Vulnerability Assessment of a Sand-rich Alluvium; A DRASTIC Model Approach.

By

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Abstract

Assessment of vulnerability of a sand-Rich aquifer has been studied using DRASTIC model . DRASTIC represents the seven hydrogeological variables comprising of **D**epth, Net **R**echarge, **A**quifer type, **S**oil medium, **T**opography, **I**mpact of vadose and **C**onductivity**.** Data information of the hydrogeological variables from various study locations(FUTO, Ihiagwa, Eziobodo, Obinze and Nekede) were obtained using standard methods. Thematic map of each variable classifying them into ranges or into different media types was obtained using the ARCGIS software. The overall vulnerability index map showing the exact vulnerability status of each subset of the study area was achieved by superimposing the vulnerability index map of each variable. Nitrate concentrations obtained by water sample analysis were used to calibrate model. high rating and weighting values were assigned to high vulnerability index of Net Recharge, Aquifer type, **I**mpact of vadose and soil medium as against Topography, conductivity and depth. The reason is essentially due to the loose arrangement of the aquifer particle prevalent in the study locations. On the overall vulnerability index, Nekede and Ihiagwa fall within low vulnerability zone whereas FUTO, Eziobodo and Obinze ocuupy the moderate vulnerability zone.. On the sensitivity analysis of variable map removal, high vulnerability index of 36.60, 34.59 and 34.58 were recorded on removal of Recharge rate, Impact of vadose and hydraulic Conductivity layers respectively. Removal of the topographic map layer resulted to the least vulnerability index suggesting that the former variables wield significant impact on the vulnerability. Effectiveness of the DRASTIC variables in assessing groundwater vulnerability in the study area decreased in this order ;**N**>**I>A>D>S>T.** Nitrate concentration is distributed as follows;. Ihiagwa (71mg/l), Obinze (60mg/l), Eziobodo (54mg/l), Nekede (41mg/l.) and Futo (30 mg/l**.** Therefore, Net Recharge variable is a key pathway to nitrate contamination to groundwater in the study locations as its concentration

Key words; DRASTIC model, vulnerability, groundwater, comtamination, sand-rich alluvium, hydrogeology.

1.0 Introduction

In the past, little concern was given to groundwater quality because good quality surface water was much available for human needs. But in the advent of technology with man's quest for high standard of living through industrialization and other human activities, the quality of environment, especially water environment was compromised. In that perspective, quest for good quality water was shifted to exploitation of groundwater. From recent past till date, groundwater has been considered as an important source of water because it is less prone to pollution than the surface water. However, it has been established that the source of groundwater pollution is essentially through land use (agricultural practice) and other anthropogenic activities [1],[2].Previous studies have also established that through pollutant intrusion from surface waters and infiltration of run-off and overland flow, the quality of groundwater is compromised [3].Therefore prevention of groundwater contamination is key to its effective management. Apart from the established treatment techniques of waste from industrial processes, municipal and other sources, vulnerability assessment is the most proactive method of groundwater pollution prevention in which areas with high risk of groundwater pollution are detected by studying its hydrogeological setting(soil texture, depth to groundwater etc).On the strength of the afore-mentioned, the groundwater vulnerability is essentially a function of geological setting because it influences the time water on the earth surface infiltrate through the soil to the aquifer till it begins to flow to different locations[4] In subsurface,, geological setting is also described as an intrinsic property of aquifer system through which groundwater flows[5],[6] Moreover. Groundwater vulnerability depends on the proximity to source of contaminant, characteristics of the contaminant and other factors capable of influencing groundwater contamination[7].Vulnerability method of groundwater contamination study delineates areas prone to pollution for outright prevention and future planning [8] . Use of Process base, statistical and overlay and index methods have also been made to assess the vulnerability of groundwater [9]. However, these approaches have drawbacks which ranges from paucity, non-availability and inaccurate water quality data to subjectivity in assigning values to descriptive units[10]. But in recent time DRASTIC model has recorded appreciable successes in groundwater vulnerability. DRASTIC model is a tool to assess groundwater vulnerability by studying the properties of geological setting which influences the transport of contaminant from ground surface to the aquifer using the Global Information System(GIS) and remote sensing [11]. DRASTIC is an acronym derived from the first letters of various hydrogeological variables which include; **D**epth of aquifer, **R**echarge, **A**quifer media, **S**and media, **T**opography and **I**mpact of vadose **C**onductivity. In Nigeria, numerous research studies have been carried out on groundwater vulnerability by ordinary groundwater analysis of trace elements but not much has been reported on the study of groundwater vulnerability with DRASTIC model, especially in areas predominant with sand rich hydrogeology . Application of DRASTIC model on groundwater vulnerability involves mapping of areas of high potential for groundwater contamination on the bases of hydrogeological setting[12]. The maps are developed by the use of GIS software, to combine data layers derived from the properties of the hydrogeological setting [9]). The environmental managers and other stakeholders leverage on the vulnerability assessment to advise the government on policy formulation regarding points of waste discharge and waste handling. In this study, DRASTIC model will be applied to assess the level of vulnerability of ground water in a university community housing two higher institutions with considerable large population of people and apparent high prevalent to water related ill health. Being densely populated with no organized waste management system, indiscriminate waste dumping and other anthropogenic activities are likely sources of pollution to ground water. Moreover, the result of the fate and transport of contaminants study which was carried out by [6] using MODPATH model indicates that the contaminant flow from Qwerri urban and other parts of the state ends up in the study area. Groundwater flow assessment and pollutant flow also revealed a flow towards the study area due to the topographic [13]. Based on their observations, the study area seems to be on a depression where sediments and run-off water are likely to percolate, thereby providing pathway for contaminant migration to aquifer. Previous studies have also shown that most municipal waste dump and waste from agricultural practices are common sources of nitrate[14]. In view of its chemical stability, high mobility , high solubility and weak sorption tendency to soil matrix, nitrate remains a huge threat to groundwater quality[15].In that light, this study therefore examines ground water vulnerability to ascertain levels of potentials to ground water pollution in various locations of the study area using DRACTIC model. The model will be calibrated to measure nitrate concentration as a contaminant

2.0 Materials and Methods

The materials to be collected include; the samples of the hydrogeological setting and water samples

2.1 Description of Study Area .

Five communities of FUTO, Ihiagwa, Eziobodo, Nekede and Obinze constitute the study area . Open dumpsites are located in each of these communities, either along the major roads or roads along residential buildings. Also, inhabitants of these communities practice varying degrees of agriculture, ranging from animal husbandry to crop farming at commercial and peasant levels. The study area is located in Owerri-west LGA (Local Government Area), Imo state, Nigeria. Figures 1(a,b and c) represent map of Nigeria, map of Imo state and map of the study area respectively. The otamiri river transverses the study area from Egbu town to the Atlantic ocean through Etche town. Geology of the place is Benin formation with unconsolidated yellow and white Coastal Plain Sands and gravel beds [6]. The area has a maximum and minimum temperature at 33.4^{o}C at 21.2^{o}C respectively [16] and an annual rainfall of between 1800mm to 2500mm, enough to ensure annual groundwater replenishment of 2.5billion cubic metres per year [17].

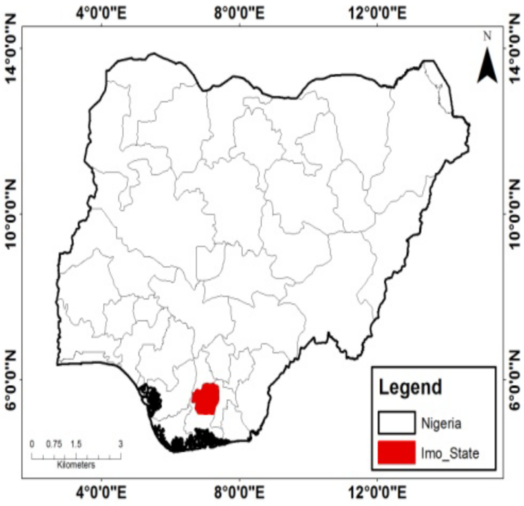

Fig 1a

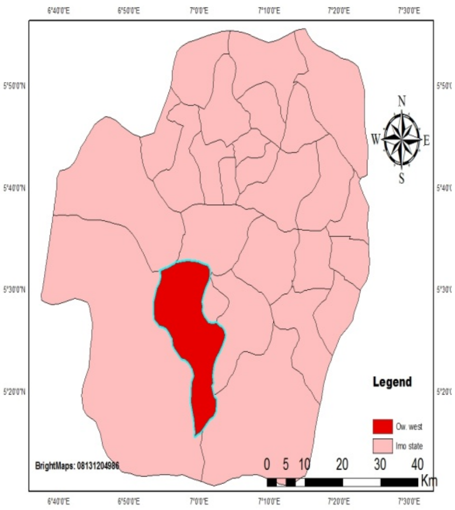

fig 1b

Fig 1c

2.2 Groundwater Data Collection

Groundwater samples were collected at random in the following towns of the study area; (Ihiagwa, Eziobodo, FederaL University of Technology Owerri (FUTO), Nekede, Obinze) within the study area. Locations of the water sample collection points were determined with the Global positioning system (GPS). The samples were collected using same techniques. Nitrate analyses was carried out on the samples with standard methods. A total of 120 samples were collected on the study area. The nitrate values were used for the DRASTIC model calibration.

