Spatial trend assessment of saline intrusion in Igbokoda/Awoye Coastal Area of Ondo State, Southwestern Nigeria

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Accepted 1st September, 2020

Access to safe drinking-water is a key water security issue, as it influences public health protection both in the developed and underdeveloped countries. This study assessed the spatial trend of water quality status of the coastal area of Ondo State, Southwestern Nigeria. Twenty-five samples were strategically collected between Igbokoda and Awoye, and analyzed to verify the water quality status. The data were subjected to statistical analysis (correlation) and geo-statistical analysis to create a spatial trend map of selected water quality parameters (salinity risk). Result showed that Temperature, pH, Turbidity and Electrical Conductivity ranged from 28.2-33.9°C, 8.08-9.48, 0.3- 34.6 NTU and 0.16 – 2.77 µS/cm, respectively. The total alkalinity and salinity ranged from 80- 415 mg/L and 0.08-1.29 mg/L, respectively. The major cations Ca^{+}, Na^{+}, and K^{+} have concentration range below detection level – 9.99 mg/L, 0.13- 1.13 mg/L, and 0.08-0.9 mg/L. The heavy metals with values above permissible limit in the groundwater samples are in the order of cadmium> lead> chromium> iron> copper> zinc. The geo-statistical analysis showed that Aiyetoro had a very high salinity, Awoye 1 has high salinity, Igbokoda, Ugbo-Nla, and Mahin had moderate salinity while Ilowo and Ilepete had the lowest salinity level. Generally, the result showed that 95% of the well sampled had salinity level above the permissible limit. Hence, the water is considered unfit for consumption without an appropriate treatment. Also, the high salinity level obtained from the result could be attributed to saline intrusion from the Atlantic Ocean and other anthropogenic activities such as agriculture and excessive groundwater withdrawal.

Key words. Drinking-water, public health, coastal, salinity.

INTRODUCTION

Water is the most dependent ecological resource (after air) in the universe, since water is needed to sustain earth's climate and essential to all forms of life (Odjegba and Busari, 2016; Olawuni, 2007; UN, 2018). Access to safe drinking water is basically linked to public health protection, poverty reduction, food security, gender equality, and preservation of ecosystems, as well as economic and social developments (UNESCO, 2019). Water quality in coastal regions has become a concern, because of its values for socioeconomic development and human health (Ukenye and Taiwo, 2019). Globally, coastal regions are recognized as regions with serious water quality issues, as access to an improved water supply systems to inhabitants of communities in the coastal belt has been a problem, majorly due to salt water intrusion (Oladapo et al., 2014; Oteri and Atolagbe, 2003; Basar, 2012; LaVanchey et al., 2017).

Coastal belt of Nigeria includes Ogun, Ondo, Lagos, Delta, Bayelsa, Rivers, Akwa Ibom and Cross River States. Igbokoda is the headquarter of Ilaje Local Government in Ondo

State, Nigeria, located within the coastal belt of the Dahomey Basin. Communities such as Ilowo, Ilepete, Aiyetoro, and Awoye are reverine settlements, and other communities such as Igbokoda, Ugbo, Ugbo-Nla, and Mahin are located at the hinterland area of the coastal region. Aiyetoro, a community in coastal region, was reported by Oteri and Atolagbe (2003) to be challenged with lack of access to safe water supply. This is attributed to the incidence to intrusion from the saline water. Further report by researchers (Talabi, 2018; Ukenye and Taiwo, 2019; Talabi et at, 2018) emphasizes that all the boreholes drilled around Igbokoda so far have yielded saline water. However, the water quality status and the extent of the intrusion at the communities located between the riverine and hinterland regions of Ilaje Local Government are yet to be understood. The consequences of saltwater intrusion for supply wells vary widely, depending on the extent of the intrusion, the intended use of the water, and whether the salinity exceeds standards for the intended use (*Barlow & Paul, 2003)*. Also, mapping of the extent of the intrusion is lacking (Oteri, and Atolagbe, 2003). This study therefore assessed the water quality status and the extent of salinity in Igbokoda/Awoye coastal region of Ondo State, as well as the spatial trend analysis of the water quality status of the region.

