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Assessment of Aquifer Vulnerability to Pollution in Selected Part of Oji River Town, Enugu State Using Drastic Model

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Abstract

Aquifer vulnerability assessment could be defined as the degree of assimilation capacity of an area to contaminant from surrounding surface above the aquifer. In this study, intrinsic vulnerability of aquifer in selected part of Oji River was evaluated using DRASTIC model in framework of GIS environment. An additional objective is to use sensitivity analysis to evaluate the effect of each DRASTIC parameter on the final vulnerability map. The results show that the study area is characterized by three vulnerability zones: Very low vulnerability' (risk index <90), 'Low vulnerability' (risk index 90 - 120) and 'Moderate' (risk index 120 - 160). The area is dominantly of low vulnerability while very low and moderate vulnerability occur in patches. The DRASTIC index value indicates that the aquifer system in the study area is relatively protected from contamination on the groundwater surface, but no area was free from contamination risk because of continuous modification of the earth and urbanization. A protective measure must therefore be put in place before exploiting the aquifer and before comprehensive agricultural activities begin in the area to mitigate the contamination risks in the moderate vulnerability zones.

Keywords: Aquifer, Vulnerability, Pollution (contamination),Groundwater, GIS, Sensitivity analysis, DRASTIC, Oji river

1. Introduction

Aquifer vulnerability is a significant approach for the assumption that the physical environment may provide some degree of protection for groundwater against human and natural impacts, particularly with respect to pollutants entering the subsurface environment. (Margat 1968; Albinet and Margat 1970). Vulnerability studies can thus provide valuable information for stakeholders working on preventing further deterioration of the environment (Mendoza and Barmen 2006). There are several aquifer vulnerability assessment methods that have been developed. The most useful is DRASTIC model. DRASTIC technique (Aller et al. 1987) is the most popular, simple, and robust method, which can determine intrinsic vulnerability by ranking different hydrogeologic parameters of an area, and has been used in different studies throughout the world (Babiker et al. 2005; Neh et al. 2015; rogibi et al. 2016; Krogulec and Trzeciak 2017). DRASTIC is an acronym standing for Depth to water D, Net recharge R, Aquifer media A, Soil media S, Topography T, Impact of Vadose zone I and Hydraulic Conductivity C.

This model was developed by Environmental Protection Agency USA (Aller et al. 1987), a standardized system for evaluating ground water pollution potential of hydrogeological settings. These DRASTIC parameters directly relate to the geological factors upon which groundwater quality depends on. This model produces a numerical value called DRASTIC INDEX which derived from the ratings and weights assigned to the various thematic layers. Higher DRASTIC index value corresponds to higher contamination potential and vice versa. Once the DRASTIC index is calculated, it is easy to delineate areas that are more susceptible to ground water contamination compared to others. It is being implemented within the Geographical Information System (GIS) environment. Shirazi et al (2012) indicated the combination of GIS and DRASTIC are more appropriate for evaluation of aquifer vulnerability.

Furthermore, data required for this method is accessible or easy to obtain from public agencies (Al-Rawabdeh et al. 2013). It allows for easy interpolation of data by non-technical experts and in particular can be used for education purposes. It provides an approach to evaluate an area based on known conditions without the need for extensive, site specific pollution data. Also, it provides an inexpensive method to identify areas that need more investigation. Several studies have been carried out using DRASTIC method in several areas in the world, and few within Enugu State, where the study area is situated using other methods (Okoli et al 2017; Okonkwo et al 2013). Oji River is a town within Oji River Local Government Area of Enugu State in the South-East of Nigeria. Other towns within Oji River Local Government Area are; Inyi, Achi, Awlaw, Akpugoeze and Ugwuoba. The Oji River was known by its thermal power station (small satellite power stations) built before independence of 1960. It was built to produce 10MW capacity of Electricity. With the aid of the river named Oji River alongside the site and coal transport from Enugu Coal site on overhead cable buckets 50km away. Oji River town has one of the largest oldest running leprosy rehabilitation settlements in the South-East and also hosts one of only four sites nationally, for the recruitment and training at police cadets in a police college which also offered training to other security personnel. Oji River town has its large portion of land cover by forest which houses some wild animals and also a new developing industrial layout. The community are predominantly farmers and traders.

In line with the desire to meet the present and future water demands of Enugu municipal and its environs, the Federal Ministry of Water Resources undertook to provide water from artesian boreholes at Oji River town through a conveyance pipeline to the existing twin tanks at Nsude, Enugu State. Water are conveyed to the existing twin tanks through pumping stations at Oji River, Obinofia and Umudim. The artesian boreholes constituted to supply 50,000 cubic meters of water per day. However, the DRASTIC INDEX of Oji River (study area), mostly affected by anthropogenic activities such as power stations, farming and quarry is yet to be reported. The area is currently undergoing a rapid surge in human population and economic activities. Hence increasing the chance of water contamination. In spite of various researches conducted on groundwater, there is no published data available to assess the aquifer vulnerability in Oji River using DRASTIC model in other to interpret, analyze and incorporate the geological, hydrological and hydrogeological data in relation to groundwater quality. It is against these problems that this study utilizes DRASTIC model to evaluate the Aquifer vulnerability to pollution within the areas of artesian boreholes drilled by Federal Ministry of Water Resources under “Enugu Supply Augmentation Project” in Oji River town. This study is therefore aimed at using hydrogeological factors to assess aquifer vulnerability of the selected part of Oji River and make some recommendations.

