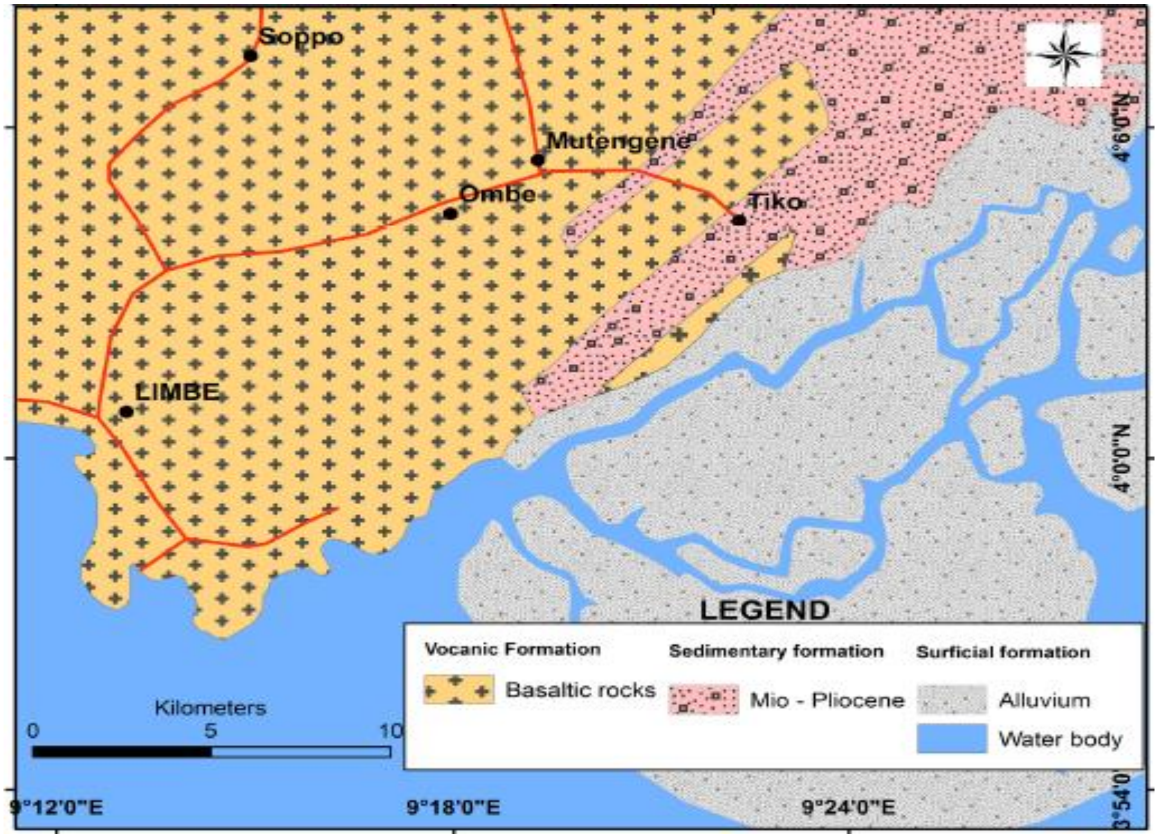

Figure 4. Geologic map of the study area.
Source: Djieto-Lordon et al. (2017).

According to Revelle (1941) when RI < 0.5, this indicates there is no sea water intrusion; when RI is between 0.5 and 6.6, this indicates the gw is slightly affected and when its greater than 6.6 it indicates its strongly affected.

The drinking water quality was assessed using a water quality index (WQI) and the World Health Organization (2006) standard. The stages of calculating the WQI are as follows:

$$q_n = 100\frac{V_n - V_{io}}{S_n - V_n} \qquad (4)$$

Where:q_n= quality rating for the n^{th} water quality parameter; n= the water quality parameter and quality rating or sub index (q_n) corresponding to n^{th}parameter, that is, a number reflecting the relative value of this parameter with respect to its standard (maximum permissible value); V_n= estimated value of the n^{th} parameter at a given the sampling point; S_n= standard permissible value of the n^{th} parameter; V_{io} = ideal value of n^{th} parameter in pure water, that is, 0 for all other parameters except pH and dissolvedoxygen (7.0 and 14.6 mg/l respectively).