2.3 Model Description and Data Acquisition

DRASTIC model was developed to evaluate the groundwater pollution potentials and this has been applied all over the world. The model is an acronym derived from the initials of the seven factors considered in the method which correspond to the seven layers as input variables for the model. It captures all the hydrogeological variables being considered in the method and it is described as follows

- **D**epth of water
- Net **R**echarge
- **A**quifer media
- **S**oil media
- **T**opography
- **I**mpact of vadose zone
- Hydraulic **C**onductivity

D, represents the depth of water. It describes the distance between the ground surface and the water table and bottom of the unconfined and confined aquifer respectively. Low water depths signify high vulnerability to groundwater contamination and vise versa. The value of the water depth was obtained using electric drilling process of schlumberger which is also referred to as vertical electric sounding (VES). With this process, water table (aquifer) resistivity was determined through which water depth was obtained.

Net Recharge(**R**) represents the amount of water per unit area of land which permeates through soil matrix to the aquifer to add to the ground water. Recharge of ground water could either come from the surface run-off/over land flow or surface water through losing stream process [18]. It is the route through which contaminants gain access to the sub-surface depending on the geological formation of the area concern. Groundwater can as well lose recharge by feeding the surface water through the process known as gaining stream, especially when the water table is high[19]. The land around the Study area is intensively cultivated with high application of chemical inputs such as fertilizer, pesticide, herbicides etc to boost yield. As stated earlier, the study area is a sink for most pollutants due to the low-land status of the topography. Also the study area has a near surface aquifer medium with water depth of between 20-70m [20]. With these scenarios, groundwater recharge in such area apparently takes place without being contaminated [21], consequently making the groundwater vulnerable to pollution. Thus, water flow to recharge the sub-surface water accompanies vertical and horizontal contaminant transport to the aquifer [22]. The groundwater recharge in the study area essentially takes place by direct infiltration occasioned by rainfall [23]). In that light, the net recharge was obtained by the following formula;

$$net\ recharge = (rainfall - evaportranspiration) \times recharge\ rate \qquad (1).$$

The twenty-one year mean annual rainfall obtained from Calabar airport rainfall station, Benin city and Onitsha metrological stations was interpolated to obtain a recharge map and spatial variation of recharge rate values across the study area in the ArcView GIS model. A representative evaportranspiration value of 2735mm/year obtained from Onitsha was adopted as presented by [23].

Aquifer is the water bearing rock of the earth crust. As reported by [5], [24] [25], aquifer was described as being consolidated and unconsolidated. Consolidated aquifer refers to the water bearing rock whose pores are saturated with water, on the other hand, the pores of an unsaturated aquifer are saturated with air. Nevertheless, both aquifers store water and determine the water yield and to a large extent the vulnerability of groundwater to contamination. The texture of the aquifer medium also plays a decisive role on the vulnerability of groundwater contamination; coarse aquifer texture allows quick and massive contaminant transport through it, hence implying higher vulnerability to groundwater contamination. On the other hand, fine aquifer medium texture with low permeability limits contaminants through the aquifer medium thereby reducing aquifer vulnerability [26]. In this study, Texture of the aquifer medium of the area was prepared with data obtained from well logging which were produced in topographic map.

Soil medium plays enormous role on the contaminant migration to any coordinate. soil of predominantly clay and fine texture with high organic matter content sequestrates most contaminants especially the organic ones by sorption , ion-exchange, biodegradation, oxidation etc, thus preventing further contaminants movement[12]. However, recalcitrant contaminants which do not have affinity to soil of fine texture meander through the pores to the aquifer. On the contrary, soil of coarse texture which has low organic content allows unhindered movement of the contaminants through the pores of the soil matrix, perhaps due to less affinity of the contaminants to the soil and also the large pore sizes occasioned by coarse soil texture. Consequently, the texture of the soil medium determines the fate of contaminant transport through the soil and by extension the vulnerability of the aquifer. For this study, the soil map was prepared from the geological map of Imo state as presented by Nwosu et al.(2016)[17] and Eke et al.(2015)[27]

Low and high elevations usually describe the **t**opography of an area. The level of elevation largely determines the flow velocity of the surface runoff and partly determines the infiltration of contaminant to aquifer. In high elevation or slope, run-off flow moves at a high velocity, by so doing producing little or no runoff percolation on the land surface which reduces infiltration of the run-off and possible contaminants there from. On the other hand, area of low elevation usually described as low land, experiences low surface run-off velocity, high run-off percolation and infiltration with contaminants. Hence, areas of low topography are vulnerable to groundwater contamination. In the study area, the topographic map was prepared from the topographic map of Nigeria showing the elevations of the study area. The map was digitized and digital elevation model was prepared in Arcview GIS software.

Vadoze zone is that zone between the soil cover and the aquifer. The pores of the material captured in this zone is partially filled with water, hence the name unsaturated zone. It is an essential factor in the monitoring of contaminant transport to the aquifer. Vadoze zone could be permeable or semi-permeable rock materials. Vadoze zone of predominantly permeable or coarse material portends high vulnerability to groundwater pollution. Impact of vadoze zone is a determinant factor to groundwater vulnerability. With Goe-physical data gathered from the study area, rated vadoze map was prepared.

Hydraulic **C**onductivity describes the ability of the aquifer to transmit water through its pores. Aquifer medium of high conductivity portends danger to groundwater as contaminants easily flow as plume with bulk flow. Therefore, hydraulic Conductivity study is useful in assessing infiltration of surface runoff, leaching of Pesticides from agricultural lands and migration of Pollutants from contaminated sites to the groundwater[28].In this study, hydraulic conductivity was obtained using the relationship between the resistivity and hydraulic conductivity in which the resistivity of the aquifer of the study location was obtained through vertical electric resistivity (VES). With the electric resistivity obtained, the hydraulic conductivity was computed with the following model;

$$K = 0.0538e^{-0.0072\rho a} \quad (2)$$

Where $^{\rho a}$ is the apparent resistivity and K represents the hydraulic conductivity

2.4 Data Analysis: The data obtained from the study were analyzed with the following techniques;

2.4.1Rating and weighting of DRASTIC parameters, DRASTIC model and vulnerability map; Every variables in the DRASTIC model was assigned rating and weighting values depending on their levels of significant on groundwater contamination. Weighting values of between 1-5 as prescribed by piscopo(2001)[29] and reported by Massawe et al.(2017)[19] were assigned to the parameters with the variables wielding significant pollution effects being assigned the highest value of 5 whereas the variables with the least pollution potential was assigned the lowest value of 1. Also, rating values of between 1 to10 were assigned to DRASTIC variables with the high values assigned to variables with high pollution potentials. Having assigned rating and weighting values to all the variables, then the overall vulnerability index was computed by summing up the individual vulnerability indexes of various DRASTIC variables to form a DRASTIC model, as follows;

$$DI = D_rD_w + R_rR_W + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_W \quad (3)$$

Where D,R,A,T,S,I and C represent various hydrogeological parameters and the subscripts r and w represent the variable rating and weighting respectively. The higher the DRASTIC index, the more the area is susceptible to groundwater pollution. With this computation, areas that have great pollution potentials for groundwater in relation to the others were identified.

Based on the data obtained for various DRASTIC variables, thematic map of each variable classifying them into ranges or into different media types was obtained using ARCGIS software. The overall vulnerability index map showing the exact vulnerability status of each subset of the study area was achieved by superimposing the vulnerability index map of each variable.