MATERIALS AND METHODS

Data source

Study area and sampling stations

The study area (Igbokoda / Awoye) is situated at Ilaje Local Government Area of Ondo State which lies at the South-western part of Nigeria. The Ilajes are a distinguished, distinct linguistic group of Yoruba people made up of four geo-political entities namely Ugbo, Mahin, Etikan and Aheri. They mainly occupy the Atlantic coastline of Ondo State of Nigeria, while a large population of them settle on land in the hinterland. The study area lies within latitude 5°57’30” – 6°20’0”N and longitude 4°33’30” – 5°3’0” E (Figure 1) and has a total land mass of about 1,318 km^2 with a

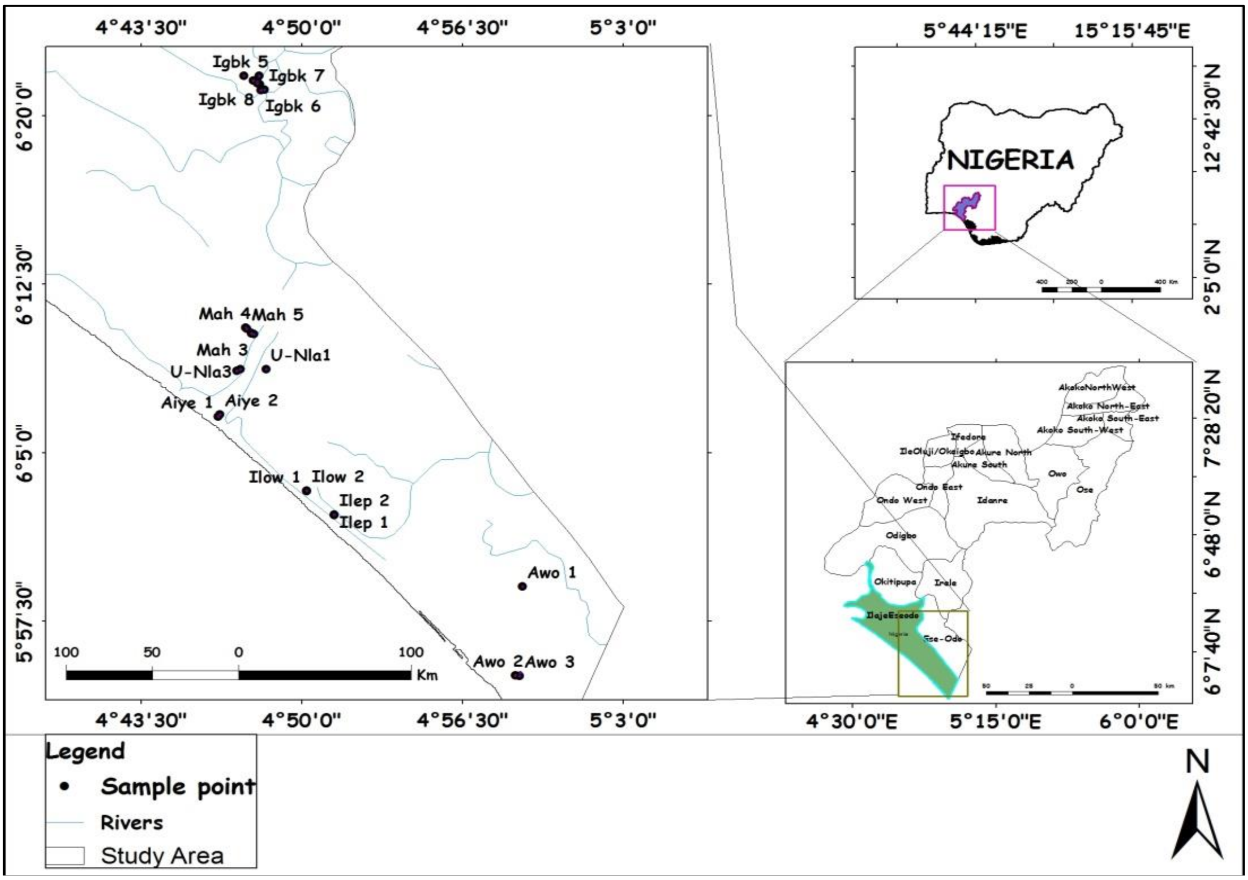

Figure 1. Map of the study area showing sampling points.