The unit weight of the n^{th} parameter (W_n) was calculated by a value inversely proportional to the recommended standard value (S_n) of the corresponding parameter.

$$W_n = \frac{K}{S_n} \qquad (5)$$

Where: S_n = standard value for the n^{th} parameters; K= proportionality constant ($K = \frac{1}{\Sigma(\frac{1}{S_n})}$).

The WQI washencalculated using Equation 6:

$$WQI = \frac{\Sigma q_n w_n}{\Sigma w_n} \qquad (6)$$

Table 1 shows the classification of water based on the WQI from the point of potability.The coordinates of each sample were determined using a Garmin GPSmap 78S. The values of the RevelleIndex and the Water Quality Index were then exported to the ArcGIS 6.0 software and used to generate maps of their spatial distribution over the study area. The areas referring to each water quality class and the Revelle Index were circumscribed on the map using ArcGIS6.0. They were automatically generated with this software surface function. Finally, slicing options were applied using these ranges of values with five groups of water quality classes to generate a spatial distribution of water quality map (Chatterji and Raziuddin, 2002). The statistical analysis of the examined groundwater parameters was computed using STATA software version 6.0.

RESULTS AND DISCUSSION

Spatial variation of the physical and chemical properties

Table 2 presents the measured parameters in the three transects the descriptive statistics and the recommended values by the World Health Organization.

Table 1. Water quality index and status of water quality.

Water quality index	**Water quality class**
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Verypoor water quality
<100	Unsuitable for drinking

Source: Chatterji and Raziuddin (2002).

Table 2. Measured parameters and descriptive statistics of groundwater in the study area.

Transect	**Wells**	**EC (µS/cm)**	**pH**	**TDS (ppm)**	**T (°C)**	**$[\mathrm{Cl}^-]$ (mg/l)**	**$[\mathrm{HCO}_3^-]$ (mg/l)**	**$[\mathrm{Cl}^-]/[\mathrm{HCO}_3^-]$**
T1	P1	592.92	7.19	419.17	28.09	93.21	85.60	1.09
T1	P2	794.17	7.05	558.33	27.89	112.13	82.70	1.36
T1	P3	680	7.26	475.83	27.77	90.29	88.71	1.02
T1	P4	808.33	7.34	566.67	26.88	131.63	105.38	1.25
T1	P5	792.5	7.24	555	27.04	140.4	90.53	1.55
T1	P9	497.27	6.86	340	27.83	65.52	83.47	0.78
T1	P10	451.67	7.26	317.5	27.48	77.42	75.00	1.03
T1	P11	570.83	6.99	399.17	27.83	74.10	90.43	0.82
T2	P6	494	7.2	331.67	26.57	88.53	124.94	0.71
T2	P7	655	7.49	429.17	27.28	83.27	196.83	0.42
T2	P8	698	7.09	455.00	27.2	102.77	160.81	0.64
T2	P12	519	7.22	340.00	27.63	39.59	120.82	0.33
T2	P15	120	6.46	82.50	27.58	34.13	137.96	0.25
T2	P16	145	6.58	100.00	27.98	39.00	107.4	0.36
T2	P17	195	6.66	143.33	27.31	25.94	107.8	0.24
T2	P18	400	6.99	271.67	27.81	39.00	109.6	0.36
T2	P19	121	6.74	85.00	27.67	43.68	128.83	0.34
T2	P21	254	6.64	176.67	27.48	39.00	109.3	0.36
T2	P26	287	6.94	214.17	26.88	40.95	79.5	0.52
T2	P27	452	7.31	316.67	27.7	23.40	103.41	0.23
T2	P28	369	7.12	252.5	27.78	22.43	101.77	0.22
T2	P29	249	6.63	185.83	27.91	25.35	105.36	0.24
T2	P30	327.27	6.96	240.00	27.48	24.38	105.86	0.23
T3	P13	298	7.37	189.17	27.23	25.35	170.7	0.15
T3	P14	262	6.34	185.00	27.5	30.81	128.2	0.24
T3	P20	233	6.2	160.83	27.75	50.12	126.98	0.39
T3	P22	203	6.79	143.33	27.73	41.93	185.95	0.23
T3	P23	222	6.85	153.33	27.03	33.15	159.62	0.21
T3	P24	230	6.84	159.17	27.88	41.73	193.57	0.22
T3	P25	232	6.71	156.67	27.2	59.09	184.32	0.32
Min		**120**	**6.2**	**82.50**	**26.57**	**22.43**	**75**	**0.15**
Max		**808.33**	**7.49**	**566.67**	**28.09**	**140.4**	**196.83**	**1.55**
Mean		**405.1**	**6.94**	**280.11**	**27.51**	**57.94**	**121.71**	**0.54**
Standard dev		**213.61**	**0.32**	**146.58**	**0.38**	**33.67**	**36.26**	**0.39**
WHO norm		**300**	**6.5-8.5**	**500**	**25**	**250**	**300**	