2.4.2 Sensitivity analysis of the DRASTIC model parameters

Previous researchers raised a number of concerns about the operations of DRASTIC model to include; impending inaccuracy of the DRASTIC model results arising from the subjectivity in assigning rates and weights to the parameters[30] and absence of experimental evidence[5]. Rather than considering the whole model variables, some researchers argued that groundwater vulnerability index could as well be computed without employing all the variables and at the same time obtain a more accurate result[31][32]. Application of sensitivity analysis was therefore suggested as apt to address these concerns. This was on the assumption that high degree of interdependence of the rated model parameters might result to risk of error as reported by Babiker et al 2005[33]. Map removal and single variable sensitivity test was adopted to determine the sensitivity of vulnerability map by removing one or two maps from the suitability analysis and to determine the effect of each DRASTIC variables on the vulnerability index respectively([34], [30]. Map removal sensitivity test was computed using the following model;

$$S = \left(\frac{\frac{V}{N} - \frac{V^1}{n}}{V} \right) \times \frac{100}{1} \qquad (4)$$

Where S represents the sensitivity value, $V, and\ V^1$ are unperturbed and perturbed vulnerability indexes respectively. $N\ and\ n$ are number of DRASTIC parametric data used for the calculations of S,$V, and\ V^1$ respectively. Single variable technique was also applied to assess the effect of using a single parametric data. This was achieved by determining the actual weight of each parameter used in the vulnerability index evaluation and that was calculated with the following equation

$$W = \frac{R_i W_i}{V} \times \frac{100}{1} \qquad (5)$$

W is the actual weight of each parameter. $R_i\ and\ W_i$ represent the rating and weight values respectively of each variables while V is the general vulnerability index.

3.0 Results

3.1 Range, Weighting and Rating of the DRASTIC model parameters;

Table 1 presents the Range, weighting and rating of each variable of the model. The range value shows the actual value of the variables measured in the field. Weighting and rating of individual variable were assigned based on the level of pollution potential of the variable to groundwater. In all study sites, recharge rate, soil media, aquifer media and impact of vadose, were assigned the highest rate values whereas the highest weighting values were assigned to aquifer depth and impact of vadose. The Vulnerability indexes calculated thereafter were observed to vary across the study site as follows: EZIOBODO.> FUTO > OBINE > IHIAGWA > NEKEDE.

Table 1: Values of Range, Rates, Weight of the DRASTIC Variables

		Depth to aquifer (m)	Recharge rate (mm)	Aquifer media	Soil media	Topography(ft) (slope %)	Impact of vadose	HydraulicConductivity (m/day)	total
Eziobodo	Range	54.8	2735	Sand	Sand	203(>18%)	sand	253.52	
	Rate	5	9	7	9	1	8	1	
	Weight	5	4	3	2	1	5	3	
	Index	25	36	21	18	1	40	3	144
FUTO	Range	56.2	2735	Sand-gravel	Sand	217 (>18%)	Sand	3854.75	
	Rate	3	9	8	9	1	8	5	
	Weight	5		3	2	1	5	3	
	Index	15	36	24	18	1	40	9	143
IHIAGWA	Range	56.8	2735	Sandgravel	sand	190 (>18%)	sandstone	310.15	
	Rate	5	9	8	8	1	6	1	
	Weight	5	4	3	2	1	5	3	
	Index	25	36	24	18	1	30	3	127
	Range	60.5	2735	Sand	Sand	229 (>18%)	sandstone	150.97	

NEKEDE	Rate	3	4	7	2	1	6	1	
	Weight	5	4	3	2	1	5	3	
	Index	15	36	21	18	1	30	33	124
OBINZE	Range	55	2735	Sand-gravel	Sand	175 (>18%)	Sand	1032.21	
	Rate	3	9	8	9	1	8	2	
	Weight	5	4	3	2	1	5	3	
	Index	15	36	24	18	1	40	6	140

3.2 DRASTIC Variables **and Assessment of Aquifer Vulnerability;**

Figs 2-8 show the rated maps of the DRASTIC variables used to compute the vulnerability index. As indicated on the maps, the rating scores represented the level of impact of a given variable to vulnerability. Rating score1 implied minimum impact of certain DRASTIC model variable to aquifer vulnerability. However, the rating scores increase progressively with the vulnerability impact .i.e the higher the rating of a DRASTIC variable, the higher the potential impact of the variable to groundwater vulnerability. Fig. 2 shows the rated map for depth to water table in various study sites. The rating score for depth to water ranged between 3 and 6. Impact of depth to water was maximum at Eziobodo, FUTO and Obinze with rating values of 6, 5 and 6 respectively and corresponding depth to water range values at 54.8, 56.2 and 55m. Ihagwa and Nekede were rated low; 3 and 4 respectively, given the apparently high depth to water range values of 56.8 and 60.5 observed in the respective study sites.

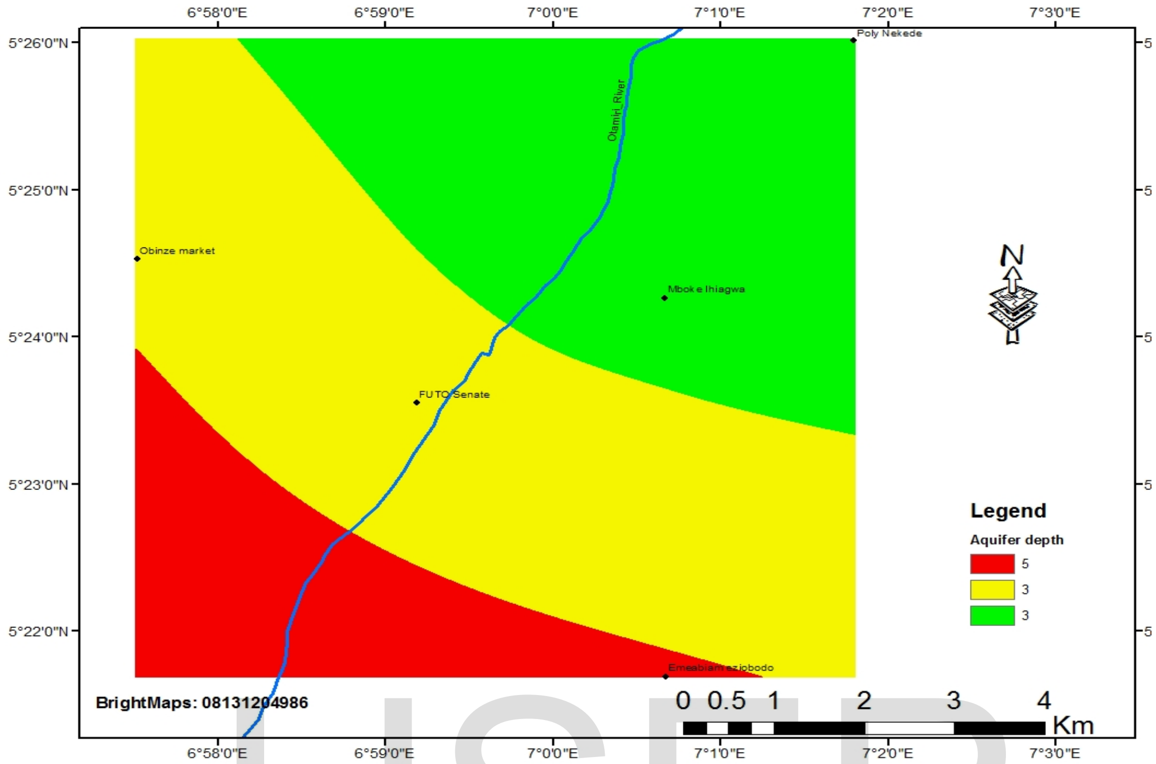

Fig. 2; Representing the rated map for groundwater depth

Fig. 3 depicts the rated map for groundwater recharge in the study area. The net recharge rate was the same in all the four study sites with the range value of 2735mm/year. Given the high range values for net recharge, it was rated 9 in all the sites suggesting high susceptibility to groundwater contamination through recharge and consequently, high vulnerability index of 36.