2. Study area

The study area Oji River $6^0$16’N $7^0$16’E is 46.3 kilometers from Enugu metropolis, the capital city of Enugu state covering an area of 403km^2 lands to the south bordering Anambra State and Abia State. The study area is characterized by gently sloping topography. The nature of the slope makes the area vulnerable to erosion. The area falls within the tropical rainforest belt of Nigeria with temperature ranges from 300^{0}C to 320^{0}C. It is characterized by two seasons, the dry and rainy season. The dry season is usually from (November-March), and is marked by an average rainfall of about 60mm. The total annual rainfall ranges from 1600m to more than 2000m. The highest annual rainfall in south eastern Nigeria is received around the eastern highlands due to the convectional and orographic nature of the rains received (Obi et al, 2001). Variations in the amount, seasonal distribution and annual rainfall variability affect peasant farming within communities adversely. The rainfall pattern which is controlled by the movement of the Inter-Tropical Convergence Zone (ITCZ) is characterized by a long wet season from April to July, with a short dry season in August, followed by a short wet season from September to October (Obi et al, 2001). The study area is densely forest and also used for cultivation of crops.

3.0 Material and methods

3.1 Data Acquisition

Reconnaissance Survey and field mapping was carried out to determine general geology of the area and as well as borehole locations from which samples were collected. Geological borehole logs obtained from an Engineering Consultant, were used to study the aquifer system in the study area. Collection of hydrogeological and geological data was based on analyses of existing borehole completion report. The data was collected from Enugu State Water Cooperation headquarters Enugu, Nigeria. The boreholes were drilled under the supervision of Federal Ministry of Water Resources Abuja for Enugu Water Supply Augmentation Project. Two datasets were available; one is for the general characteristics of a well, including construction data, well owner, and well depth and geographic coordinates. The other is for lithology data including intervals, material types, and well screens position. In addition, information such as depth to groundwater, static water levels, borehole yield and particle size distribution results were also available. Total number of eight (8) boreholes were selected in the study area because these artesian boreholes supply water to the most of the inhabitants of the area and Enugu metropolis for domestic, industrial and agricultural purposes. The data were available in different forms such as geological maps, Stratigraphic log, grain size distribution analysis, water analysis result and geophysical data.

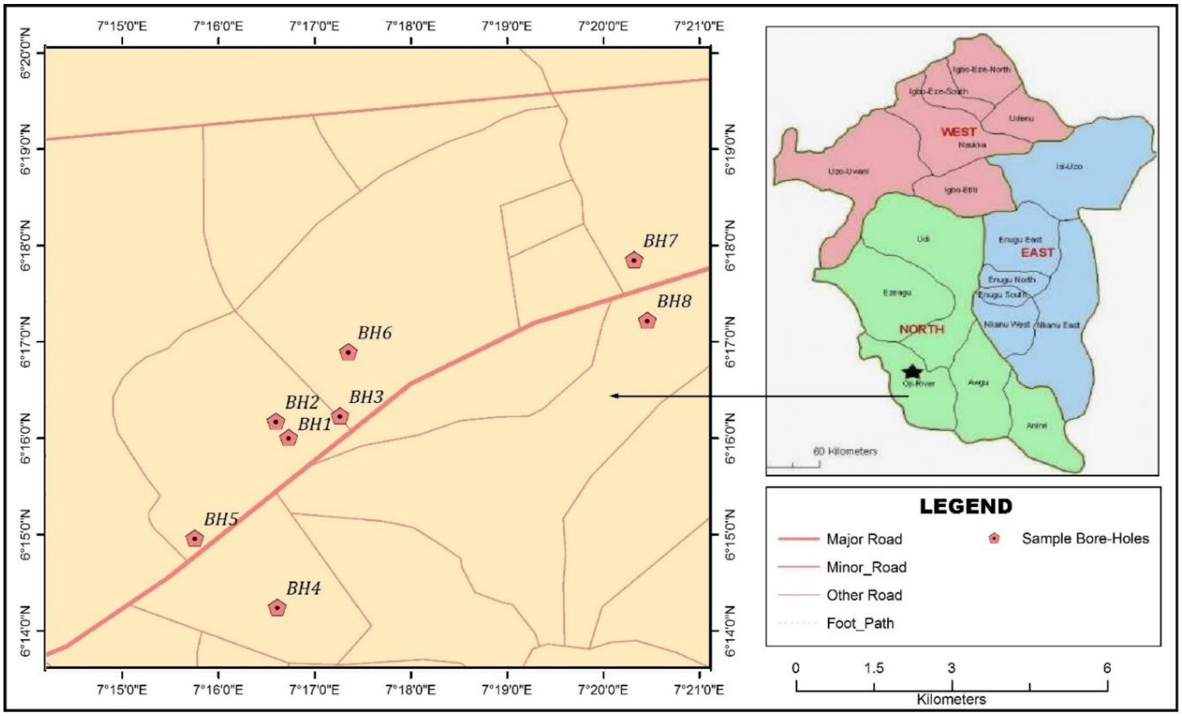

Fig. 1: shows the map of Enugu and the boreholes in the study area Oji river (October, 2019).

3.2 DRASTIC Model Analysis

The DRASTIC parameters used for this study was determined using the reports gathered during data acquisition, application empirical formulae and Arc GIS 10 Suits. This was illustrated in Figure 2.