Min = minimum; max = maximum; EC = Electrical conductivity; TDS = Total dissolved solids.

The pH of the gw varied from 6.2 to 7.49 with a mean value of 6.94. The EC values varied from 120.00 to 808.33

Table 3. Spatial variation of the mean values of some physico-chemical parameters of gw along three transects.

Transect	Temp (°C)	pH	TDS (ppm)	EC (µS/cm)	$[\mathrm{Cl}^-]$ (mg/l)	$[\mathrm{HCO}_3^-]$ (mg/l)	$[\mathrm{Cl}^-]/[\mathrm{HCO}_3^-]$
T_1	27.60^a	7.15^b	453.96c**	648.46c**	98.09c**	87.73a**	1.11c**
T_2	27.48^a	6.93^b	241.61b**	352.35b**	44.76b**	120.01b**	0.36b**
T_3	27.47^a	6.73^{a*}	163.93a**	240.00a**	40.31a**	164.19c**	0.25a**

TDS, Total dissolved solids; EC, Electrical conductivity; No significant difference in the columns for the values carrying the same letters (P>0.05); Significant difference in the columns for the values carrying the different letters (* P<0.05; **P<0.001)

µS/cm with a mean value of 405.10 µS/cm which is higher than the norm indicating a high amount of dissolved salts in the water. The values of EC in all wells in transect 1 exceeded the minimum recommended value. The total dissolved solids ranged from 82.50 to 566.67 ppm with a mean value of 280.11 mg/l which is about 50% lower than the norm. Most of the values of the TDS were within the recommended range for drinking water except for values obtained from wells P_2, P_4 and P_5 which exceeded the recommended value. The temperature varied between 26.57and 28.09^{0}C with a mean value of 27.51.

The bicarbonate level varied between 75.00 and 196.83 mg/l with mean value of 121.71mg/l. Chloride values were found to vary from 22.43 to 140.4 mg/l with mean value of 57.94. These values of chloride are within the recommended standard level. A high level of chloride in freshwater is an indicator of pollution (Chandra et al., 2012). The Secondary Maximum Contaminant Limit (SMCL) for chloride is 250 mg/l. This is the level above which the taste of the water may become objectionable to the consumer. In addition, high chloride concentration levels in the water contribute to the deterioration of domestic plumbing materials, water heaters and equipment in municipal water works.The levels of TDS, EC, and Cl^- decreased significantly from transect 1 to 3 as shown in Table 3 while the level of bicarbonate ions increased significantly. This indicated that saline intrusion was more pronounced in sites near the ocean.

Extent of sea water intrusion in the coastal aquifer

In the study area, RI varied from 0.126 to1.551 as shown in Table 4. According to Revelle (1941), this suggests that some areas in the study area have not been affected (RI less than 0.5) while others have been slightly affected (RI is between 0.5 and 6.6). The relationship between the ratios of $\frac{[\mathrm{Cl}^-]}{[\mathrm{HCO}_3^-]+[\mathrm{CO}_3^{2-}]}$ indicates a strong positive linear relation with Cl concentrations (*r* = 0.94, *p* < 0.01).This linear relationship indicates the mixing of saline water and fresh groundwater (Zaharin et al., 2009). Figure 5 shows the extent of the groundwater salinization in the study area. From Table 5, about 77% of the groundwater in the study area was unaffected by sea water intrusion, while 23% of the aquifer was slightly affected by pollution from sea water. The hotspots include locations of wells P_1, P_2, P_3, P_4 and P_5. Thus, efforts should be made to reduce the pollution of ground water due to sea level rise in the area.

