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EVALUATION OF COASTAL AQUIFER VULNERABILITY TO SEAWATER INTRUSION USING GIS BASED GALDIT DEPENDENT MODEL IN APAPA, LAGOS STATE, NIGERIA

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Abstract
Saltwater intrusion is a global phenomenon which threatens freshwater aquifer and thereby make it difficult in the coastal environment to tap freshwater for sustainable groundwater exploitation and management. Lagos State has witnessed a tremendous population growth and rapid urbanization, which in turn has culminated into over-abstraction of groundwater resources, thereby making the coastal aquifers vulnerable to seawater intrusion owing to the nearness of the boreholes to the sea-shore. A GIS GALDIT dependent index, consisting of six (6) hydrological, hydrogeological and geomorphological parameters, based on assigning weights and ranges, has been used to assess the vulnerability of the coastal aquifers to seawater intrusion in Apapa area of Lagos State. The method involved obtaining GALDIT parameters and Index scores for all the boreholes and classifying the boreholes into vulnerability classes of high, low and moderate vulnerability. In this study, a total of ten (10) boreholes were assessed. The GALDIT Index obtained ranged from 6 - 6.5, which implied moderate vulnerability class. The results indicated that all the boreholes were moderately vulnerable to saltwater. This might be due to distance of the boreholes to the sea shore and consequent migration of saltwater into the coastal aquifers. The distance of the boreholes to the seashore ranged from 16 to 331m and the average distance of the boreholes to the seashore was 200m .It can be concluded from the study that Apapa has been affected by saltwater intrusion from the adjoining sea, which makes any boreholes located in the area vulnerable.

Keywords: GALDIT Index, Vulnerability, Coastal aquifer, Groundwater, Seawater intrusion

1. Introduction

Globally, saltwater intrusion has been a drastic problem in the coastal region and thus the aquifer system is in danger of this phenomenon. The aquifer system in Lagos State has been hydrogeologically demarcated into four systems with the first aquifer regarded as recent sediment which is near surface aquifer, thesecond and third aquifer are being tapped form the coastal plain sand while the fourth aquifer belongs to the Abeokuta formation. Apapa, the case study for this research has predominantly experienced accelerated industrialization as a results of urban expansion coupled with environmental pollution. Most of the boreholes drilled in this region have potential to be vulnerable to seawater intrusion due to its nearness to the seashore with a lot of environmental activities. However, under over abstraction conditions, the pressure of freshwater head will decrease allowing saline water to form a cone and advance towards the tapping well, which will be contaminated eventually. This phenomenon is known as upconing (Johnson *et al.,* 2017).

The most frequently used method globally for evaluating groundwater vulnerability to seawater intrusion is GALDIT. It is a numerical ranking system, based on six (6) hydrogeological, hydrological and morphological parameters by assigning weights and ranges (Chachadi and Lobo-Ferreira 2001, 2007; Lobo-Ferreira *et al.,* 2007) and has been used in numerous coastal region (Louma *et al.,* 2017; Kazakis *et al.,* 2018). The method is a qualitative spatial method developed by Chachadi and Lobo Ferreira (2005), to evaluate the vulnerability of coastal aquifers for saltwater intrusion. GALDIT stands for "Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; ground water Level above mean sea level; Distance from the shore, Impact of existing status of saltwater intrusion in the area; and Thickness of the aquifer" (Paulo *et al. ,* 2005).

Groundwater vulnerability is the sensitivity of groundwater quality to anthropogenic activities which may prove detrimental to the present and/or intended usage-value of the resource (Vrba and Zaprozec, 1994) .Vulnerability Index is calculated by the cumulative score of the weighted indicators, where each of these indicators is assigned a value based on its relative importance for the specific situation (Koroglu, 2016).

The concept of GALDIT has been used in many countries in which Nigeria is not an exception.Adiat, 2018 evaluate the vulnerability of the coastal aquifer to seawater intrusion in Lekki area of Lagos State, Nigeria using the concept of GALDIT Vulnerability Index.Lappas *et al.,* 2016 utilized GALDIT index to evaluate the groundwater vulnerability to seawater intrusion in Atlantic Coastal Aquifer, Central Greece. The study inferred that there are impact of the salinization occasioned by a low vulnerability index in uplands and by high vulnerability in the low-lands along the shoreline.Zerin and Subrina , 2016 used the GALDIT approach for aquifer vulnerability assessment in South Florida.

Giuseppe *et al.,* 2017, evaluated the vulnerability to seawater intrusion for the Coastal Aquifer of Dares Salaam in Tanzania using GALDIT Vulnerability Index. The research inferred that high and moderate vulnerability classes are rather more concentrated in the northern part of the city.
Sun *et al.,* 2019 utilized the GALDIT approach in evaluating the seawater intrusion vulnerability of Jeju Island, South Korea and inferred that in most of the study area, sustainable groundwater management has mid- to long-term vulnerability.

Saliha *et al.,* 2012 carried out a research by applying GALDIT approach for the cartography of groundwater vulnerability to the aquifer of Chaouia Coast, Morocco. The study concluded that aquifers are vulnerable to the seawater intrusion with a high risk in the fringe littoral areas and areas in proximity to the estuary of Oum Er-Rbia River and can reach 3 km towards land.In this present study, GIS-based GALDIT dependent model has been utilized to assess the coastal aquifer to potential seawater vulnerability using numerical ranking system in Apapa coastal area, Lagos state, Nigeria.