population of about 290, 615 at the 2006 census. Most part of the coastal area is water logged with sparse settlement. The study area has an elevation which ranges from 15m above sea level to about 1meter below sea level. The climate of Ondo State is of the Lowland Tropical Rain Forest type, with distinct wet and dry seasons. In the south, the mean monthly temperature is 27°C, and a mean relative humidity of over seventy five percent (75%). Ondo State has two distinct geological formations which are; sedimentary rocks in the south and the region of Precambrian Basement Complex rocks in the north. Some few kilometers north of Aaye occurs the Basement Complex Sedimentary rocks boundary. The Sedimentary rocks are mainly of the post Cretaceous sediments and the Cretaceous Abeokuta Formation. The study area lies within the easternmost part of Dahomey Basin, Southwestern Nigeria**,** bordered to the north by the crystalline rocks of the Southwestern Nigeria Basement Complex and to the South by Atlantic Ocean christened the Bight of Benin. The Dahomey Basin is a combination of inland/coastal plain sand that stretches from Southeastern Ghana through Togo and the Republic of Benin to Southwestern Nigeria (Adeyemo et al., 2015). The study area is drained by many tributaries, streams and rivers some of which are connected directly or indirectly to the Atlantic Ocean. Selected areas include Igbokoda, Ugbo, Ugb-Nla, Mahin, Ilowo, Ilepete, Aiyetoro, Awoye, respectively.

The method employed for this study is field investigation/sampling and laboratory analysis. A detailed sampling exercise was carried out on the field. After collection, samples were tightly covered and transported to the laboratory for detailed water quality testing. A $2^1/_2$ liters plastic bottle was utilized; all plastics utilized were pre-rinsed with distilled deionized water. Samples were collected from twenty five strategic locations (21-groundwater and 4-surface water) in eight different settlements between Igbokoda and Awoye namely; Igbokoda, Mahin, Ugbo, Ugbo-Nla, Ilepete, Ilowo, Aiyetoro and Awoye areas of the Ilaje Local Government. pH, temperature, and Electrical Conductivity were measured *in-situ* by probe method using Hanna pH meter; the heavy metals were measured using Atomic Spectrophotometer by AAS model ICE300. The geographical coordinates of the sampling points were taken using the Garmin *e*trex 10 GPS (Appendix 1). All water samples were done in triplicate. The water quality result was subjected to statistical analysis (descriptive and correlation) and geostatistical analysis was carried out using the Inverse Distance weighing method.