Extent of the gw suitable for drinking

The suitability of groundwater for drinking purposes in the study area was determined using WHO (2006) guidelines. The computed Water Quality Index (WQI) ranged from 28 to 115 as indicated in Table 6.

The spatial distribution of water quality in the aquifer is presented in Figure 6. The EC, pH, TDS, Cl^- and HCO_3^-all contributed to the WQI values. However, values of chloride and electrical conductivity were the main parameters responsible for the high values of WQI. In some locations, the TDS also significantly increased the WQI.

The area covered by different water quality classes were calculated from the WQI maps and are presented in Table 7. About 34.4% of the gw is currently considered to be good for drinking while 65.6% is either poor, very poor or unsuitable for drinking. Hot spots that require attention are wells P_2, P_3, P_4 and P_5, all along transect 1, which is closest to the sea.

Solution to reduce sea water intrusion

About 23% of the aquifer of the study area is affected by sea water intrusion rendering the water non-potable. In order to reduce the intrusion of ocean water, there are two possibilities; construction of dykes or barriers and planting a halophyte plant. Anti-salt barriers or dykes can be used to combat saline intrusion (Barry, 1988). However, they are limited in that they are effective only in controlling surface sea water flow but, they do not prevent the intrusion of underground sea water (Diawara, 1988).

A more effective solution is the planting of halophyte plants like mangrove trees of the Rhizophoraceae family. They should be planted on both sides of the mouth of the River Njenguele over a distance of 500 m. Mangrove trees stabilize the coastline and serve as a barrier against erosion due to swell by reducing the energy of the waves

Table 4. Revelle Index of gw in the study area.

Transects	Wells	Coordinates (meters)		Revelle index
		X	Y	
T1	P1	523612	442388	1.089
T1	P2	523716	442314	1.356
T1	P3	523850	442252	1.018
T1	P4	523686	442146	1.249
T1	P5	523541	442236	1.551
T1	P9	523484	442900	1.061
T1	P10	523331	443210	1.11
T1	P11	523439	443241	1.136
T2	P6	524016	442888	0.524
T2	P7	523988	442900	0.393
T2	P8	524090	442922	0.461
T2	P12	523488	443253	0.328
T2	P15	524299	442711	0.184
T2	P16	524245	442703	0.287
T2	P17	524262	442665	0.317
T2	P18	524267	442570	0.356
T2	P19	524346	442372	0.201
T2	P21	524202	442404	0.357
T2	P26	523612	443589	0.549
T2	P27	523399	443827	0.485
T2	P28	523303	443870	0.383
T2	P29	523604	443966	0.398
T2	P30	523634	443866	0.313
T3	P13	524259	442912	0.244
T3	P14	524291	442921	0.461
T3	P20	524437	442532	0.322
T3	P22	523976	441835	0.126
T3	P23	523903	441878	0.140
T3	P24	523899	441857	0.131
T3	P25	523907	441841	0.132
Min				**0.126**
Max				**1.551**
Mean				**0.555**
Standard deviation				**0.418**

and by modifying the hydrocirculations (Furukawa et al., 1997). Mangrove trees have a root system that filters water, and can thus exclude up to 90% of salts from interstitial waters thanks to glands located in their leaves (Tymbery et al., 2019). Mangrove trees planted a short distance offshore, control high energy waves which erode the coastline and prevent the meeting of coastal marine waters and fresh waters. In addition, the complex geochemical reactions taking place in the sediment around the trees can immobilize toxic metals and consequently purify coastal waters. Furthermore, mangrove trees serve as a natural barrier against the gradual rise in mean sea level and saline intrusion into aquifers and arable land. They also have a significant refuge value and hence they enhance aquatic biodiversity.