2. Description of the Study Area

The study area is Apapa, located to the west of Lagos Island and near the Lagoon and Atlantic Ocean. It is conditioned by a web of environmental hazards in all spheres due to several activities in this area. It lies geographically between Latitudes 6^o 22'N and 6^o 24'N and between Longitudes 3^o 20'E and 3^o 40'E (Figure 1) and boarded to the north and west with Lagos Mainland and Ajereomi Ifelodun Local Government areas with elevation ranging from between 2 m to 5 m above mean sea level (Ola *et al.,* 2010). It is a densely populated and highly industrialized area. The area is densely built-up, majorly occasioned by petroleum product structures such as storage tanks, terminals, pipelines and industrial activities. It is accessible by various road networks such as water way, by ferry, boats and footpaths. Apapa is a tropical climate region marked by dry and wet seasons from November to March and April to October. Annual mean precipitation and temperature of Apapa are 1600 mm and 25 °C, respectively, with 75% humid (Ola *et al.,* 2010). The wet season is overcast, the dry season is partly cloudy, and it is hot and oppressive year round. Over the course of the year, the temperature typically varies from 23.8 °C - 32.8 °C and is rarely below 21.7°C or above 34.4°C (Jeje, 1983). During most months of the year, there is significant rainfall in Apapa. There is only a short dry season. The climate here is classified as Am by the Köppen-Geiger system. The annual rainfall is 1645 mm | 64.8 inch (Jeje, 1983).Geologically, it is within the coastal alluvium deposits of the Dahomey Basin. Several groundwater studies have been embarked upon in Apapa and environs to comprehend the hydrogeology, aquifer properties and how vulnerable are the aquifers to the seawater intrusion (Oteri 1986; Longe *et al.,* 1987; Adepelumi *et al.,* 2009; Ola *et al.,* 2010; Ayolabi *et al.,* 2013). Most of these studies identified four major aquifers and increasing salinity with depth within the alluvial and coastal plain sand. The aquifers are separated by alternating sequences of clay, clayey sand, and sandy clay with varying thicknesses.

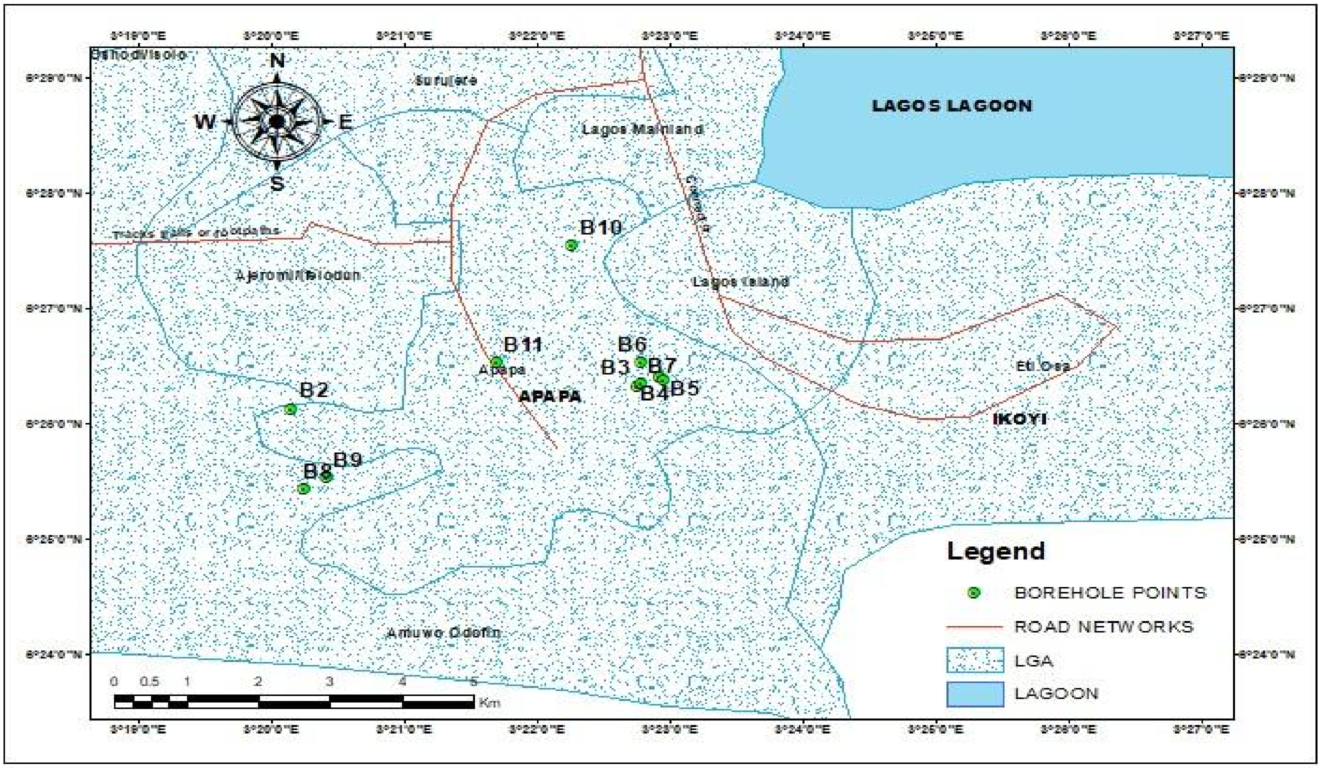

Figure 1: Location Map of the study area showing the spatial distribution of the boreholes

3. Methodology

Geophysical borehole logs of Eleven (11) boreholes were utilized for this study using the vulnerability index method. All the parameters as codified in the GALDIT model were acquired from the composite logs. Figure 2 showed the representative composite logs of the boreholes used for this study. The geophysical borehole logs consisted of Natural Gamma(NGAM) to demarcate the lithological units and Long normal electrical resistivity components (LN) to discriminate the types of water in the study area. The aquifer vulnerability of to seawater intrusion were evaluated according to the principle adopted by Chachadi and Lobo-Ferreira, 2005 and Adiat *et al.,* 2018 (Table 1).The GALDIT Method were adopted to estimate the coastal aquifer vulnerability to sea water intrusion using "GALDIT" formula. Firstly, the values of each of the "GALDIT" parameters for all the boreholes used for the study were obtained. A particular parameter of the acronym is codified as follows:

G: Groundwater Occurrence (Aquifer Type) -acquired by visual inspection of the log's geo-section

A: Aquifer Hydraulic Conductivity-acquired from the study area logs using a mathematical formula (Fatoba *et al.,* 2014): K (in m/s) = 10^{-5} X 97.5^{-1} x $\rho^{1.195}$; K (in m/day) = 60 x 60 x 24 x [K in (m/s)] (1) Where ρ is the average resistivity obtained from the log.

L: Depth to freshwater-acquired from the study area wire-line logs by obtaining the vertical depth to freshwater.

D: Distance from seashore-acquired from Google Earth through a linear distance measurement tool used laterally across the study area from the borehole point with known coordinate to the closest ambient seawater.

I: Impact of saline water-acquired from the log using the measurement of the average resistivity of the saline water intruded area and inversing it to determine its conductivity.

T: Thickness of aquifer-acquired from the wire-line logs through direct visual inspection and estimation of the various aquifer thicknesses across study area logs.