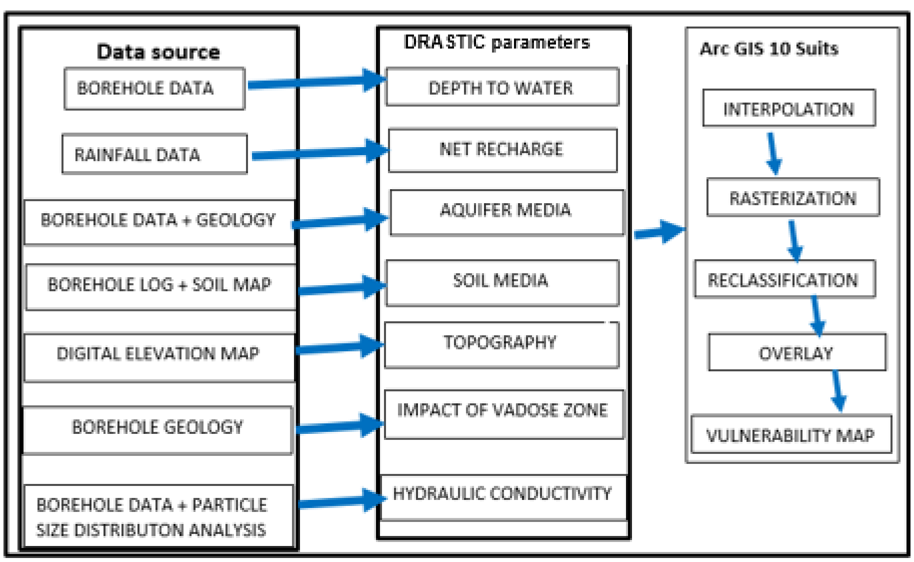

Fig2. shows the sequence DRASTIC model parameters determination and the data source used for this study**.**

From figure 2, depth to water table, Aquifer media and impact of vadose zone were gotten from the critical evaluation of the borehole depth section and geology of the study area. The soil media (S) index was obtained by digitizing the existing soil maps; this was used to compare with the soil media recorded in the borehole log. Net recharge was calculated using Navulur method. Here, Net Recharge is taken to be about 12% of the average annual rainfall gotten from the rainfall data (Navulur, 1996). The topography represents the slope of the area gotten from the Digital elevation model(DEM) using GIS. Hydraulic conductivity was determined from Hazen's Equation (equation 1) using the particle size distribution analysis result in the borehole data. The Hazen method was applied in this study because it is widely accepted and used. (Eggleston and Rojstacze 2001)

$$K_S = c(d_{10})^2 \quad (1)$$

Wherehydraulic conductivity Ks is expressed in cm/sec, c is a constant that varies from 1.0 to 1.5, and d_{10} is the soil particle diameter (mm) such that 10% of all soil particles are finer (smaller) by weight. (Cronican and Gribb 2004; Hazen,1892)

The values gotten from the parameter analysis were implemented within the geographical information system (GIS) environment following the process of interpolation, rasterization, reclassification and overlay to produce vulnerability map. It is important to note that combination of GIS and DRASTIC are more appropriate for evaluation of groundwater vulnerability (Shirazi *et al*, 2012). More so, GIS is regarded as an efficient technique for interpreting, analyzing and incorporating the geological, hydrological and hydrogeological data (Anbazhagan & Nair 2004; Jha & Peiffer 2006; Jha *et al*. 2007).

3.3 DRASTIC Index Calculation

The DRASTIC Index [DI] was calculated using the DRASTIC index formula (equation 2). This index is used to estimate contamination/pollution potential and consequently compute aquifer vulnerability distribution of the area. It entails applying linear combination of all the factors of the equation derived from the numerical index of the rating and weight assigned to the seven model parameters. The rating for each DRASTIC factor is assigned a value between 1 and 10. These ratings provide a relative assessment between ranges in each factor. The higher the rating is the more significant on pollution potential, Table 1[Classification of weight and rating of DRASTIC parameters (Aller *et al.* 1987; Ewusi *et al.* 2016)]. Each factor is assigned a relative weight range of 1–5 (Table 1). The most significant factor is allocated five; the least significant is allocated one. DRASTIC is an acronym for Depth to water **D**, Net recharge **R**, Aquifer media **A**, Soil media **S**, Topography **T**, Impact of Vadose zone **I** and Hydraulic Conductivity **C**.

$$DI = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (2)$$

where **DI** DRASTIC Index, **Dr** rating for the depth to water table, **Dw** weights assigned to the depth to water table, **Rr** rating for ranges of aquifer recharge, **Rw** weight for the aquifer recharge, **Ar** ratings assigned to aquifer media, **Aw** weights assigned to aquifer media, **Sr** ratings for the soil media, **Sw** weights for soil media, **Tr** ranges for topographic (slope), **Tw** weights assigned to topography, **Ir** ratings assigned to vadose zone, **Iw** weights assigned to vadose zone, **Cr** ratings for hydraulic conductivity, **Cw** weights given to hydraulic conductivity.

3.4 Vulnerability to Contamination Rating

This was generated from the DRASTIC Index value. Each parameter was subsequently classified into ranges based on its different effect on contamination. Table 2 shows the categories of vulnerability based on the DRASTIC Index values. This table represents a guide through which the risk zones for sensitivity of aquifer vulnerability to pollution in the study area were revealed.

3.5 Sensitivity Measurement

The impact of each parameter in the vulnerability index was identified through single parameter sensitivity analysis. The analysis helped to avoid the subjectivity to nature for vulnerability assessment which provided very important information to assign the weighting and rating ranges of the parameters. The single parameter sensitivity analysis test indicated the influence of each parameter on final vulnerability measurement and compared the effective/real weight of each input parameter with that of theoretical weight (Saidi et al. 2010). Effective weight of each parameters is computed by the Equation (3).