RESULTS AND DISCUSSION

The result of the physical and chemical parameters showed a temperature value of 28.2 – 33.9°C, with a mean value of 29.9°C (Appendix Table 2). Positive correlation exists at $p<0.01$ probability between Temp and Na^+ at $r = 0.444$, indicating a relationship such that an increase in temperature may cause the concentration of Sodium to be elevated. A negative relationship ($r = -0.483$) exists between Temperature and Total Hardness. This indicates that an increase in temperature may cause a decrease in concentration of total hardness, while a relationship at $p = 0.01$ probability exist between temperature and Sulphate ($r = - 0.586$). The pH value ranged from 8.0 (Awoye Borehole) to 9.48 (Ugbo-Nla) with mean value of 8.67 ± 0.36 for groundwater and 8.25 - 10.29 for surface water (Appendix Table 1). When compared with World Health Organization (WHO, 2011) standard for drinking water quality (6.5 – 8.5), pH values for 12 samples (57%) were found to be above 8.5. However, pH as a primary standard parameter has no health implication (SON, 2007). Additionally, there is similarity in the pH values of the surface water samples and the borehole samples at Ilowo, Ilepete, and Aiyetoro. About 57% of wells sampled were alkaline. The EC values ranged from 106 µS/cm for Mahin 2 to 2770 µS/cm for Aiyetoro with a mean value of 683.80 ± 536.10µS/cm. The range of EC values fell within the WHO (2011) acceptable limit of 1000 µS/cm except Igbokoda 7 and Aiyetoro borehole. Conductivity values exceeding 1000 µS/cm are indicative of saline intrusions into the groundwater. It can be an indicator of the concentration of dissolved ions which may cause the water to be corrosive, salty or brackish, resulting in scale formation (Orewole et al., 2007). Conductivity has a very strong positive correlation with Chloride (0.932) and Sodium (0.592) at $p < 0.01$ probability level. Total alkalinity and total hardness values ranged from 80-415 mg/L with a mean of 257 ± 96.59 mg/L and 4-260 mg/L with a mean of 138.29 ± 77.03 mg/L, respectively (Figure 2). About 81% of samples fell above the allowable total

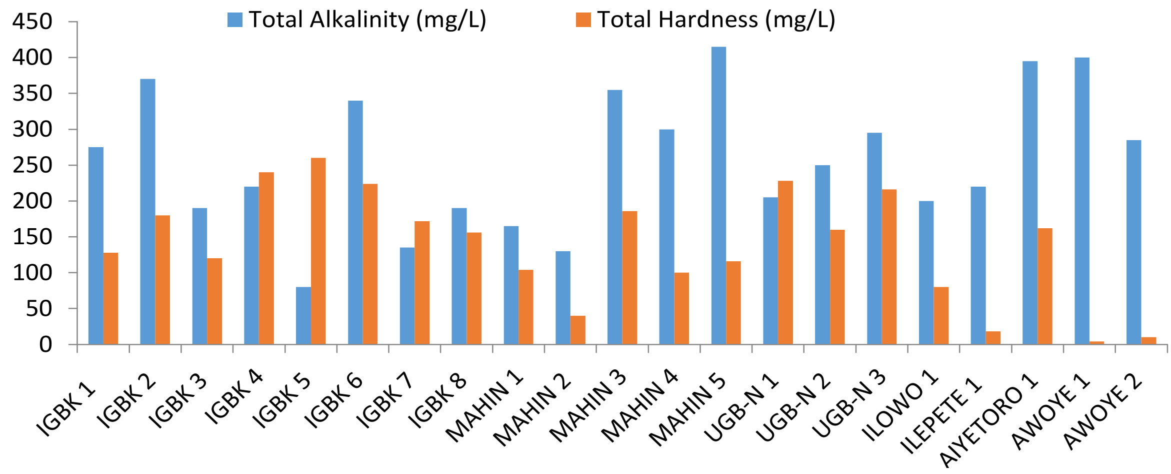

Figure 2. Mean values of Total Alkalinity and Total Hardness for the sampling points.