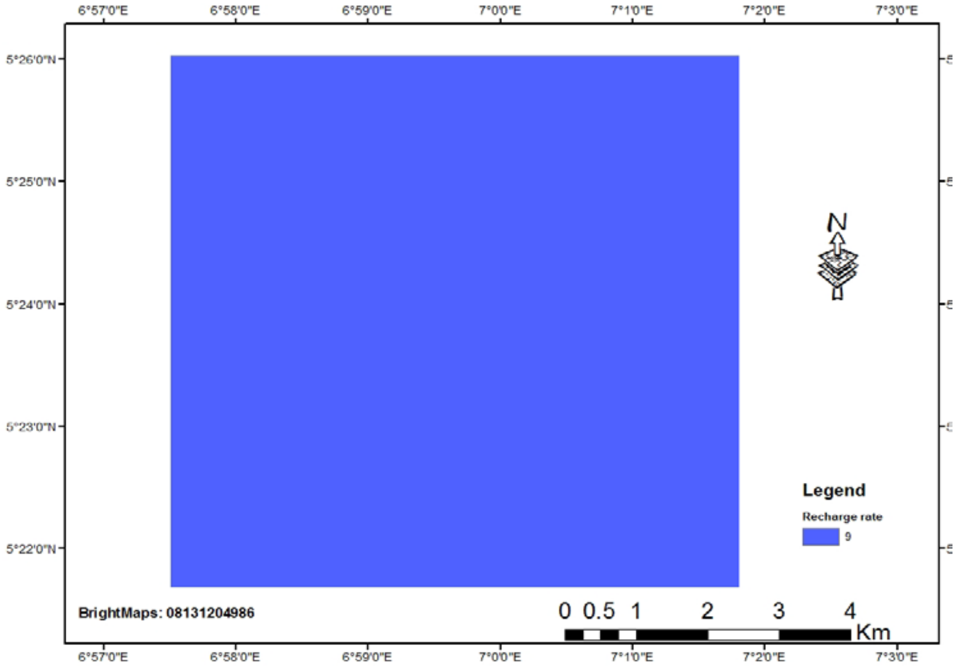

Fig 3; Recharge rate map for the study area.

In the course of groundwater recharge, aquifer medium performs the function of attenuation of the potential contaminants to groundwater and as well the function of groundwater storage. The capacity of the aquifer medium to attenuate depends on its consistency or compositions [12]. The aquifer texture consists mainly of unconsolidated alluvium deposit of coarse, medium and fine sand. Aquifer consisting of fine particle sizes has high potential to attenuate the contaminants hence containing less contaminated water in its storage and vise versa [12]. Type of aquifer particle also determines the migration time of water and by extension the contaminants. Time of contaminant migration through aquifer of fine particle sizes seems to be longer than that of the coarse particles due to flow permeability differences between the two aquifer media[32].

In this study, the map representation of the aquifer rating was shown on fig. 4. The map showed that the study locations consist of sand-gravel aquifer for Ihiagwa, FUTO and Obinze and sandy aquifer for Eziobodo and Nekede. The Sand-gravel-rich aquifer of Ihiagwa , FUTO and Obinze was assigned a high score of 8 with vulnerability indexes of 24 whereas the sand-rich alluvium aquifer of Eziobodo and Nekede which was rated a lower score of 7 with vulnerability indexes of 21.

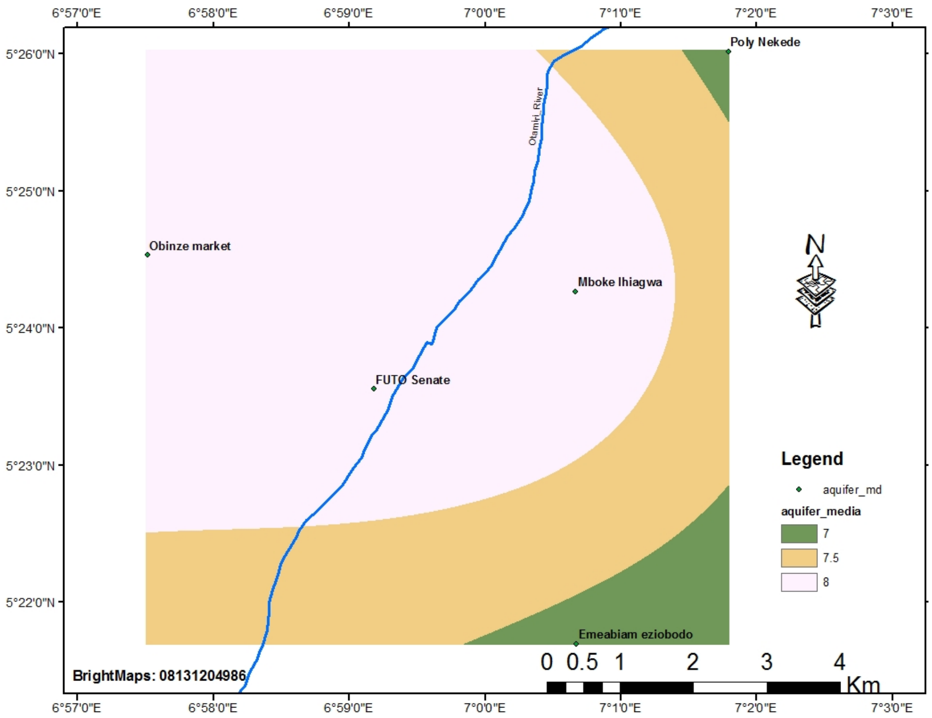

Fig. 4; Map of aquifer rating

The Map showing the rating of soil media in the study areas is shown on fig. 5 . Soil texture and type in the study area were virtually same; it is predominantly coastal plane sand of Benin formation. High rating score of 9 was assigned to the study areas with a vulnerability index of 18 .

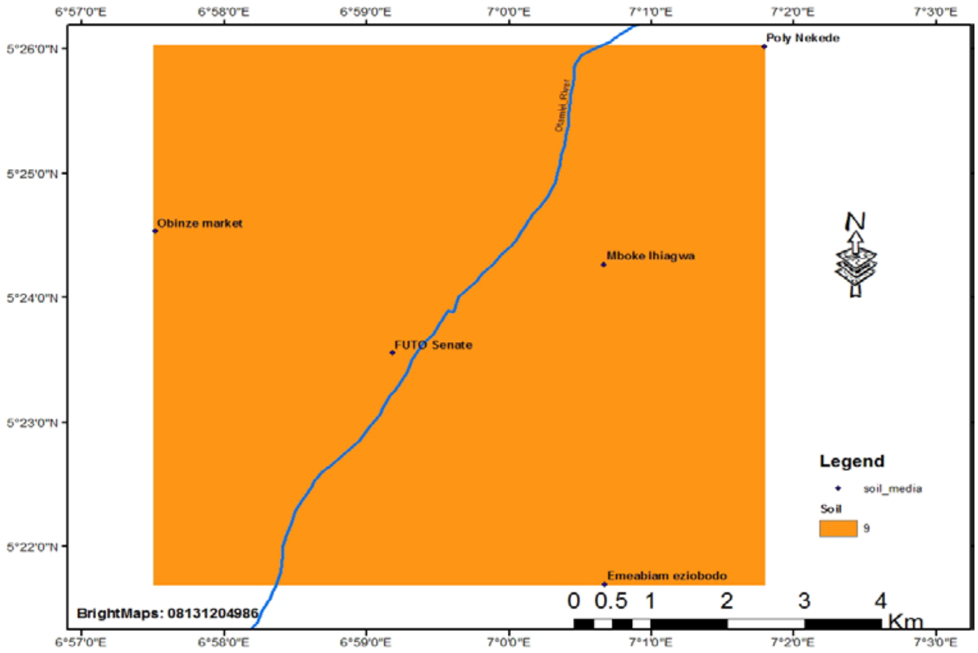

Fig. 5: Map showing the rated Soil Media

Variation in elevation of the study area is presented in fig. 6. The map showed an elevation of little variation among the study sties which was too insignificant to be reflected on the figure. Although From the result, Obinze has the lowest elevation of 175ft, however, the elevation value of the entire study area varied for Nekede, FUTO, Eziobodo, Ihiagwa and Obinze respectively as follows; 229>217>203>190>175ft. This trend showed a reduction of slope steepness from Nekede to Obinze,