Secondly, weight were assigned to each GALDIT parameter from 1- 4 with 1 being equivalent to low weight while 4 is equivalent to high weight. Thereafter, each parameter was classified into four and subsequently rated (Table 1). Ratings ranging from 2.5 - 10.0 were used. Where 2.5 is corresponds to low and 10.0 corresponds to high influence on vulnerability.

Table 1: Assigned Weights and ratings for each parameter
(Chachadi and Lobo-Ferreira, 2005, Adiat *et al.,* 2018)

S/N	Factors	Weights	Indicator Variables		Ratings
			Class	**Range**	
1	Groundwater Occurrence (Aquifer Type): G	1	Confined Aquifer		10
			Unconfined Aquifer		7.5
			Leaky Confined Aquifer		5
			Bounded Aquifer		2.5
2	Aquifer Hydraulic Conductivity: A	3	High	> 40	10
			Medium	10 – 40	7.5
			Low	5 – 10	5
			Very Low	< 5	2.5
3	Depth to Freshwater zone:L	4	High	> 170	2.5
			Medium	150 – 170	5
			Low	130 –150	7.5
			Very Low	< 130	10
4	Distance from Shore: D	4	Very Small	< 500	10
			Small	500 -750	7.5
			Medium	750 -1000	5
			Far	>1000	2.5
5	Impact of Saline water: I	1	High	> 2	10
			Medium	1.5 – 2.0	7.5
			Low	1.0 – 1.5	5
			Very Low	< 1	2.5
6	Thickness of Aquifer: T	2	High	> 40	10
			Medium	30 - 40	7.5
			Small	20 – 30	5
			Very Small	<20	2.5

Thirdly, the GALDIT index were obtained by calculating the each indicator scores and adding them up using the GALDIT Index = $\sum_{i=1}^{6} \{ (wi)Rj \} / \sum_{i=i}^{6} Wi$ (2)

Where Wi represents the weight of the ith indicator and Ri is the rating of the ith indicator

The "highest value of GALDIT-Index" were estimated for the eleven (11) boreholes by substituting the values of the weight and the highest ratings of the indicators presented in Table 1.

$$\text{Highest value} = \{(1)*R_1 + (3)*R_2 + (4)*R_3 + (4)*R_4 + (1)*R_5 + (2)*R_6\} / \sum_{i=1}^{6} Wi \quad (3)$$

The "Lowest GALDIT-Index" was obtained by substituting the lowest importance ratings of the indicators as :

$$\text{Lowest value} = \{(1)*R_1 + (3)*R_2 + (4)*R_3 + (4)*R_4 + (1)*R_5 + (2)*R_6\} / \sum_{i=1}^{6} Wi \quad (4)$$

The vulnerability of the study areato seawater intrusion were evaluated based on extent of the GALDIT Index. Lastly, GALDIT-Index were estimated for each boreholesto classified the aquifers to seawater intrusion into three classes of vulnerability as proposed by Chachadi and Lobo-Ferreira (2005) and Adiat *et al* (2018) (Table 2). The individual GALDIT paramaters were grided using Sufer 24 software to produce a raster image .These raster images were then imported into the ARCGIS 10.8 environment to poduce various thematic maps such as the aquifer hydralic conductivity map,depth to freshwater map, distance to the sea shore map, Impact of salinity map ,thickness of Aquifer map of the study area and also aquifer vulnerability map using ARCGIS 10.8.

Table 2: Classes of GALDIT Vulnerability (Chachadi and Lobo-Ferreira, 2005, Adiat *et al.,*2018)

S/N	GALDIT-Index Range	Vulnerability Classes
1	≥ 7.5	High Vulnerability
2	5.0-7.5	Moderate Vulnerability
3	< 5.0	Low Vulnerability

4. Results and Discussion

The geophysical borehole logs used for the study showed that the depth of the borehole varied across the locations from 195–288m and the depth logged varies across the boreholes varied from 184 -266m respectively (Figure 2, Table 3).The results of the GALDIT Vulnerability Index acquired from the boreholes assessed in the study area are explained and presented in Table 4.