Table 1: Classification of weight and rating of DRASTIC parameters (Aller *et al.* 1987; Ewusi *et al.* 2016)

PARAMETER	RATING	WEIGHT	PARAMETER	RATING	WEIGHT
DEPTH TO WATER TABLE (m)			**TOPOGRAPHY (Slope %)**		
0 – 1.5	10		0.229 – 0.458	10	
1.5 – 4.6	9		0.458 – 0.687	9	
4.6 – 9.1	7		0.687 – 0.916	7	1
9.1 – 15.2	5	5	0.916 – 1.145	5	
15.2 – 22.9	3		1.145 – 1.374	3	
22.9 – 30.5	2		1.374 – 1.603	1	
>30.5	1		**IMPACT OF VADOSE ZONE**		
RECHARGE (mm)			Karst Limestone	10	
0 – 50	1		Basalt	9	
50 – 100	3		Gravel/Sand	8	
100 – 175	6	4	Sandstone/ limestone formation	6	5
175 – 225	8		Sandy Clay	4	
>225	9		Shale	3	
AQUIFER MEDIA			Silt/Clay	1	
Karst Limestone	10		**HYDRAULIC CONDUCTIVITY (m day^{-1})**	RATING	
Sand and gravel	8		12 – 14	1	
Clay, gravel/Silt, Sand, fine Gravel	7		14 – 16	2	
Bedded Sandstone, Massive limestone, Shale sequence, Fine to Coarse sandstone	6	3	16 – 18	3	
Sand, Sandstone with shale	5		18 – 20	4	3
Weathered Metamorphic Igneous	4		20 – 22	5	
Silty Clay	3		22 – 24	6	
Massive Shale	2		24 – 26	7	
Clay	1		26 – 28	8	
SOIL MEDIA			28 – 30	9	
Gravel or thin Soil	10		30 – 32	10	
Sand	9				
Peat	8				
Loamy Sand	7				
Laterite/sandy loam, Laterite/sandy clay (coarse), Clayey laterite	6	2			
Loam	5				
Silty Clayey Loam/ Silty Loam	4				
Clayey loam	3				
Silty Clay (fine)	2				
Clay	1				

$$W = \frac{P_w P_r \times 100}{V} \quad (3)$$

where **W** refers to effective weight for each factor, **Pr** is the rating values given for each parameter(factor), **Pw** is the weights assigned for each parameter, **v** is the DRASTIC vulnerability index.

Table 2: Drastic Index Categories

Vulnerability Class	DRASTIC Index
Very low	<90
Low	90 -120
Moderate	120 -160
High	160 – 180
Very High	> 180

Source: Aller *et al* (1987)

3.0 Results and Discussions

Depth to Groundwater D

From the analysis of the borehole report, the depth to the groundwater which is also the depth to top of an aquifer for confined situation is represented by aquifer level. The study area falls within the same depth range (>30.5m) of rating 1 (Table 1). According to the rates of DRASTIC classification, these boreholes have very low vulnerability to contaminant/pollution since the depths fall within the deeper range (>30.5m) which implies a longer travel time for contaminants. Due to its high potential in vulnerability, a weight value 5 was assigned to Depth parameter. The Raster map of depth to groundwater produce by interpolation of indicators using ArcGIS 10.1 software is shown in Figure 4. The map shows the same colour indicating that the Depth ranges of the same rating.

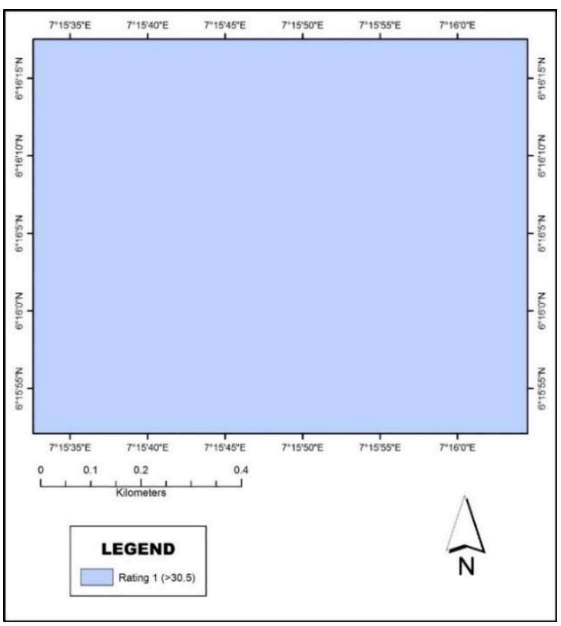

Fig: 4: Depth to water table map of the study area

Table 3: Depth to water table ratings

Depth (m)	Rating
52	1
56	1
74	1
50	1
56	1
62	1
59	1
95	1

Net Recharge R

The Net recharge of the study area (Oji River) is taken to be about 12% of the average annual rainfall of the study area (Navulur, 1996). The highest annual rainfall in south eastern Nigeria is received around the eastern highlands (Enugu) due to the convectional and orographic nature of the rains received (Obi et al, 2001). The study area has high groundwater recharge rate and is at high risk because of permeable pathway from the surface and also from the river to the aquifer. According to the climate data, the average annual rainfall of Oji River is 1806 mm/year. The net recharge is therefore;

$$12\% \text{ of } 1806 \text{ mm/year} = 216.72 \text{ mm/year}$$

According to the DRASTIC rating, the study area falls within the range (175 – 225) is rated 8 and weight value 4 (table 1) showing high vulnerability to contaminants considering only the net recharge. This is shown in the generated raster map in figure 5. The map shows the same colour indicating that the net recharge ranges of the same rating.