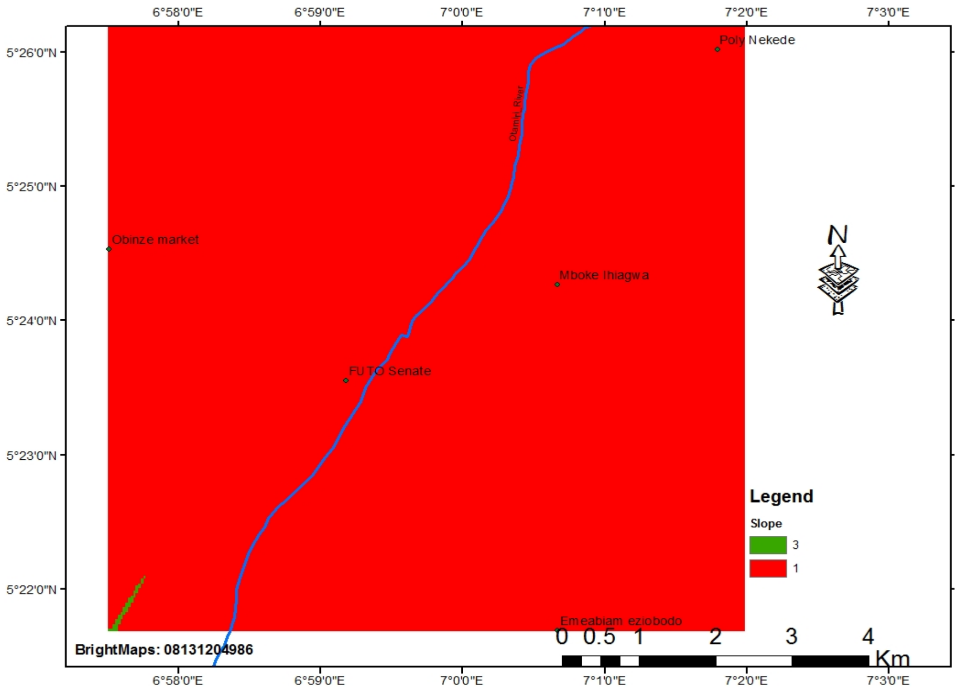

Fig. 6: Map showing the rated Elevation

Impact Vadose zone of the study area has been mapped in the figure 7. The map represents the sandstone dominant in the vadose zone of Nekede and Ihiagwa. The map also showed that Eziobodo, FUTO and Obinze, have vadose of sandy materials. In this regard, vadose zone of sand was assigned a high rate score of 8 given its high permeability and consequent high vulnerability to groundwater contamination, whereas the sand stone was rated 6..

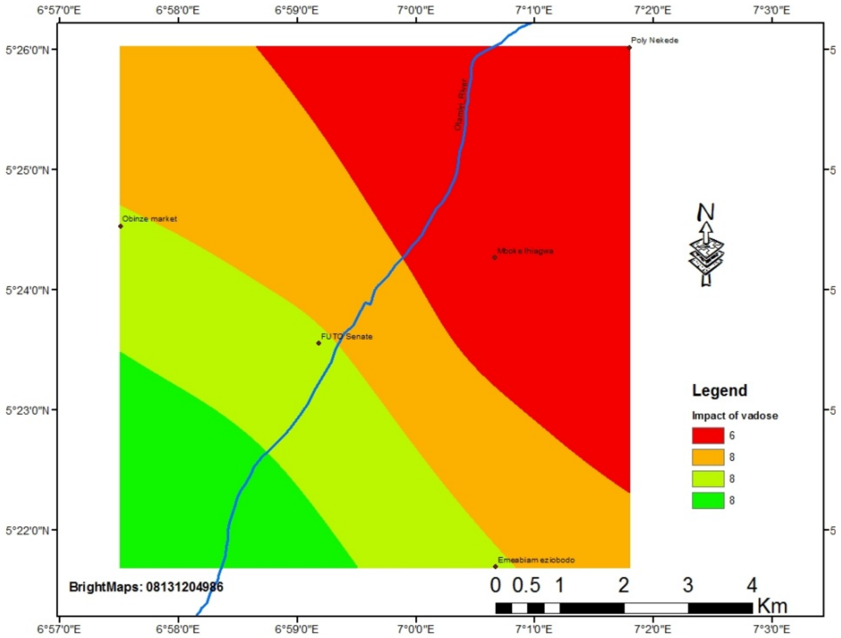

Fig 7; Rated Vadose Zone Map

The map showing the rated hydraulic conductivity of the study area is shown in fig. 8. The figure showed that the hydraulic conductivity varied significantly. Hydraulic conductivity was highest at Ihiagwa with 3854m/day followed by Obinze at 1032m/day, while the least was at Nekede with 150m/day. Rating and weighting were assigned accordingly as shown on table 1.

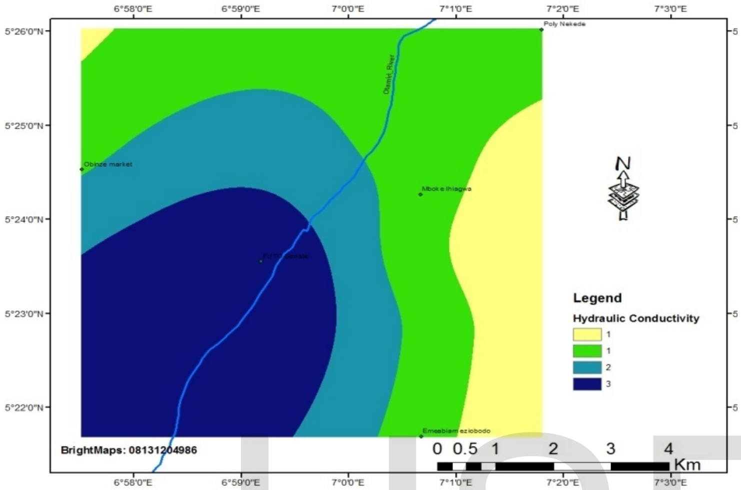

Fig8; Map showing the rated Hydraulic Conductivity

The groundwater contaminant analysis of the study area was carried out on Nitrate concentration because it is a good indicator for groundwater quality and also the most common contaminant in groundwater and aquifer[35]. The map of the average nitrate concentration is shown on fig. 9. Nitrate concentrations of the groundwater in the study area were distributed as follows;. Ihiagwa(71mg/l),Obinze(60mg/l),Eziobodo(54mg/l), Nekede(41mg/l.) and Futo(30 mg/l).

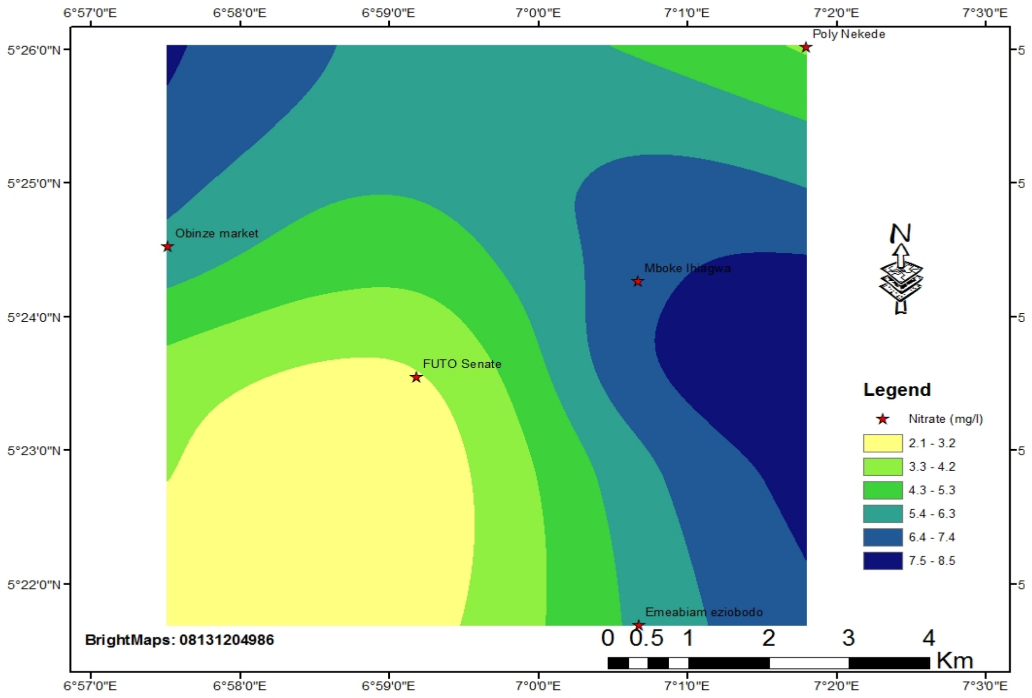

Fig. 9: Map of the Average Nitrate Concentration

The final vulnerability index of the study area was classified into three categories; low, moderate and high vulnerability. Based on the vulnerability index values which ranged between 120 and 160, the area was classified into the three risk zones as stated in the GIS map of fig. 10. From the figure, Ihiagwa and Nekede fall within the low vulnerability range whereas Obinze, FUTO, Eziobodo which share boundry with mgbirichi town whose vulnerability was on the high side (though not captured in the study area) were within the moderate vulnerability range.