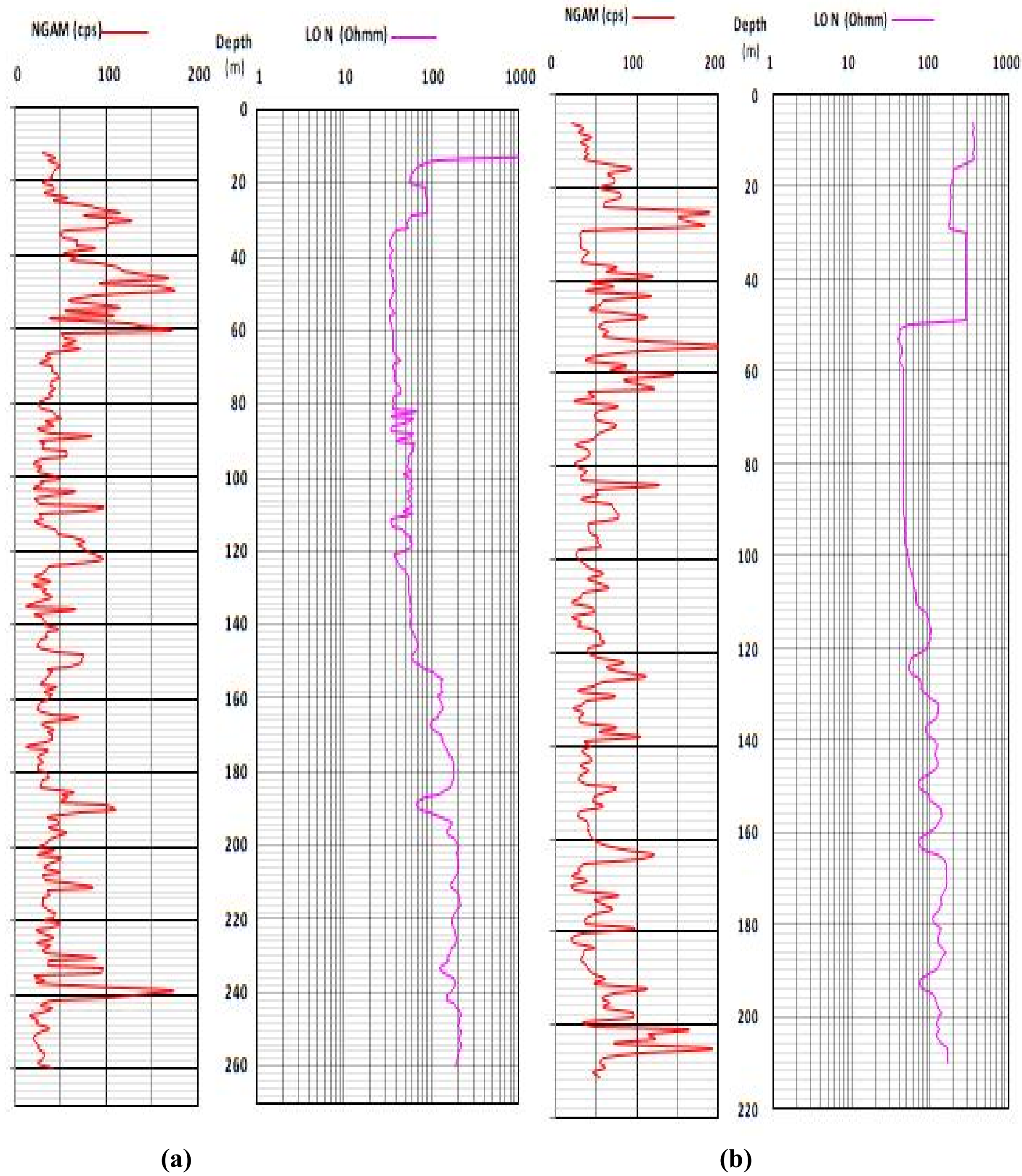

Figure 2:Representativegeophysical borehole logscomprising of NGAM and LN of (a) Apapa Wharf (Borehole 1) and (b) Tin Can (Borehole 2)Island used in the study.

Table 3: Properties of the geophysical borehole logs used in the study area

S/N	Borehole Identity	Latitude	Longitude	Elevation	Depth Drilled(m)	Depth Logged (m)
1	BhLog1	6.440167	3.382278	2	260	260
2	BhLog2	6.435478	3.336078	2	234	211

3	Bhlog3	6.438761	3.3795	5	236	171
4	Bhlog4	6.440022	3.382392	2	260	259
5	Bhlog5	6.439567	3.382678	3	234	184
6	Bhlog6	6.442092	3.379994	3	195	191
7	Bhlog7	6.439111	3.379861	3	265	265
8	Bhlog8	6.423889	3.337722	2	288	266
9	Bhlog9	6.425444	3.340389	3	240	222
10	Bhlog10	6.459111	3.371306	2	216	214
11	Bhlog11	6.442129	3.361934	2	220	220

Table 4: GALDIT Parameters obtained for the eleven (11) boreholes used in the study area.

S/N	Borehole Identity	Borehole Location	G	A	L	D	I	T
				(m/Day)	(m)	(m)	(S/m)	(m)
1	BhLog1	Apapa Wharf	Confined Aquifer	3.15	256	331	0.01	60
2	BhLog2	Tin Can Island	Unconfined Aquifer	1.92	200	160	0.0125	149
3	Bhlog3	Apapa Wharf	Confined Aquifer	4.74	166	80	0.028	79
4	Bhlog4	Apapa Wharf	Unconfined Aquifer	1.92	258	317	0.018	109
5	Bhlog5	Apapa Wharf	Unconfined Aquifer	3.59	172	250	0.023	66
6	Bhlog6	APMT Yard Apapa	Unconfined Aquifer	6.56	180	286	0.00	84
7	Bhlog7	Apapa Wharf	Confined Aquifer	2.25	240	243	0.017	102
8	Bhlog8	Snake Island	Unconfined Aquifer	1.93	260	267	0.03	138
9	Bhlog9	Snake Island	Confined Aquifer	5.79	190	73	0.007	96
10	Bhlog10	Naval Base	Unconfined Aquifer	5.46	210	16	0.01	155
11	Bhlog11	Azare Crescent	Confined Aquifer	2.66	220	469	0.02	162

The results of the geophysical borehole logs showed that groundwater occurrences in the study area is restricted confined and unconfined aquifer. Aquifer Hydraulic conductivity in the study area varies 1.92 m/day to 6.56 m/day. Borehole 4 at Apapa Wharf has low aquifer hydraulic conductivity of 1.92 m/day while borehole 6 has the highest aquifer hydraulic conductivity of 6.56 m/day (Figure 3, Table 4).The depth to the freshwater interface across the study area ranged from 166 m to 260 m with the upper freshwater depth delineated at 166m in borehole 3 and the lower freshwater interface delineated at 260 m in borehole 7(Figure 4,Table 4). The distance of the Boreholes to a nearest ambient sea shore varied from borehole to boreholes from 16 m to 469m with borehole 10 having the lowest distance value to the sea shore while borehole 11 having the highest value to the sea shore (Figure5, Table 4).However, impact of salinity were felt but also varied from location to locations in the study area from 0.00 - 0.03 S/m. The thickness of the aquifer varied from borehole to boreholes from 60 – 162m with borehole 1 having the lowest thickness of 60m and borehole 11 having the highest thickness of 162 m respectively (Figure 5, Table 4). The GALDIT Vulnerability index results showed that the boreholes examined were moderately vulnerable and the proportions of their vulnerability depends largely on the hydrogeologic significant of the aquifer unit in the study area. A synoptic overview of all the calculated GALDIT elements for all the boreholes in the study area are shown in Table 4. The vulnerability assessment showed that the GALDIT index scores varied between 5.83 - and 6.50 (Figure 6, Table 5) indicating that all the boreholes are moderately vulnerability to seawater intrusion. This might be attributed to the nearness of the borehole to the sea shore, over-exploitation of the groundwater resources occasioned by accelerated imbalance of the hydrogeological settings which corresponds to the types of water in the study area. The results of the GALDIT Index also indicated that 100 % of the boreholes in the study are moderately vulnerable to sea water intrusion. The boreholes in the study area are impacted by saltwater and are vulnerable to seawater intrusion. This invariably makes the groundwater system to be under severe stress, over pressure and are at risk of sea water into the freshwater aquifer.