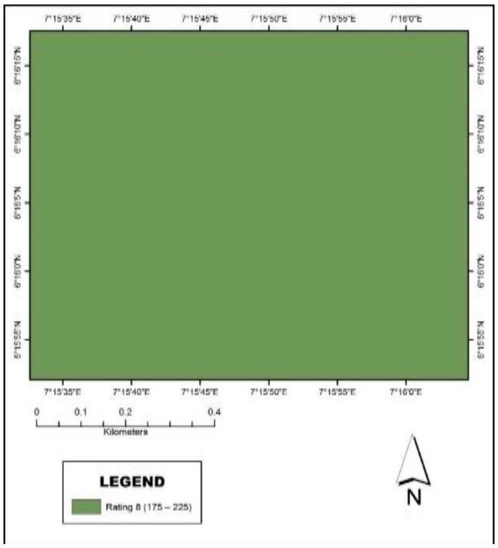

Fig. 5: Net Recharge map of the study area.

Table 4: Recharge rating

Recharge (mm)	Rating
216.72	8

Aquifer Media A

The study area was classified into three rating (5, 6, 8) based on the model modified from Aller *et al*., 1987 and Ewusi *et al*., 2016 (table 1). The rating 8 has been assigned to sand and gravel (sand and fine gravel). The typical rating 6 has been assigned to fine-coarse sandstone and typical value 5 has been assigned to the aquifer media, sandstone with shale. The borehole report stated that the sand member of Imo Formation described as 'Ebenebe' Sandstone, is a good water producing member with high yield potential and its shale member is responsible for the presence of confined aquifer. This zone characterizes a high vulnerability index implying that a contaminant can be easily transported to the aquifer through the soil. Based on this classification, a raster map was generated (figure 6) different zone of aquifer media.

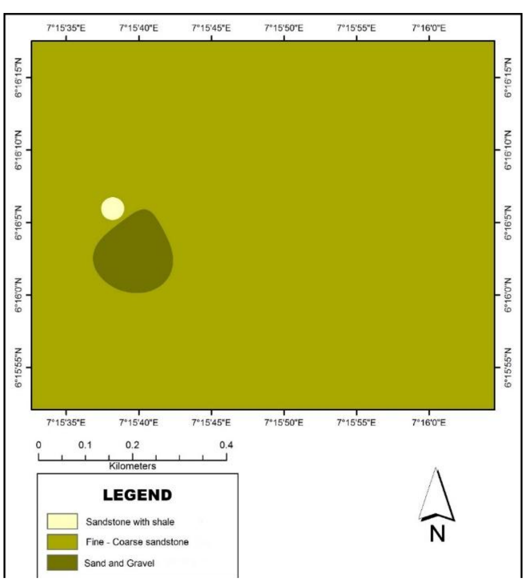

Fig. 6: Aquifer media map of the study area.

Table 5: Aquifer media rating

Aquifer media	Rating
Sand and Gravel	8
Sandstone with shale	5
Fine to coarse sandstone	6
Fine to coarse sandstone	6
Fine to coarse sandstone	6
Fine to coarse sandstone	6
Fine to coarse sandstone	6
Fine to coarse sandstone	6

Soil Media S

The soil map of Oji River compared with the upper part of the well logs revealed that the soil media comprised majorly of laterite sandy clay (coarse), Laterite sandy loam and clayey laterite. Based on the nature and porosity of soil media in the study area a rating of 6 were assigned (table 1). Figure 7 shows the generated raster map of the soil media.

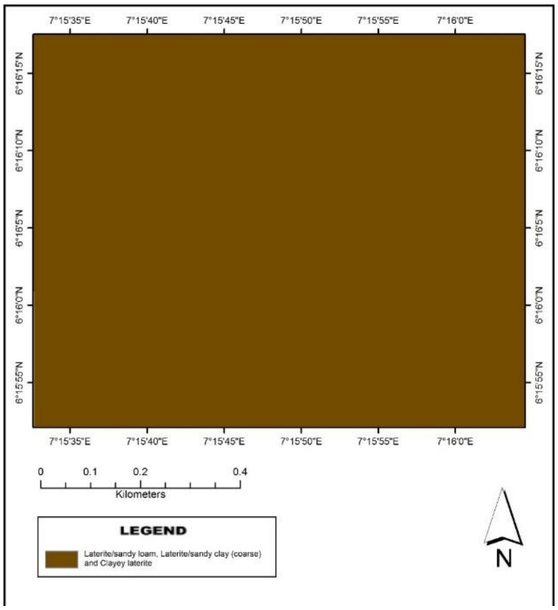

Figure 7. Soil media map of the study area.

Table 6: Soil Media types and rating

Soil media	Rating
Laterite sandy loam	6
Clayey laterite	6
Laterite sandy clay (coarse)	6
Laterite sandy clay (coarse)	6
Clayey laterite	6
Laterite sandy clay (coarse)	6
Laterite sandy clay (coarse)	6
Laterite sandy clay (coarse)	6

Topography T

Slope calculated in terms of percentage and degree using the Digital Elevation Model (DEM) covering the study area were obtained. The obtained percentage slope values are reclassified according to slope index ranges. Considering only the topography, the vulnerability to contaminants varies due to nature of terrain. The study area shows two major types of land forms

which consists of high relief central zone with undulating hills and ridges and the lowland area. The areas with low slope tend to hold water longer, and therefore allows greater infiltration of recharge water and greater possibility of contaminant migration. While the areas with high slope allows quick flow of water which does not favour infiltration. The slope percentage values of 0.31%, 0.70%, 0.99% and 1.13% were rating 10, 7, 5 and 5 respectively while slope percentage values of 1.27%, 1.29% and 1.52% were rating 3, 3 and 1. Weight value 1 was assigned to topography (slope) parameter according to model modified from Aller *et al*., 1987 and Ewusi *et al*., 2016 (table 1). thematic map of the slope for the study area is shown in (Fig. 8).