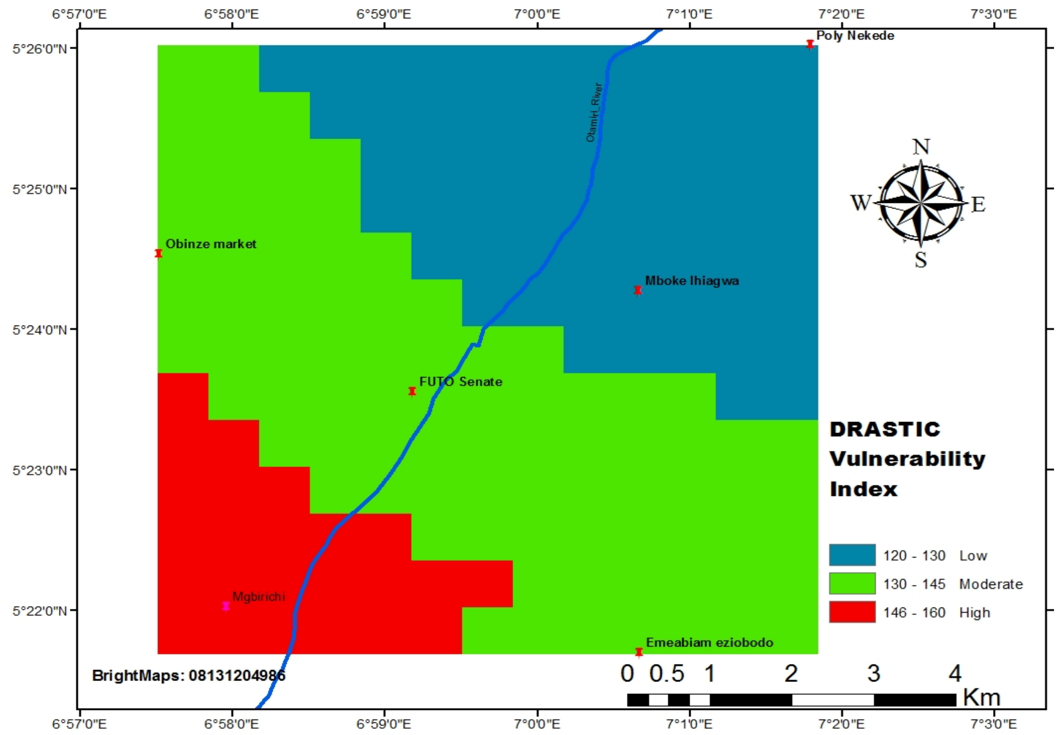

Fig. 10: GIS Map showing the Risk Zones

Percentage distribution of the variables in the entire study area was holistically analyzed with the assigned corresponding rating values. Values for depth to water table across the study area were distributed in the ranges of 30-50ft and 50-75ft . Depth to water table with 30-50ft occupied 28% and was assigned the rating value of 5 whereas the depth to water range value of between 50 to 75ft which was assigned the rating value of 3 took the remaining 72%. Percentage distribution of the soil medium was also assessed and the result revealed that the study medium was predominantly sandy in which 99% of the study area was occupied by sand. On the topography, the entire study area was virtually on the same slope range of >18 hence having the same percentage distribution. In terms of aquifer medium, the sand - rich alluvium occupied the 72% whereas the sand-gravel has 28% of the rock unit. Although the aquifer is dominated by sand-rich in comparison with the sand-gravel but high rate of 8 was assigned to sand-gravel as against the sand-rich alluvium which was rated 7.

3.3 Sensitivity Analysis of the DRASTIC Model Variable Map Removal

Descriptive statistical tools such as mean, standard deviation, standard error, skewness, minimum and maximum values were employed in the analyses of the seven rated variable maps used for the computation of DRASTIC index. Statistical inference tool, namely, Analysis of Variance (ANOVA) was used to test for significant difference in the mean vulnerability index when one or more variables were removed. This analysis answers the question whether significant difference exist in the mean vulnerability index when a map of a particular variable is removed and when maps of different variables are removed. Results of these analyses are shown on tables 2-5

Table 2 : Descriptive Statistics of Vulnerability Indexes of the DRASTIC Variables in Various Sampling Locations

	N	Minimum	Maximum	Sum	Mean	Std. Deviation	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
Depth to aquifer	5	15.00	25.00	95.00	19.00	5.477	.609	0.913
Net Recharger	5	36.00	36.00	180.00	36.00	.000	.	.
Aquifer	5	21.00	24.00	114.00	22.80	1.643	-.609	.913
Soil media	5	18.00	18.00	90.00	18.00	.000	.	.
Topography	5	1.00	1.00	5.00	1.00	.000	.	.
Impact of vadoze	5	30.00	40.00	180.00	36.00	5.477	-.609	.913
Hydraulicconduct.	5	3.00	9.00	24.00	4.80	2.683	1.258	.913
Valid N (listwise)	5							

The results in Table 2 show the minimum and maximum vulnerability index values for depth to aquifer, recharge rate, aquifer, soil media, topography, impact of vadose, and hydraulic conductivity variables. There are glaring variations among the variables except topography, net recharge and soil media where the minimum and maximum index values were the same. However, Net Recharge and Impact of vadoze recorded the highest vulnerability index values, followed by the aquifer media with topography recording the lowest value. Table 2 also shows the mean vulnerability indexes for the variables. Similarly, variations in vulnerability index values took to the same trend as previously observed. The results further show that the average deviation (standard deviation) of depth to water in the sampled locations from their mean value was 5.477; the average deviation of aquifer in the sampled locations was 1.643 while the average deviations of impact of vadose zone and hydraulic conductivity from their means were 5.477 and 2.683 respectively. On the other hand, recharge rate, soil media and topography had constant values across the study locations and thus had zero average deviation. Further investigation on the nature of the distribution of the variables; show that depth to water and hydraulic conductivity were positively skewed while aquifer and impact were negatively skewed. On the other hand, recharge rate, soil media and topography were uniformly distributed across the study locations

Table 3: Descriptive Statistics of Vulnerability Indexes of the DRASTIC Variables in Various Sampling Locations when one of the variables is removed

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Depth	5	7.24	6.35113	2.8403	-.6440	15.1280	1.06	16.33
Recharge rate	5	39.60	3.176	1.4202	35.6548	43.5412	36.75	43.54
Aquifer	5	8.42	4.665	2.0864	2.6312	14.2168	1.02	13.95
Soil media	5	17.83	23.05	10.3104	-10.7984	46.4544	.60	45.23
Topography	5	1.18	0.934	0.4176	0.0205	2.3396	0.34	2.78
Impact	5	34.59	20.501	9.1687	9.1297	60.0423	.81	48.64
Hydraulic **C**onductivity	5	34.59	20.502	9.1687	9.1297	60.0423	.81	48.64
Total	35	20.4920	19.62799	3.3177	13.7495	27.2345	.34	48.64

Results on Table 3 show variations of the vulnerability index upon removal of one map layer of a variable. High variations of vulnerability indexes of 39.60, 34.59 and 34.58 on removal of recharge rate, impact of vadose and hydraulic conductivity layers respectively were observed. On the contrary lowest variation of vulnerability index value was observed on removal of Topography map layer. The results also showed that the vulnerability index in the study locations varied most from its mean when the soil layer was removed with an average deviation of 23.05 and an estimated standard error of 10.3104. It was also observed that the least vulnerability index variation on removal of the topographic map layer was obtained. The next in the hierarchy are the impact of vadose zone and hydraulic conductivity with standard deviations of 20.501 and 20.502 and standard errors of 9.1687 each respectively. Thus, any measurement or estimation of vulnerability index must include the soil medium, the impact of vadose zone and the hydraulic conductivity.