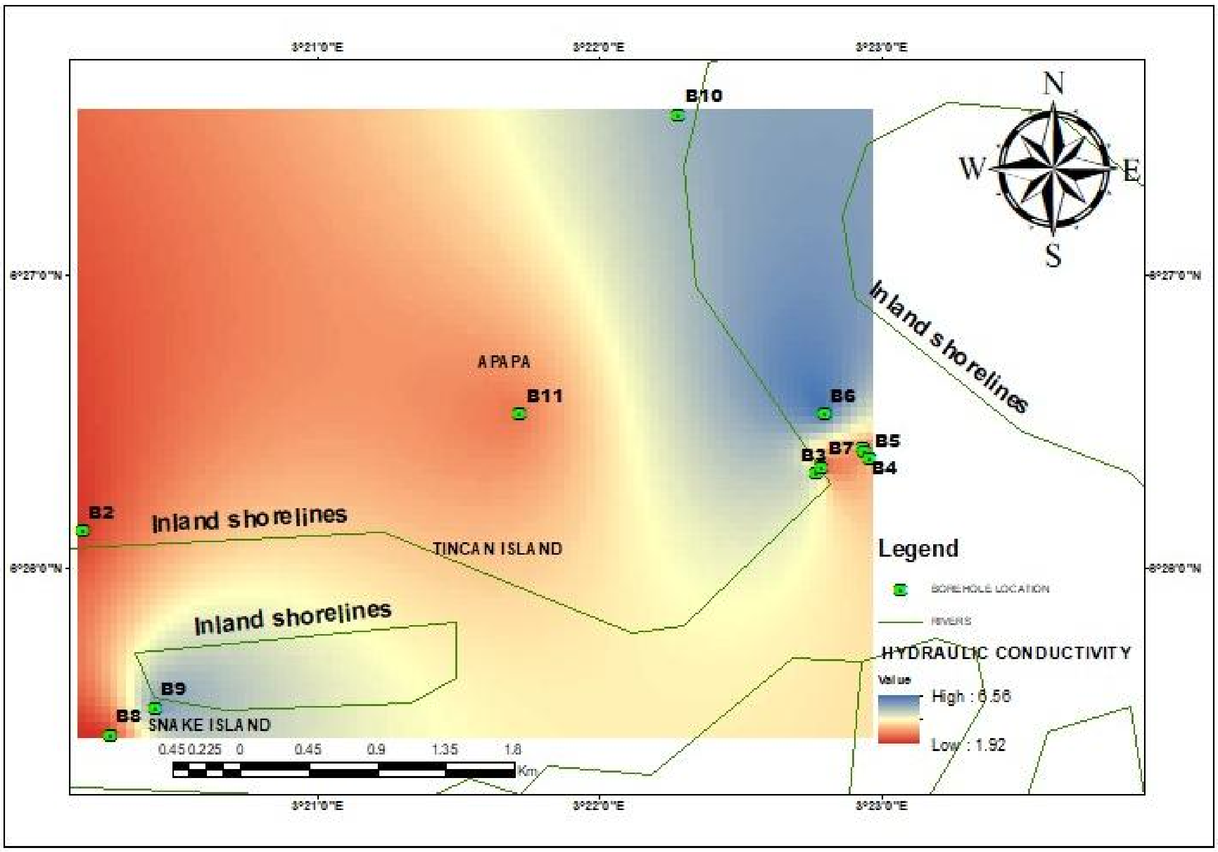

Figure 3: Map showing the Aquifer hydraulic Conductivity (m/day) of the study area