Table 7: Slope Values and Rating

Slope (%)	1.13	1.13	1.29	1.52	1.27	0.99	0.31	0.70
Rating	5	5	3	1	3	5	10	7

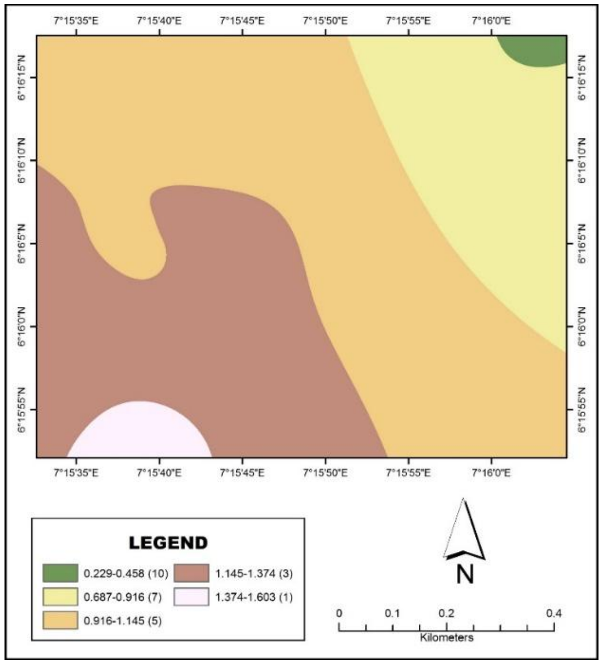

Fig 8: Topography (Slope) map of the study area

Impact of vadose zone I

Impact of vadose zone was prepared from the lithological cross sections obtained from the borehole data. The vadose zone is the layer above the aquifer, it was classified into two categories; shale and very fine sandstone. The typical rating of 3 and 6 was assigned to shale and very fine sandstone respectively (Table 1). Figure 9 shows the interpolated map of impact of vadose zone in the study area.

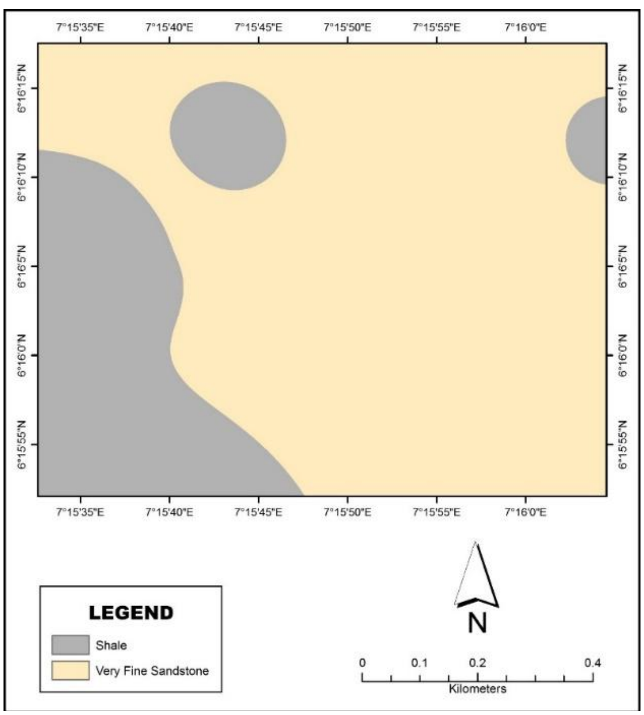

Fig 9: Impact of vadose zone map of the study area

Table 8: Impact of vadose zone and rating

Impact of Vadose zone	Rating
Dark grey hard shale	3
Shale	3
Very fine sandstone	6
Shale	3
Shale	3
Shale	3
Very fine sandstone	6
Shale	3

Hydraulic Conductivity C

Hydraulic conductivity result was derived from Hazen equation (equation 1). An aquifer with high conductivity is vulnerable to substantial contamination as a plume of contamination can move easily through the aquifer. Therefore, it is a function of the grain size, shape, sorting and packing of the aquifer materials and properties of the fluid passing through the aquifer. The different hydraulic conductivity zones were computed and assigned ratings according to their ranges (table 2). The study area was classified into six (1, 2, 3, 7, 8 and 10) according to the criteria of DRASTIC Model. Figure 10 shows the hydraulic conductivity map of the area generated using GIS.

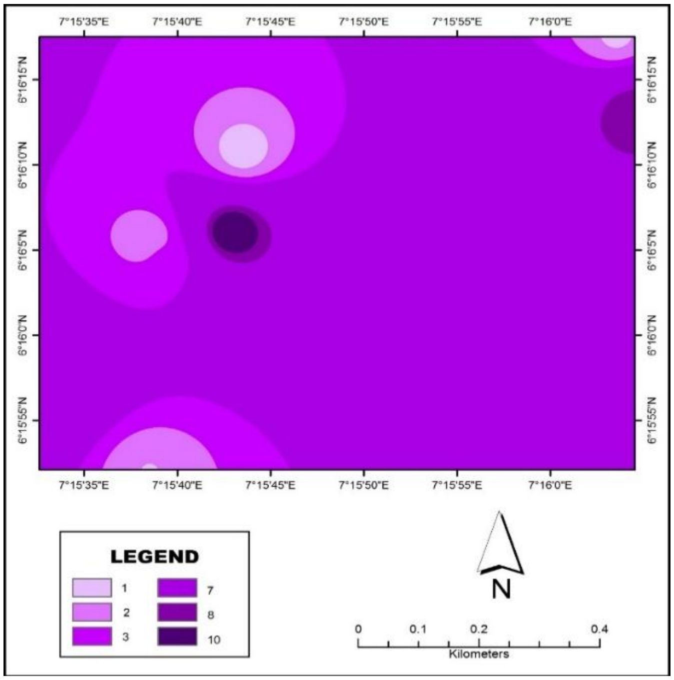

Figure 10: Hydraulic conductivity map.