alkalinity limit of 150 mg/L set by WHO (2011) and 71% for the Total Hardness 100 mg/L by W.H.O (2011), respectively. These show that the groundwater within the study area is highly alkaline and hard. The results of salinity indicated that it had values ranging from 0.08 mg/l (Mahin 2) – 1.29 (Aiyetoro 1) mg/L, with mean value of 0.31 ± 0.25 mg/L; only the borehole at Mahin 2 has values below the WHO permissible limit of 0.1 mg/L. A strong positive correlation exists at $p = 0.01$ between Salinity: Total hardness (0.512), Salinity: Nitrate (0.775), Salinity: K^+ (0.571) and Salinity: Zn (0.692) (Appendix Table 3). This shows a common source as an increase in salinity would cause one among the other to increase. High salinity concentration of the water samples shows that the water is brackish. This is traceable to the proximity of the area to the Atlantic Ocean and corroborates with the findings of Onyema and Nwankwo, (2009). The spatial trend of salinity showed that the area has salinity concentration which could be ranked in terms of risk (Figure 4.) as; Low (< 0.15), moderate (0.15 < 0.3), high (0.3 < 0.45) very high risk (> 0.45). Spatial trend showed that the riverine settlements (Ilepete, Ilowo and Awoye in part) towards the southern part of the study area have the lowest risk, which could be attributed to proximity of the well to the tributary of the Atlantic Ocean. Awoye 1 has high salinity risk; this is traceable to coastal erosion which was reported by Awomeso et al. (2015) as the location is vulnerable to the rising and falling of the Ocean tides. It was also observed that the spatial trend of salinity increases Northward (Mahin, Ugbo-Nla and Igbokoda). This could be traced to the excessive groundwater abstraction in the area which is due to increased population density from the coastal river banks at Ugbo-Nla to Igbokoda. This was in agreement with the findings of Oteri, (2003), that coastal salinity is caused by excess groundwater exploitation. A very high salinity concentration was found at Aiyetoro. This could be traced to many factors; the initial impact of proximity to Atlantic Ocean created an intrusion at the coastal region. However, anthropogenic activities such as agricultural activities in this area which reflect in the concentration of Chloride indicate high presence of chloride salt in the area, and the very high electrical conductivity recorded are all traced to anthropogenic activities, that is, agriculture.

Sodium ion values were below the maximum acceptable limit of 200 mg/L set by WHO (2011) with value range of 0.13 mg/L at Igbokoda 4 to 1.13 at Aiyetoro. Calcium has values ranging from 0 mg/L to 9.9 mg/l with a

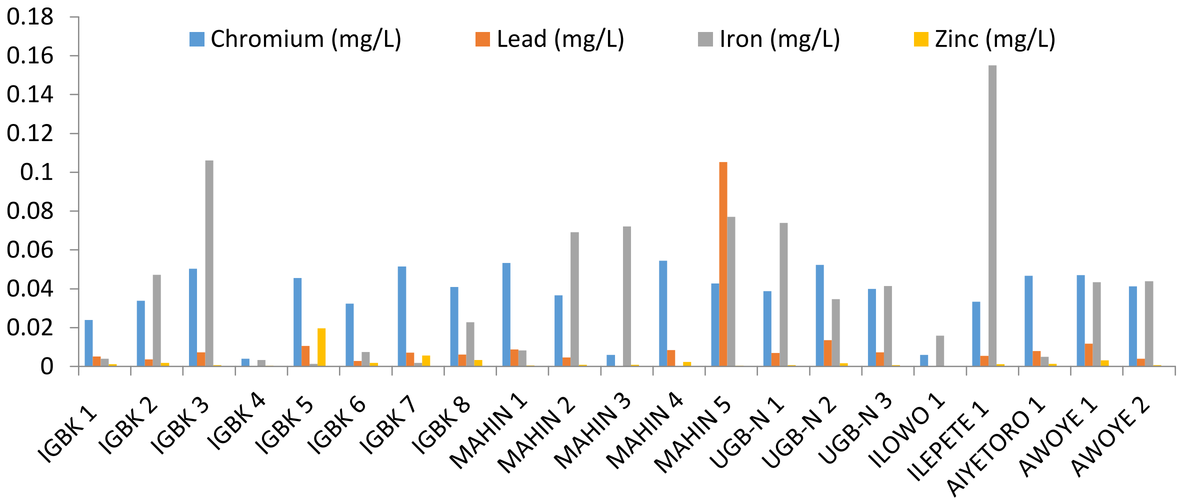

Figure 3. Mean value of Heavy metal parameters (Zinc, Lead, Chromium, and Iron).