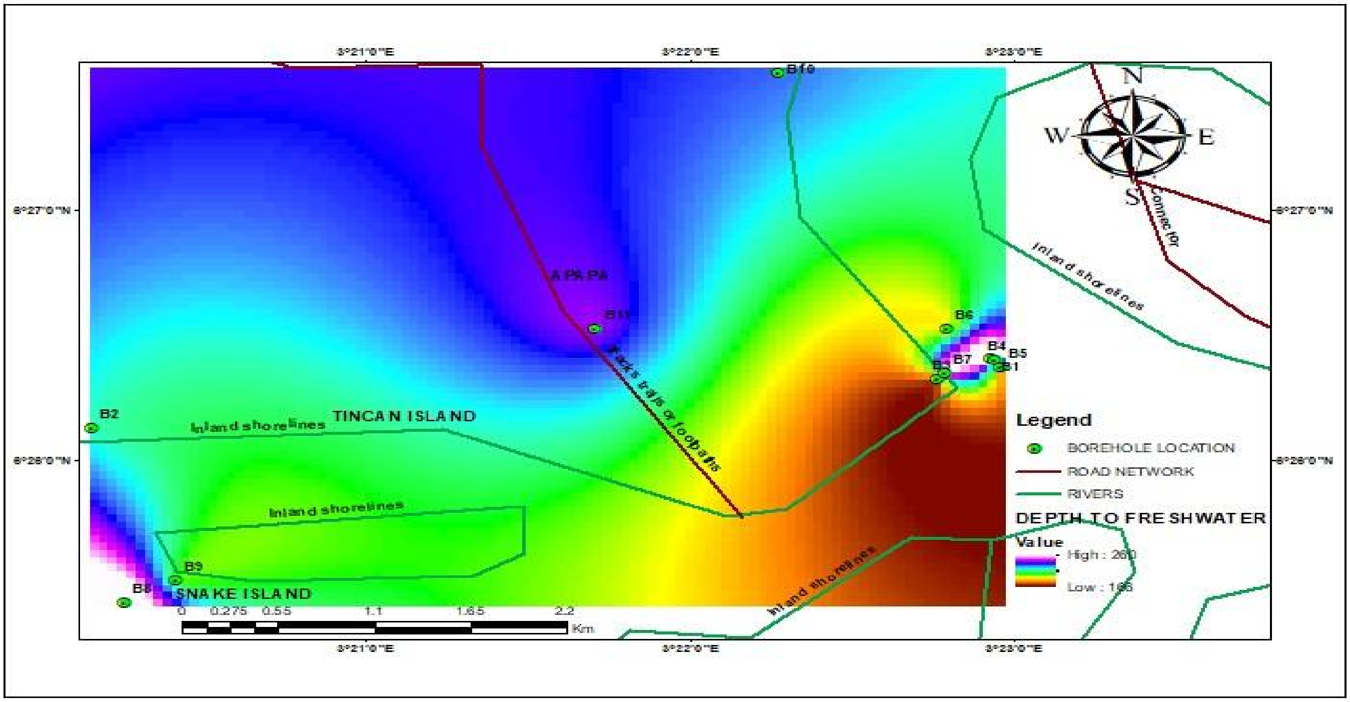

Figure 4: Depth to freshwater map of the study

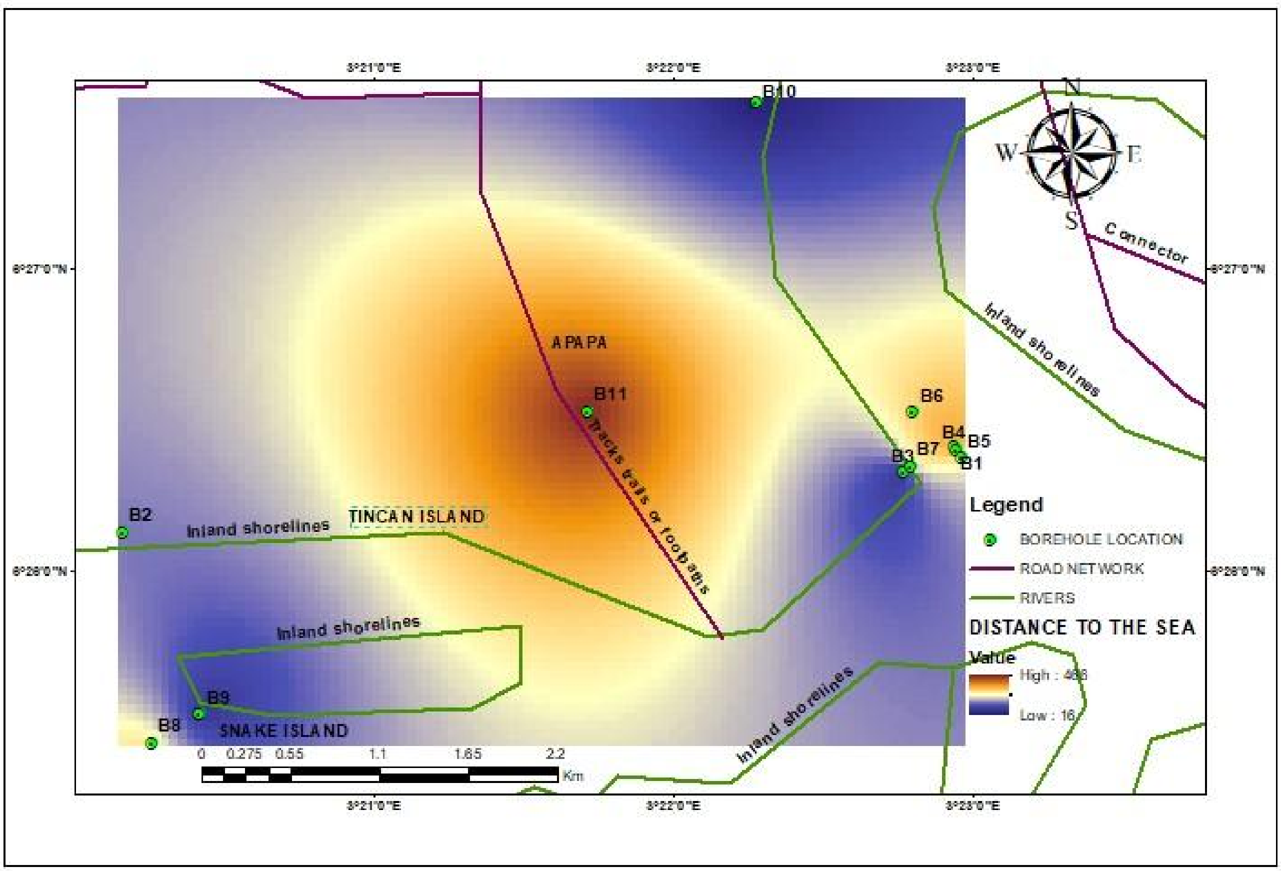

Figure 5: Distance of the boreholes to ambient sea-shore Map of the study

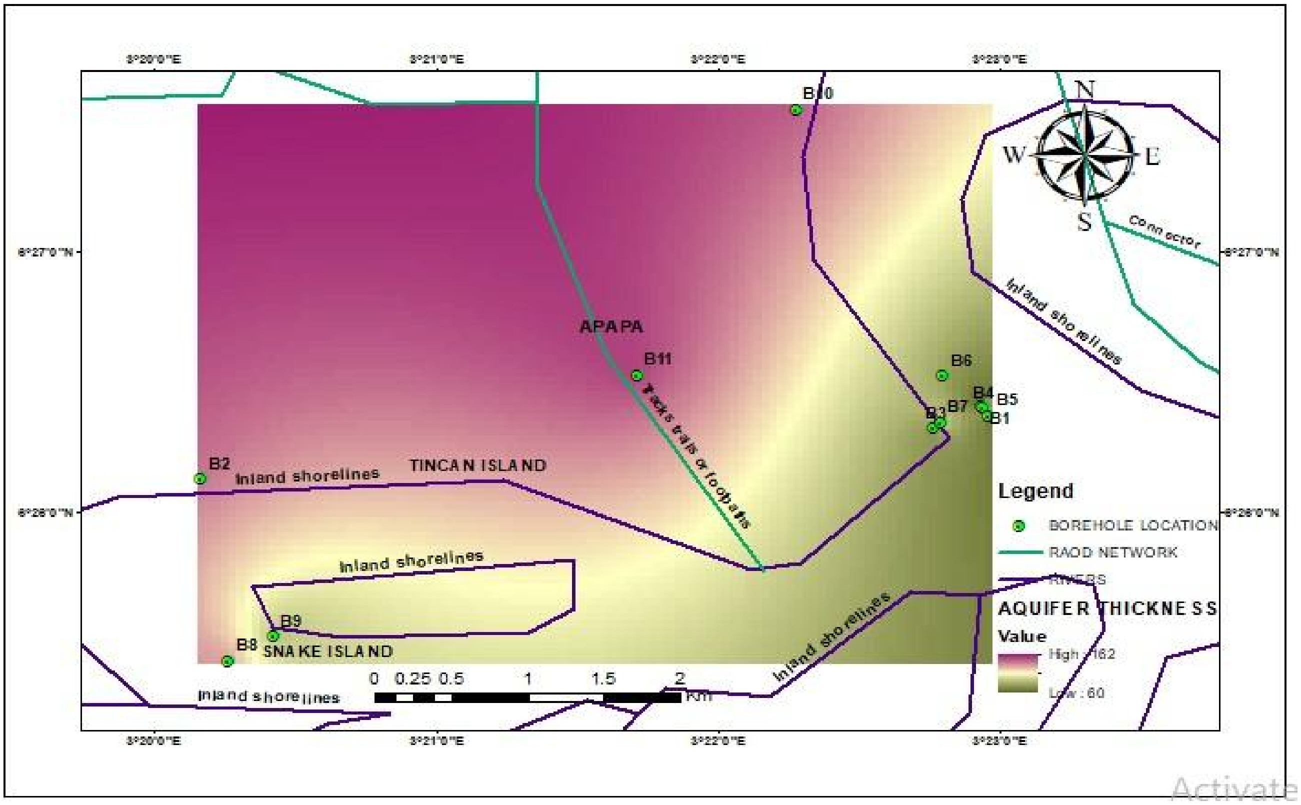

Figure 5: Aquifer Thickness/Potential Map of the study area

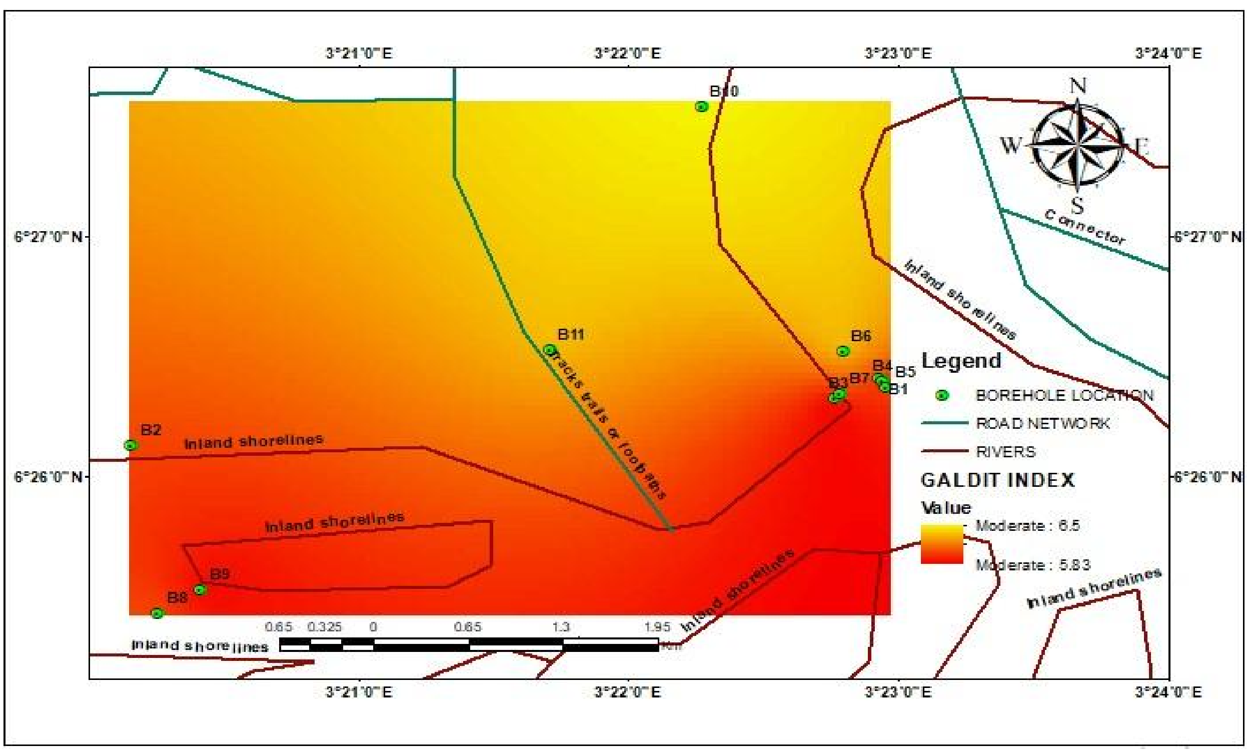

Figure 6: GALDIT Index score Map of the study area

5. Conclusion

The evaluation of coastal aquifer vulnerability to seawater intrusion using the GALDIT vulnerability index method has been carried out in Apapa, Lagos. This was aimed at assessing how vulnerable are the aquifer in the study to saltwater using geophysical borehole logs. The generated GIS maps showed various threshold for various part of Apapa coastal aquifer with the impact of saltwater intrusion. The use of GALDIT method to the coastal aquifer has resulted in the assessment of the effects of the salinization occasioned by a moderate vulnerability index along the shoreline of the coast close to the Atlantic Ocean. GALDIT parameters were consequently acquired for all the boreholes in the study area. The GALIDIT Index (GI) score for all the boreholes were acquired from weight assigned and exact rating in the study area. The study showed that that the GI scores ranged between 5.83 and 6.50 respectively indicating that all the borehole are moderately vulnerable to seawater intrusion. Numerical evaluation of the study showed that all the boreholes are moderate vulnerable to seawater intrusion which amounts to 100 % of the study. This implied that the groundwater system is at risk of pollution from saltwater intrusion ingress. There might be a further intrusion of the saltwater into the coastal aquifer which might be as a results of topographical effects, climate change, and the exact position of the boreholes in the nearest future which might change the vulnerability status of these boreholes.