Table 9: Hydraulic conductivity values and rating

K (m/day)	Rating
16.454	3
14.156	2
31.190	10
13.935	1
25.561	7
12.650	1
13.500	1
27.994	8

Generally, after the raster maps for the seven DRASTIC parameters were prepared and classified, all parameters were input into the equation 2 (DRASTIC index equation) and the DRASTIC index value for the study area was calculated, the index value vary from 99 to 130 and reclassified based on the Aller *et al* (1987) standard classification table 2. The study area gave three vulnerability categories; Very low vulnerability' (risk index <90), 'Low vulnerability' (risk index 90 - 120) and 'Moderate' (risk index 120 - 160) Table 10. These categories are function of the sensitivity of the DRASTIC parameters. The area is dominantly of low vulnerability while very low and moderate vulnerability zones were found in patches figure 11. The study area was found with deeper depth to water table, high net recharge, permeable aquifer media (sandstone), low permeability soil media, undulating to elevated topography, semi-permeable vadose zone and low to high hydraulic conductivity.

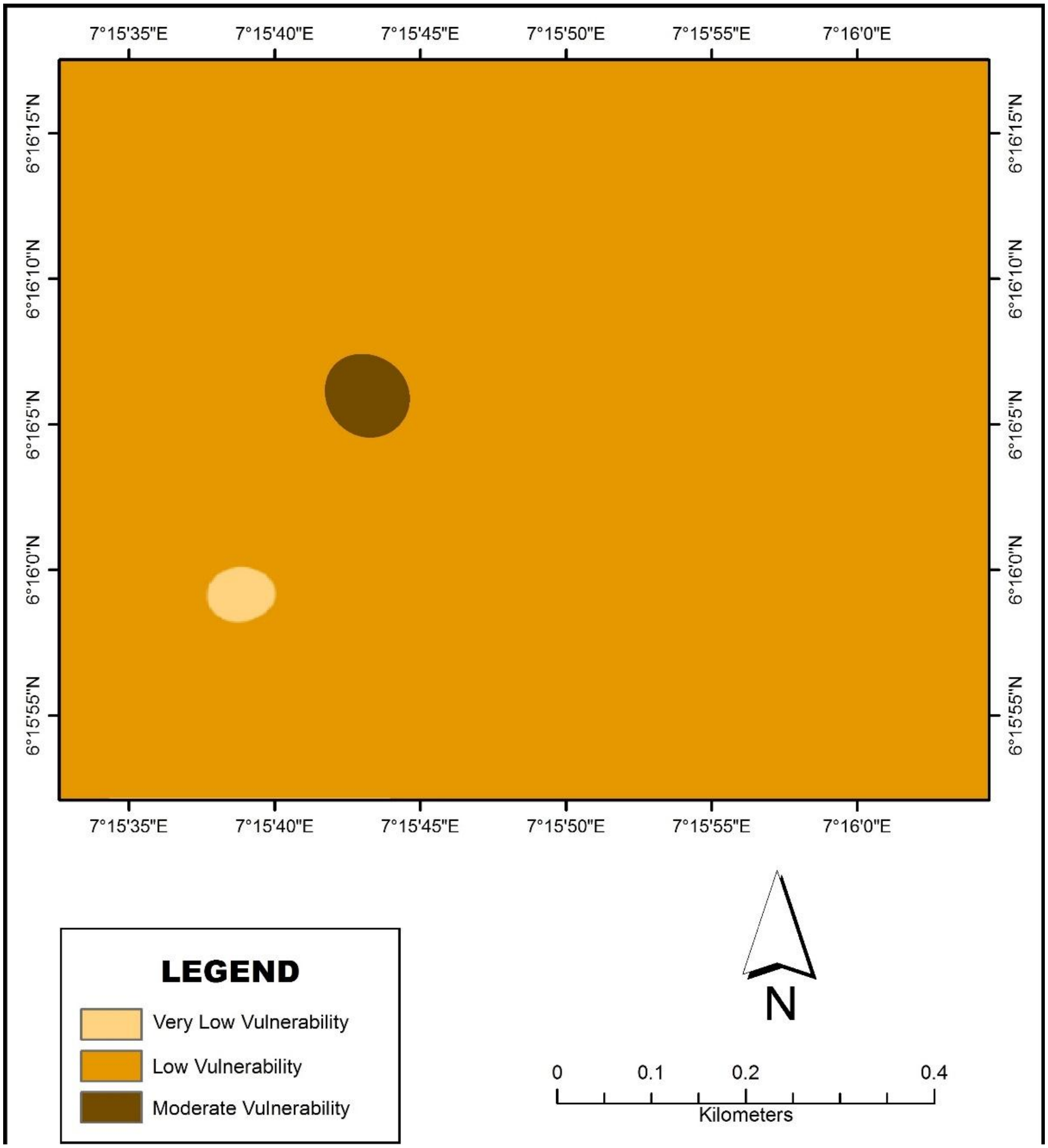

Figure 11: Aquifer vulnerability map based on the DRASTIC method.