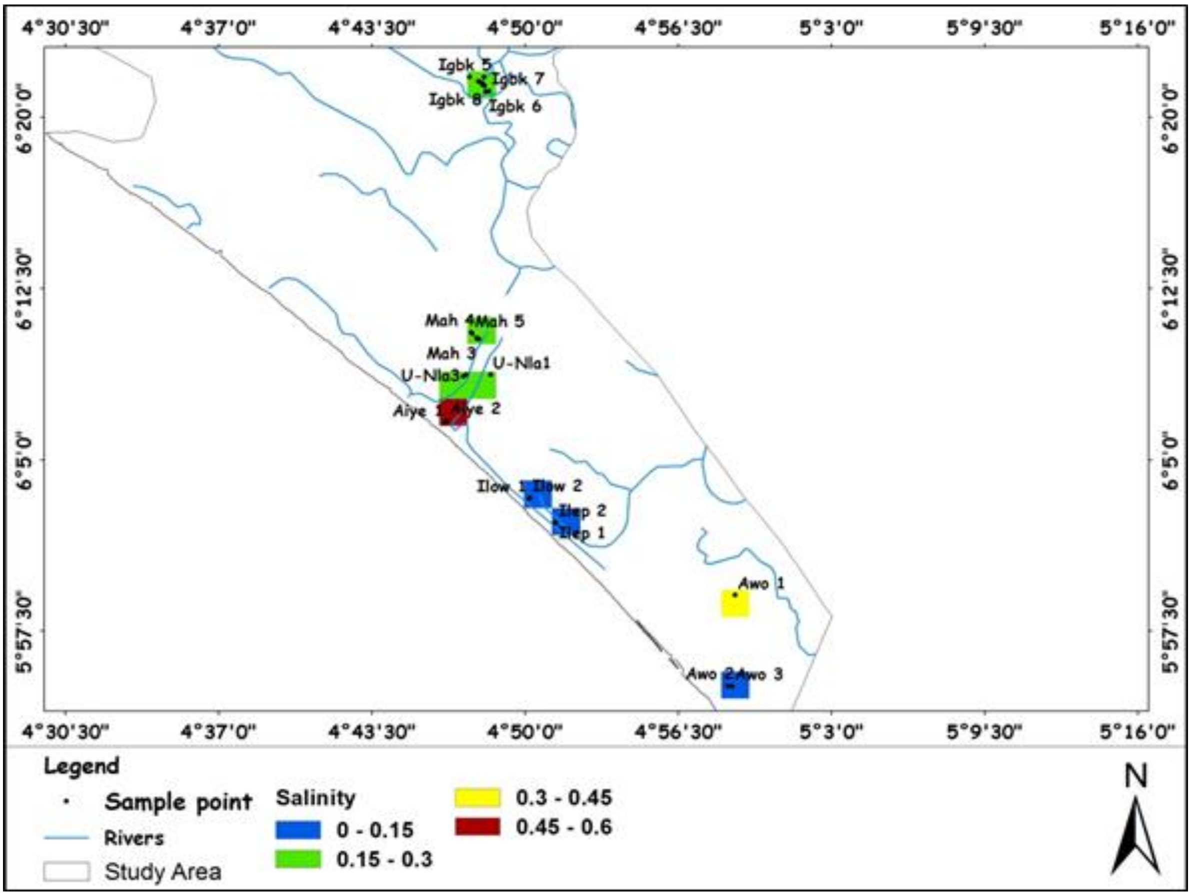

Figure 4. Geostatistical mapping/analysis of groundwater salinity.