Conclusion

Based on the methodology used in this study and the results obtained, it can be concluded that:

(1) About 23% of the ground water resources in the study area is presently slightly polluted by seawater intrusion.
(2) Ground water contamination by sea water intrusion is a major concern for the fresh water supply in the study

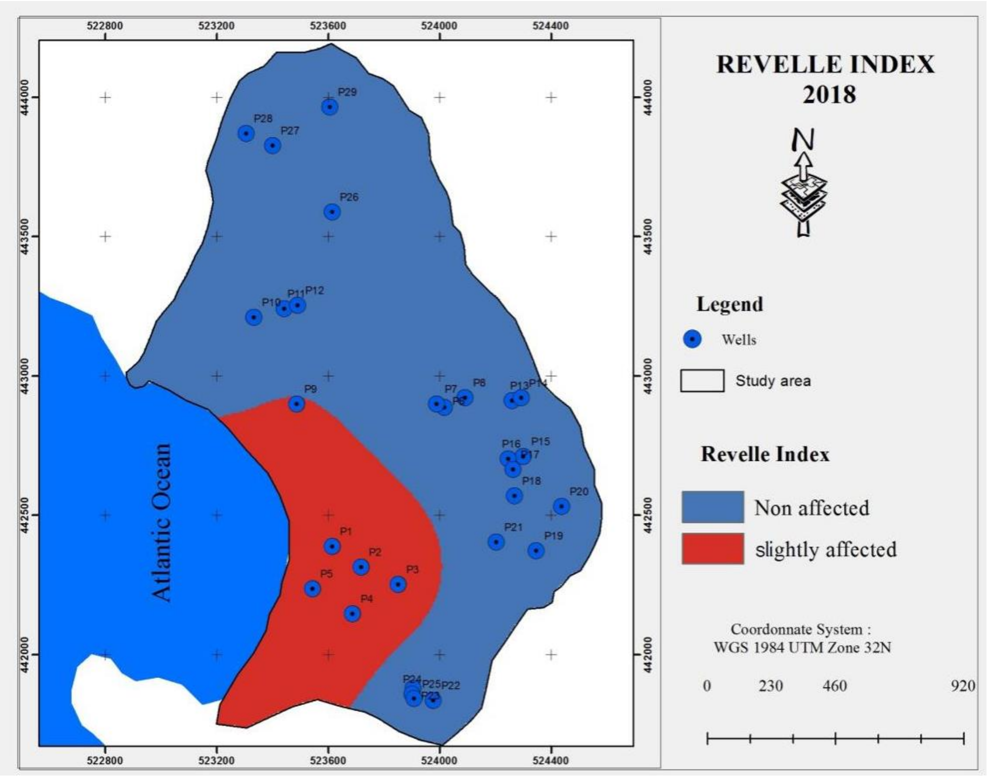

Figure 5. Spatial variation of sea water intrusion into ground water in Limbe.

Table 5. Extent of sea water intrusion into ground water in Limbe.

Degree of sea water intrusion	Area (ha)	Percentage of total
Notaffected	185.96	77
Slightlyaffected	55.36	23
Total	**241.32**	**100**

Table 6. Water quality index in the study area.

Transects	Wells	Coordinates (m)		WQI
		X	Y	
T1	P1	523612	442388	84
T1	P2	523716	442314	108
T1	P3	523850	442252	93
T1	P4	523686	442146	115
T1	P5	523541	442236	114
T1	P9	523484	442900	73
T1	P10	523331	443210	67
T1	P11	523439	443241	84
T2	P6	524016	442888	72
T2	P7	523988	442900	96
T2	P8	524090	442922	97
T2	P12	523488	443253	69
T2	P15	524299	442711	28

Table 6. Contd.