Table 4: ANOVA Table on Test of Significance of the Removal of One of the Variables for Vulnerability Index

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7317.851	6	1219.642	5.907	.000
Within Groups	5780.925	28	206.462		
Total	13098.776	34			

Table 4 presents the results of the ANOVA test of significance upon removal of one DRASTIC model variable map layer. The results showed that there was significant difference in mean vulnerability index when one of the map layers for vulnerability index was removed. A p-value of 0.000 was obtained at 0.05 level of significance, thus, indicating that $p < 0.05$.

Table 5: **Descriptive Statistics of Vulnerability Indexes in the study area when more than one** DRASTIC model variable map laye **is removed**

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	
					Lower Bound	Upper Bound		
DRASI and C	5	0.0348	.02584	.01156	.0027	.0669	.02	.08
DRAI and S	5	0.4300	.24940	.11153	.1203	.7397	.12	.80
DRA and I	5	0.5120	.15073	.06741	.3248	.6992	.30	.70
RA and I	5	6.7040	6.96248	3.11371	-1.9411	15.3491	.90	16.32
R and I	5	11.2940	3.85541	1.72419	6.5069	16.0811	7.80	16.67
R	5	41.7680	9.45436	4.22812	30.0289	53.5071	28.60	53.06
Total	30	10.1238	15.67346	2.86157	4.2712	15.9764	.02	53.06

The results in Table 5 show the descriptive statistics of mean, standard deviation, standard error of the mean, 95% confidence interval for the mean, the minimum and maximum values of the vulnerability index when more than one variable map layers were removed. Maps of the variables which are of less significant to total vulnerability index were preferentially removed. In that regard topography map layer was preferentially removed followed by the topography and conductivity map layers, then topography, conductivity and soil medium map layers until all the variables are removed. From the result, the least mean variation of vulnerability index value was obtained by removing only the topography map layer(0.0348) and variation of vulnerability index value increased as other less significant variables were removed at a time . There was highest mean variation of vulnerability index on removal of Net recharge map, followed by the variation of vulnerability index computed by the removal of net recharge and impact of vadose zone.. The table equally shows increase in the mean variation index as number of variables used in the computation of vulnerability index decreases. It is also important to observe that the more the variable map layers are removed, the higher the standard error of the mean. It can be seen from the table that the highest standard error (4.228) was obtained when the mean vulnerability index was estimated with only net recharge rate map removal. A further investigation was carried out to find out if there is significant difference in the mean vulnerability index when more than one variable were removed.

After the application of sensitivity analysis to ascertain the significance of removing one variables map layer and more than one map layer at a time on the groundwater vulnerability index, it was also pertinent to carry out the single variable analysis which was geared towards determining the effectiveness of each variable in the DRASTIC model on the groundwater vulnerability of the study area. This was achieved by comparing the theoretical and effective weight of each parameter. The theoretical weights are those assigned to individual variables to determine the vulnerability index, whereas the effective weights are computed using equation 5

TABLE 6 showing theoretical and effective weights of DRASTIC model parameters on various study locations

EZIOBODO				FUTO				IHIAGWA				NEKEDE			
parameter	Theoritical weights	Theoritical weights(%)	Effectiveweight (%)	parameter	Theoritical weights	Theoritical weights(%)	Effective weight (%)	parameter	Theoritical weights	Theoritical weights (%)	Effective weight (%)	parameter	Theoritical weights	Effective weight (%)	Eff e wei (%)
D	5	3.5	17.36	**D**	5	3.49	10.48	D	5	3.94	19.69	D	5	4.03	12.
R	4	2.5	25	R	4	2.8	25.16	R	4	3.12	28.35	R	4	3.23	12.
A	3	2.1	14.58	A	3	2.09	16.78	A	3	2.36	18.90	A	3	2.42	16.
S	2	1.4	12.5	S	2	1.4	12.59	S	2	1.6	0.79	S	2	1.6	3.2
T	1	0.69	0.69	T	1	0.7	0.7	T	1	0.79	23.62	T	1	0.8	0.8
I	5	3.5	27.8	I	5	3.49	28.0	I	5	3.94	21.62	I	5	4.03	24.
C	3	2.1	2.08	C	3	2.09	6.3	C	3	2.36	2.4	C	3	2,42	2.4

Table 6 presents the theoretical and effective weights of DRASTIC variables in all the study locations. Virtually all the DRASTIC variables were effective in determining the groundwater vulnerability index as the effective weights of most variables deviate positively from their theoretical weights except the hydraulic conductivity variable in Eziobodo and Ihiagwa where the effective weights are less than the theoretical weights and in Nekede, where there was zero deviation. In that regard, theoretical weight of the hydraulic conductivity was equal to that of the effective weight. There was also zero deviations observed for topography variable in Eziobodo, FUTO and Obinze. However, effective values for all other variables (**I**mpact of vadose, **A**quifer, **D**epth and **S**oil type) were quite higher than their theoretical values. Comparing various study locations, NET RECHARGE exerted the most effectives weights of 25, 25.16 28.35, 12.9 and 25.71 in Eziobodo, FUTO, Ihiagwa, Nekede and Obinze respectively. However, the effectiveness of the DRASTIC variables in assessing groundwater vulnerability in the study area decreased in this order ;R> **I>A>D>S.**

4.0 Discussions.

In Eziobodo study site, depth was assigned a moderately high rate and maximum weight of 5 due to its seeming high pollution potentials to the groundwater. With the low water table observed on the site, groundwater might be easily compromised by contaminant transport. In this perspective the contaminants discharged on the land surface migrate a short distance through the upper horizon of loose soil structure to ,pollute the groundwater, without the rigors of moving through a high depth which might attenuate the contaminant by adsorption or die-off as the case may be[17]. Impact of vadoze was assigned the maximum weighting value and also rated high due to apparent sandy deposit of the vadoze zone. With the prevailing geological deposit and the consequent large porosity, the contaminants meander through the pores unhindered to make contact with the ground water. Same reason of large porosity of sandy deposit was adduced for high rating and weighting values assigned to aquifer and soil medium. Also, the recharge rate was assigned very high rating and weighting values. With high recharge rate, which was as a result of the sand deposit, contaminant migration becomes inevitable[19] [6]).The Rating and weighting of Hydraulic conductivity and the topography values were comparatively low due to the perceived low pollution potential to groundwater. The same reasons were adduced for the rating and weighting vales assigned to DRASTIC model variables in FUTO, Ihiagwa, Nekede and Obinze. For instance, the aquifer media in FUTO, Ihiagwa and Obinze are of sand-gravel and thus were assigned comparatively high weighting and rate values due to apparent ease with which contaminant migrate through the soil matrix which is occasioned by the large pore sizes of the aquifer media. The depth.rating map as presented in fig 2 was in tune with the hydrogeology setting of the study area. The maximum value of impact of depth to water implies that the depth of groundwater in Eziobodo, FUTO and Obinze poses high vulnerability to groundwater contamination as substantiated by [36] [6].On the account of the prevailing circumstance, it therefore implied that Eziobodo was most susceptible to contamination, with Nekede being the least susceptible. In the case of same recharge rate observed in the study site evenness of the study sites devoid of deep depressions could account for the common recharge rate values observed[8]. However, high annual rainfall of > 2500mm/year observed during the study could be attributed to the high recharge rate [37]). Comparing with previous studies of similar hydrological and meterololgical settings[12],[4]., the net recharge values of the present study sites were high. This could be attributed to the presence of river and irrigation water from irrigated farms virtually in all the sites [10]. [38]). Given the high range values for net recharge, it was rated 9 in all the sites, suggesting high susceptibility to groundwater contamination through recharge and consequently, high vulnerability index of 36.