mean of 3.76± 3.25 mg/L while potassium values ranged from 0.08-0.94 mg/L with a mean of 0.46 ± 0.27 mg/L. There is however, no health-based drinking water standards for K (Nkono and Asubiojo, 1998). Results of anions indicated that SO_4 recorded a range of values between 0 to 53 mg/L with a mean of 19.39± 16.10 mg/L. However, they were below the WHO (2011) limits of 500 mg/l. High sulphate concentrations can cause scale formation and may be associated with a bitter taste in water that can have a laxative effect on humans and young livestock (Orewole et al., 2007). Nitrate concentrations range from 0.6 mg/L (Igbokoda 1) – 99.8 mg/L (Igbokoda 5) and a mean of 18.4 ± 27.33 mg/L; two of the water Igbokoda 4 and 5 has Nitrate concentration higher than the acceptable limit of WHO Standard of 50 mg/L. High Nitrate concentration in the water samples is traceable to the proximity of a drainage carrying a very toxic waste water. This was supported by Munster et al., (2003) and Jafari et al., (2017). The health implication associated with high concentrations of NO_3, especially in young children, is the blue baby syndrome, which can cause death in children (Orewole et al., 2007). Chloride values ranged from 0– 544 mg/L with a mean of 16.53 ± 5.90 mg/L. values of Chloride recorded values were within the acceptable limits of 250 mg/L set by WHO (2011) except for the borehole at Aiyetoro which has a very high chloride value. High concentration of chlorides is harmful to plant growth, domestic and industrial pipeline and infrastructures. Also, high chloride content in water affects taste of water (Adebowale et al., 2008). The results of the heavy metals Zinc, Iron, Cadmium and Lead showed mean values of 0.0023± 0.004 mg/L, 0.04± 0.041 mg/L, 0.0025 ± 0.0085 mg/L and 0.0108± 0.022 mg/L (Figure 3). The result showed that the all water sampled has zinc value, that is, within the acceptable limit of 1.5 mg/L prescribed for drinking water (WHO, 2011). The values of Iron for the water sample are also within the acceptable limit of 0.3mg/L prescribed for drinking water (WHO, 2011). Ugbonla 2 has cadmium concentration above the drinking water acceptable limit of 0.002 mg/L with a value of 0.0392 mg/L. This indicates that the water is not fit for drinking without appropriate treatment. The water sample has lead concentration that is within the acceptable limit of 0.015 mg/L (WHO, 2011).

Conclusion

It was observed from this study that the spatial trend of saline water intrusion between Igbokoda and Awoye Coastal areas increases towards Igbokoda with a high level of salinity risk which is also influenced by anthropogenic activities; excessive groundwater abstraction. The natural occurrence of saline water intrusion could become severe when influenced by human activities; poor sanitation exercise, inappropriate agricultural waste disposal, excessive groundwater abstraction. Most of the groundwater within the study area is alkaline and hard. Hence, urgent attention is required for protection of groundwater resource in this region for its importance as the major source of drinking water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Appendix Table 1. Sampling points, GPS Coordinates and relative positions from the ocean.

Location	Longitude (E)	Lattitude (N)	Elevation
Igbokoda 1	4°48′17.8″	6°21′22.8″	21
Igbokoda 2	4°48′11.9″	6°21′29.7″	5
Igbokoda 3	4°48′1.9″	6°21′33.1″	4
Igbokoda4	4°47′38.5″	6°21′45.2″	6
Igbokoda 5	4°48′16″	6°21′45.5″	14
Igbokoda 6	4°48′20.6″	6°21′7″	14
Igbokoda 7	4°48′28.6″	6°21′8.6″	6
Igbokoda 8	4°48′11.87″	6°21′26.2″	6
Mahin 1	4º48′2.8″	6°10′16.2″	8
Mahin 2	4°47′57.4″	6°10′18.9″	3
Mahin 3	4°47′57.6″	6°10′17.9″	4
Mahin 4	4°47′42.9″	6º10′33.6″	8
Mahin 5	4°47′45.9″	6°10′31.1″	2
Ugbo-Nla 1	4°48′32.9″	6°8′42.4″	5
Ugbo-Nla2	4°47′31.0″	6°8′41.9″	6
Ugbo-Nla 3	4°47′22.6″	6°8′38.4″	3
Ilowo 1	4°50′10.7″	6°3′16.9″	2
Ilowo 2	4°50′11.8 ″	6°3′18.4″	2
Ilepete 1	4°51′18.2″	6°2′12.7″	3
Ilepete 2	4°51′18.5″	6°2′13.5″	3
Aiyetoro 1	4°46′36.1″	6°6′36.1″	1
Aiyetoro 2	4°46′40″	6°6′42.2″	1
Awoye 1	4°58′55″	5°59′2.9″	1
Awoye 2	4°58′36.8″	5°55′4.4″	-1
Awoye 3	4°58′47″	5°55′3″	0

Appendix Table 2. Showing means results of physicochemical analyses of samples.