T2	**P16**	**524245**	**442703**	**29**
T2	P17	524262	442665	35
T2	P18	524267	442570	57
T2	P19	524346	442372	28
T2	P21	524202	442404	42
T2	P26	523612	443589	44
T2	P27	523399	443827	64
T2	P28	523303	443870	53
T2	P29	523604	443966	42
T2	P30	523634	443866	48
T3	P13	524259	442912	51
T3	P14	524291	442921	48
T3	P20	524437	442532	41
T3	P22	523976	441835	40
T3	P23	523903	441878	40
T3	P24	523899	441857	44
T3	P25	523907	441841	43
Min				**28**
Max				**115**
Mean				**62**
Standard deviation				**26.41**

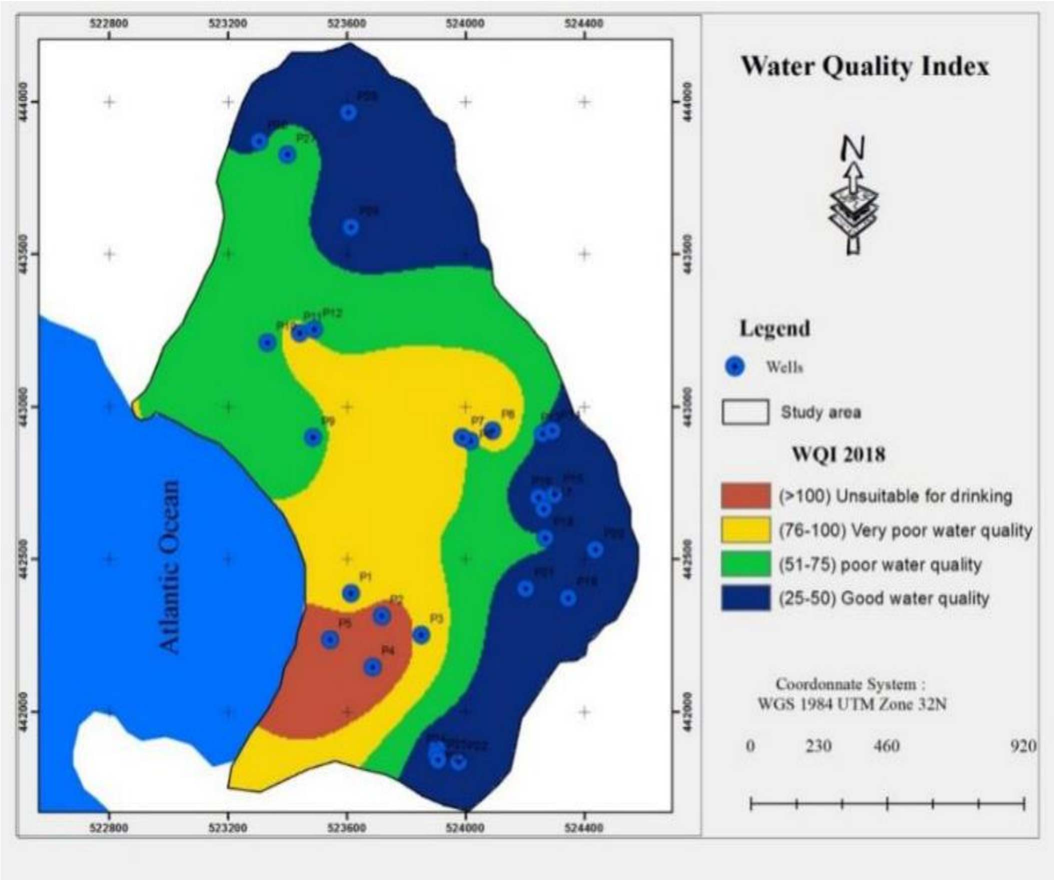

Figure 6. Spatial variation of ground water quality in Limbe.

Table 7. Proportion of different water quality classes in the study area.

Water quality class	Area (ha)	Percentage of total
Unsuitable for drinking	16.38	6.79
Verypoor	60.63	25.12
Poor	81.30	33.69
Good	83.01	34.40
Total	**241.32**	**100.00**

area especially around locations of wells P_2, P_3, P_4 and $P_{5.}$

(3) About 34.4% of the ground water resources in the study area is currently considered to be good for drinking while 65.6 % is either poor, very poor or unsuitable for drinking.

(4) To minimize the impact of sea water intrusion on the quality of gw in the study area a halophyte plant like mangrove should be planted at the mouth of River Njenguele, which is the main natural drain in the study area.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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