Table 5: GALDIT Index Scores for the Eleven (11) Boreholes used in the study area

S/N	**Borehole Identity**	**Bore Loca**	**(W=1)**		**(W=3)**		**(W=4)**		**(W=4)**		**(W=1)**		**(W=2)**		**Galdit Index**	**Vulnerability**
			R	**W*R**	**R**	**W*R**	**R**	**W*R**	**R**	**W*R**	**R**	**W*R**	**R**	**W*R**	**(GI)**	**Classes**
1	BhLog1	Apapa Wharf	10	10	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	6.00	Moderate Vulnerability
2	BhLog2	Tin Can Island	10	10	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	6.00	Moderate Vulnerability
3	Bhlog3	Apapa Wharf	7.5	7.5	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	5.83	Moderate Vulnerability
4	Bhlog4	Apapa Wharf	7.5	7.5	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	5.83	Moderate Vulnerability
5	Bhlog5	Apapa Wharf	10	10	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	6.00	Moderate Vulnerability
6	Bhlog6	APMT Yard	7.5	7.5	5	15	2.5	10	10	40	2.5	2.5	10	20	6.33	Moderate Vulnerability
7	Bhlog7	Apapa Wharf	10	10	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	6.00	Moderate Vulnerability
8	Bhlog8	Snake Island1	10	10	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	6.00	Moderate Vulnerability
9	Bhlog9	Snake Island2	7.5	7.5	2.5	7.5	2.5	10	10	40	2.5	2.5	10	20	5.83	Moderate Vulnerability
10	Bhlog10	Naval Base	10	10	5	15	2.5	10	10	40	2.5	2.5	10	20	6.50	Moderate Vulnerability
11	Bhlog11	Azare Crescent	7.5	7.5	5	15	2.5	10	10	40	2.5	2.5	10	20	6.33	Moderate Vulnerability