Parameter	Groundwater samples		Surface water samples	
	Mean	standard deviation	Mean	standard deviation
Temp	29.93	1.83	30.68	0.655
pH	8.67	0.37	8.93	0.91
Turbidity	6.8	9.38	15.64	4.64
Electrical conductivity	0.68	0.54	101	148.77
Salinity	0.26	0.11	340	209.92
Total suspended solid	3.48	9.04	250	177.95
Total acidity	48.67	27.65	7500	5246.59
Total alkalinity	257.86	96.60	62.95	19.15
Total hardness	138.29	77.04	73	21.59
Chloride	63.43	121.23	7.2	4.17
Nitrate	18.4	27.33	1.12	0.47
Sulphate	19.39	16.11	0.88	0.38
Calcium	3.76	3.25	0.14	0.27
Sodium	0.67	0.22	0	0
Potassium	0.46	0.27	0.35	0.41
Zinc	0.002	0.00	0.01	0.017
Copper	0.0001	0.00	0.003	0.004
Iron	0.04	0.04	0.04	0.022
Cadmium	0.0025	0.01	30.68	0.655
Lead	0.011	0.02	8.93	0.91
Chromium	0.037	0.02	15.64	4.64

Appendix Table 3. showing the correlation matrix of water quality parameters.

	TEMP	pH	TUR	E.C	SAL	T.AL	T.H	Cl	Nitrate	SO_4^{2-}	Ca	Na	K	Zn	Fe	Cd	Pb	Cr
TEMP	1																	
pH	-0.361	1																
TU	0.011	-0.05	1															
E.C	0.322	0.048	-0.283	1														
SAL	-0.085	-0.197	-0.248	0.433	1													
T.ALK	0.288	0.073	0.056	0.375	0.136	1												
T.H	-0.483*	0.421	0.142	0.201	0.512*	-0.109	1											
Cl	0.431	0.014	-0.172	0.932**	0.265	0.328	0.154	1										
Nitrate	-0.298	-0.104	-0.274	0.133	0.775**	-0.288	0.581**	0.038	1									
SO_4^{2-}	-0.586**	0.145	-0.04	-0.073	0.296	-0.216	0.32	-0.248	0.272	1								
Ca	-0.413	0.635**	-0.366	0.244	0.323	0.149	0.476*	0.055	0.287	0.287	1							
Na	0.444*	-0.068	-0.532*	0.592**	0.282	0.218	-0.299	0.496*	-0.021	0.057	0.065	1						
K	-0.004	-0.064	-0.163	0.415	0.571**	-0.301	0.514*	0.346	0.543*	0.471*	0.111	0.302	1					
Zn	-0.167	-0.182	-0.2	0.205	0.692**	-0.424	0.35	0.053	0.725**	0.284	0.321	0.178	0.506*	1				
Fe	0.223	-0.009	0.044	-0.338	-0.388	0.06	-0.382	-0.268	-0.356	0.006	-0.223	-0.019	-0.116	-0.3	1			
Cd	-0.107	0.454*	-0.024	-0.062	-0.033	0.011	0.023	-0.038	-0.1	0.038	0.164	0.142	0.055	-0.066	-0.05	1		
Pb	-0.201	0.285	-0.171	0.066	-0.007	0.354	-0.078	-0.112	-0.117	0.197	0.479*	-0.11	-0.219	-0.043	0.195	0.007	1	
Cr	-0.233	0.268	-0.419	0.197	0.006	-0.078	-0.162	0.023	0.006	0.403	0.317	.547*	0.133	0.243	-0.02	0.212	0.222	1