The prevailing rating value assigned to aquifer medium was as a result of obvious loose and unconsolidated aquifer structure of the study area. In the light of the foregoing, the aquifer tends to allow easy transport of contaminants through it and by so doing increasing the vulnerability to groundwater contamination [5]. However, aquifer media of Ihiagwa , FUTO and Obinze were more vulnerable to contamination and consequently constitute contaminant pollution potential than Eziobodo and Nekede. The predominant coastal plane sand typical of the study area accounted for the same Soil texture and type shown in figure 4 hence reason for high rating score of 9 assigned to the study areas with a vulnerability index of 18. What that means is that the impact of soil media is the same in all the respective locations because all the locations were within the same geologic zone [19]). Generally the type of soil media (sand) in the study area, allows reasonable amount of infiltration of water and contaminants into the aquifer. It was observed that infiltration of water in the study area was 25mm/hr more than the similar soil type [39]). The marginal elevation variation observed in fig 5 was an indication that the study area was on the plane surface. However, the slight variation observed where elevation reduced from Nekede to Obinze made an impact on the vulnerability of the aquifer in which Nekede, on a high elevation experienced lower percolation of run-off and consequent lower infiltration and by implication lower vunerability to aquifer contamination as against Obinze which situates at a lower elevation. From the topographic map, the study locations stood on a common steep slope range of >18%..Consequent upon this observation, the study locations were assigned the same low rate of 1. Being on a steep slope, surface runoff and over land flow, in company of the contaminants tend to move to depressed surfaces, making infiltration to subsurface and consequent pollution less significant in the study locations. This implied minimal effect on the vulnerability of aquifer of the study locations [7]. From the results of vadose zone observed in various study sites as presented on fig 6, it was obvious that the vadose zone of the entire area was predominantly sandy, confirming its parent Benin formation status [36]). The vadose zone has significant impact on the movement of water and contaminant. This is predicated on the permeability of the vadose material and therefore key to studying the contaminant transport through subsurface [40]. Vadose of sandstone consistency is less permeable and then makes more significant impact on the attenuation of contaminant than that of the sand[22][35]). The material is permeable with consequent high impact on the contaminant migration. Hence, vadose zone in Nekede and Ihiagwa being dominated by sandstone, stands a risk of being more vulnerable to contamination than that of Eziobodo, FUTO and Obinze which lie on a sandy vadose material.

On the percentage distribution of the geological variables, the percentage distribution pattern for depth to water table implied that a little portion of the entire study area was occupied by comparatively low depth to water table. Based on the prevailing distribution pattern, the study area has low vulnerability to groundwater contamination occasioned by the shallowness of depth to water table. On the contrary, the percentage distribution of the sandy soil medium in the study area portents high vulnerability groundwater contamination due to high permeability [41]). In view of the considerable level of permeability associated with sandy soil medium with its tendency to allow easy contaminant migration down subsurface, the soil medium was rated 9. Previous investigations discovered that soil medium of sort wield significance influence on groundwater vulnerability [41]). The percentage distribution of slope in the study locations is the same. As stated earlier, the common slope range of >18, results to low runoff percolation hence low vulnerability to groundwater contaminations collaborating the low vulnerability rate of 1 earlier assigned to it [15]. The high percentage distribution of sand-rich as against the sand-gravel reflects the parent geological setting of benin formation. The prevailing distribution pattern has the tendency to high vulnerability to groundwater contamination in those parts occupied by sand-gravel rock unit, which apparently due to high relative permeability. Observations of other researchers in these contexts are in line with the present study [36] [27]). In regards to nitrate distribution, the DRASTIC variables such as topography and water to depth, seemed to wield significant influence on the extent of distribution of nitrate . Low nitrate concentration observed in Nekede and FUTO study locations could be attributed to high elevation and water depth. Comparatively, high nitrate concentration in Obinze Ihiagwa and Eziobodo might be as a result of low water depths and low elevations. In addition, heavy and incessant dumping of waste and applications of fertilizer account for the high nitrate concentration recorded in Ihiagwa. The vulnerability classifications associated with the study locations was not unconnected with the characteristics of geological deposits already discussed.

In the descriptive statistics, the skewed vulnerability index value increased towards net recharge variable and impact of vadoze zone means that the aforementioned variables posed the highest risk to groundwater contamination in the study area. Depth to water, aquifer and soil media posed the moderate risk whereas topography and impact of vadose impacted low risk to groundwater contamination. On the analysis of average standard deviation of various DRASTIC parameters from the mean, depth to aquifer and impact of vadose zone are the most variable in the study locations. In line with this observation, previous studies have affirmed that low variability of the variables means low influence of variation to groundwater vulnerability index[18]. This also suggested that the groundwater vulnerability arising from aquifer media and impact of vadose zone varied appreciably across the study area. The pattern of distribution of DRASTIC variables implies that depth to water and hydraulic conductivity had effects on ground water vulnerability in more study sites than aquifer and impact of vadoe zone. The uniform distribution of recharge rate, soil media and topography implied that the effects of the mentioned variables on groundwater vulnerability are the same across the study area.

On the removal of map layers high vulnerability index observed when recharge rate, impact of vadose and hydraulic conductivity layers were removed could be attributed to high theoretical weights and rates assigned to those variables. Removal of Topography, depth and aquifer media layers seem to be less significant to the vulnerability index, perhaps due to low weight and rate values assigned to them[26].. ANOVA test of significance of vulnerability index when one layer map was removed, further confirmed that each DRASTIC variable wields unique impact on vulnerability index of the study location[19]). The descriptive statistics of vulnerability index upon removal of more than one map layer, produced less significant effects on the vulnerability index, perhaps due to low weights assigned to the individual variables as well as their internal variation[18]). The observed trend on the mean variation index suggested that some variables were less significant in working out the groundwater vulnerability index The prevailing situation on the theoretical and effective weights of DRASTIC variables in all the study locations, proved that hydraulic conductivity of the geological setting and the topography in those study locations were not effective variables in determining the groundwater vulnerability index. This goes further to confirm the earlier observation of low vulnerability index significance when the rated hydraulic and topographic index maps were removed. On the other hand, the difference in the effective and theoretical values observed for all other variables where the effective values for **I**mpact of vadose, **A**quifer, **D**epth and **S**oil type were higher than their respective theoretical values, suggested that those variables play determinant roles in the assessment of groundwater vulnerability of the study area. However, net recharge tends to be the most effective variables in assessing groundwater vulnerability given its highest effective values observed across the study sites

5.0 Conclusion

Use of DRASTIC model was made to assess the vulnerability of groundwater in the study area. The result showed that the area was within low and moderate vulnerability zones. The integrated aquifer vulnerability map revealed that Ihiagwa and Nekede fall within low vulnerability zone due to apparently high groundwater water depth associated with the study areas. Obinze, FUTO, Eziobodo were characterized by moderate vulnerability zone. The glaring low groundwater table and most importantly, applications of agro-chemicals arising from intensive crop farming and land discharge of waste from animal husbandry prevalent in Obinze, FUTO and Eziobodo account for the prevailing level of groundwater vulnerability. The vulnerability index of net recharge and impact of vadose were highest and the value decreased in this order; Depth>Aquifer media>Soil type>Hydraulic conductivity>Topography, meaning that net recharge and Impact of Vadose made the most significant impact on aquifer of the entire study area than the other DRASTIC variables. In analyzing the level sensitivity of vulnerability index to various DRASTIC variables, high vulnerability indexes of 36.60, 34.59 and 34.58 upon removal of vulnerability map of Net Recharge, Impact of Vadose and Conductivity respectively showed that the vulnerability index is most sensitive to the map removal of the mentioned DRASTIC variables but low sensitive to map removal of other variables with removal of topography map being least sensitive. Therefore the single variable sensitivity analysis showed that Net Recharge, Impact of Vadose and Conductivity are key factors to aquifer vulnerability of the study area. On the sensitivity analysis of removing more than one vulnerability map, where variables of less significant to total vulnerability index were preferentially removed, Net recharge has the highest mean variation index followed by the variation index computed by the removal of net recharge and impact of vadose zone. The least mean vulnerability index was obtained by removing only the topography map layer . The analysis to determine the effectiveness of various DRASTIC variables to aquifer vulnerability equally revealed that Net recharge is most effective. This study serves as reference point to policy makers and other stakeholders on the best approach to map out zones under the risk of groundwater pollution and general urban and land use planning.

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Cover letter

The study dwelled on the **Vulnerability Assessment of a Sand-rich Alluvium using DRASTIC Model Approach. The study location is a densely populated community housing two major high institution in which water related illnesses are prevalent.** Data information of the hydrogeological variables from various study locations obtained using standard methods were Thematically mapped with ARCGIS software . The variables were quantified with the help of DRASTIC model This study revealed the susceptibility of various study locations to groundwater pollution. With this study, government and stakeholders on environmental issues can make bold approach towards solving the problem of groundwater pollution and its associated illnesses.

The authors wish to state that there is no conflict of interest. That we all contributed toward the success of the research work and that it is our collective consent to send the work to the Journal of Hydrogeology and Hydrologic Engineering.

The study contains figs 1-10 and tables 1-6. Contact information of the corresponding author is as follows

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