References

Adepelumi AA, Ako BD, Ajayi TR, Afolabi O, Omotoso EJ (2009) Delineation of saltwater intrusion into the freshwater aquifer in Lekki Pennisula, Lagos Nigeria. *Environ Geol* 56:927–933

Adiat K. A. N (2018). Application of Geophysical Borehole Logs for Aquifer Characterization in Coastal Environment of Lagos, Southwestern Nigeria. *Nigerian Journal of Basic and Applied Science*, 26(1): 31-45 DOI: http://dx.doi.org/10.4314/njbas.v26i1.4

Ayolabi EA, Folorunso AF, Odukoya AM, Adenira AE (2013) Mapping saline water intrusion into the coastal aquifer with geophysical and geochemical techniques: the University of Lagos campus case (Nigeria). *SpringerPlus* 2(433):1–14

Chachadi A.G. and Lobo-Ferreira J.P (2001). Seawater Intrusion Vulnerability Mapping of Aquifers Using GALDIT Method. Proceedings of the Workshop on Modelling in Hydrogeology, Anna University, Chennai, 143-156.

Chachadi, A., and Lobo Ferreira, J. P. (2005). Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: Part 2-GALDIT Indicators Description, 1–12.

Chachadi, A.G. and Lobo-Ferreira, J.P (2007). Assessing aquifer vulnerability to seawater intrusion using GALDIT method: part 2, GALDIT indicators description. Water in Celtic Countries Quantity, Quality and Climatic Variability, IAHS Publ. 310, pp. 172–180.

Fatoba, J. O, Omolayo, S. D, Adigun E. O (2014). Using geoelectric soundings for estimation of hydraulic characteristics of aquifers in the coastal area of Lagos, southwestern Nigeria. International Letters of Natural Sciences ISSN: 2300- 9675, Vol. 11, pp 30-39

Giuseppe S, Flavia F, Francesco M (2017). Assessment of Vulnerability to Seawater Intrusion for the Coastal Aquifer of Dares Salaam, Tanzania.17th International Multidisciplinary Scientific GeoConference SGEM

Jeje, L.K., (1983).Aspect of Geomorphology in Nigeria. In a Geography of Nigeria. Ed.Heinemann Educational Books (Nig.) pp 17-44

Johnson, R. L., Holmquist, D., Redding, K., and McDaniel, C. (2017). Water Quality with Vernier; Vernier Software Technology. Retrieved January 5, http://www.vernier.com/products/books/wqv/

Kazakis N., Spiliotis M., Voudouris K., Pliakas F.K and Papadopoulos B (2018). A fuzzy multicriteria categorization of the GALDIT method to assess seawater intrusion vulnerability of coastal aquifers. Science of the Total Environment 621: 524-534.

Koroglu, A. (2016). Vulnerability Index (pp. 725–726). Springer Netherlands.http://doi.org/10.1007/978-94-017-8801-4_220

Lappas I, Kallioras A, Pliakas F and Rondogianni T (2016). Groundwater Vulnerability Assessment to Seawater Intrusion through GIS - Based Galdit Method. Case Study: Atalanti Coastal Aquifer, Central Greece. *Bulletin of the Geological Society of Greece*, vol. L, p. 798-807

Lobo-Ferreira, J.P., Chachadi A.G., Diamantino C. and Henriques M.J (2007). Assessing aquifer vulnerability to seawater intrusion using GALDIT method: part 1, application to the Portuguese Monte Gordo aquifer. Water in Celtic Countries Quantity, Quality and Climatic Variability, IAHS Publ. 310, pp. 161–171

Longe E. O, Malomo S, Olorunniwo MA (1987) Hydrogeology of Lagos metropolis. *Journal of Africa Earth Science* 6(2):163–174

Luoma S., Okkonen J and Korkka-Niemi, K (2017). Comparison of the AVI, modified SINTACS and GALDIT vulnerability methods under future climate-change scenarios for a shallow low-lying coastal aquifer in southern Finland. *Hydrogeology Journal* v. 25:1 203–222.

Ola P. S, Bankole O. M, Anifowose A.Y (2010) Sub-surface geology and groundwater distribution patterns in Lagos Island environs, South western Nigeria. *Environtropica* 57:89–103

Oteri A.U (1986) Interpretation of electric logs in aquifers of the Dahomey basin of Nigeria. *Journal of Africa Earth Science* 2:54–61

Paulo, J., Ferreira, L., Chachadi, A. G., Diamantino, C., and Henriques, M. J. (2005). Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of Monte Gordo.

Saliha Najib1, Adrian Grozavu, Khalid Mehdi, Iuliana Gabriela Breabăn, Hakima Guessir, Khadija Boutayeb (2012). Application of the Method Galdit for the Cartography of Groundwaters Vulnerability: Aquifer of Chaouia Coast in Morocco. Scientific Annals of "Alexandru Ioan Cuza" University of Iasi Vol. Lviii, S. Ii – C, *Geography Series,* Online Version), 2284-6379 E-ISSN.

Sun W. C, ChungM, GyuKim M ,Mesfin T , and WonKoh G(2019). Application of GALDIT in Assessing the Seawater Intrusion Vulnerability of Jeju Island, South Korea. *Water MDPI*, 11, 1824; doi:10.3390/w11091824 ,www.mdpi.com/journal/water

Vrba, J and Zaporozec, A (1994). *Guidebook on Mapping Groundwater vulnerability*, International Contributions to hydrogeology, Volume 16.Hannover: International Association of Hydrogeologists (IAH).

Zerin T, and Subrina T (2016). Application of the Method of Galdit for Groundwater Vulnerability Assessment: A Case of South Florida, *Asian Journal of Applied Science and Engineering*, Volume 5, No 1, ISSN 2305-915X(p); 2307-9584(e).