Table 10: Vulnerability index range of the study area

VULNERABILITY INDEX RANGE	DRASTIC INDEX
<90	Very low
90 – 120	Low
120 – 160	Moderate

Sensitivity Measurement

Single parameter sensitivity analysis was computed using equation 3. The sensitivity of each of the parameters revealed the degree of influence of each parameter to vulnerability of aquifer. Fig 12 shows the bar-chart of the degree of influence of each parameters.

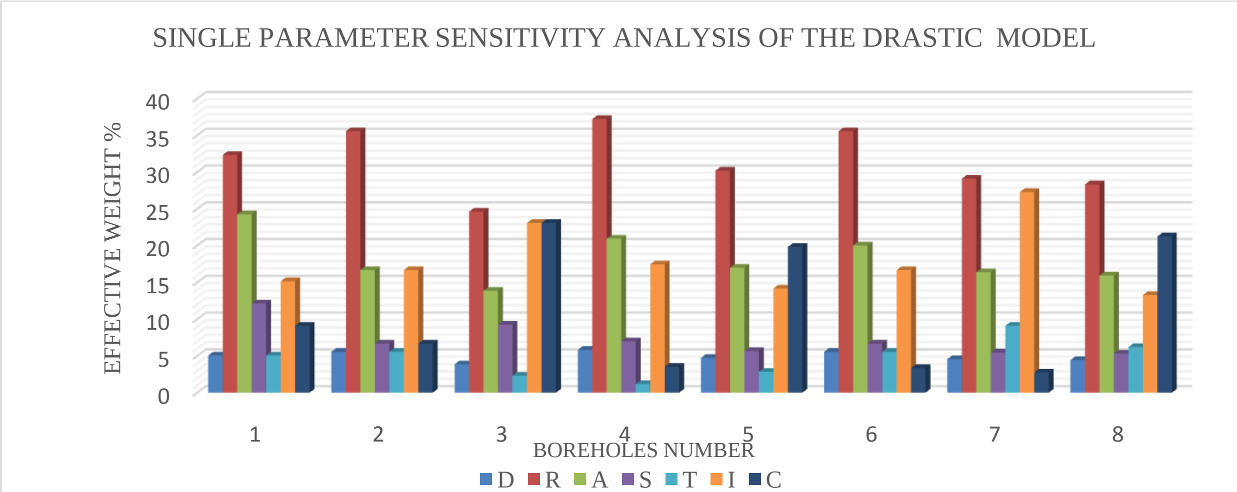

Figure 12: Bar chart showing the sensitivity of each parameter in each borehole

Figure 12, shows the distribution of sensitivity of the individual parameter in each borehole. From the figure, the rate of recharge has the highest impact while depth of water table and topography have the lowest impact for each borehole. However, this chart does not represent the sensitivity of the parameters of the area. Consequently, this sensitivity analysis was represented in figure 13 to characterizes the distribution of continuous variables in the area.

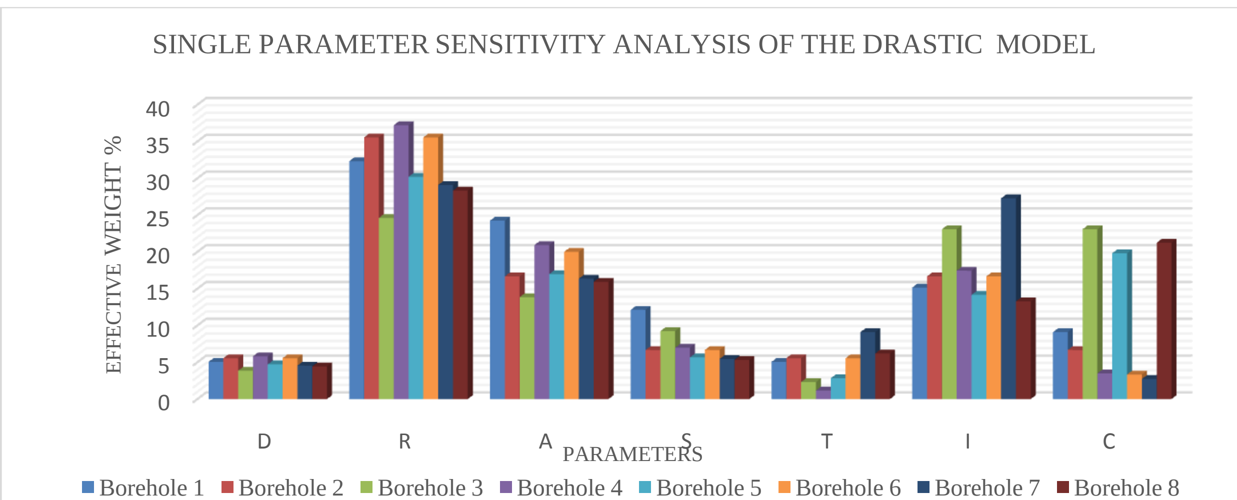

Fig. 13: A Histogram chart of sensitivity of each of the DRASTIC parameters

It can be seen from figure 13 the increasing order of sensitivity of DRASTIC parameter (from low to high) is Topography **T**, Depth **D**, soil media **S**, Hydraulic conductivity **C**, Impact of vadose zone **I**, Aquifer media **A**, and Rate of recharge **R.** However, subjectivity is unavoidably associated with the selection of ratings and weights that was assigned to the seven parameters. Such a selection strongly affects the result of the final vulnerability map, hence poses some level of uncertainty to DRASTIC model. To minimize this problem of uncertainty, sensitivity analysis which characterizes the distribution of individual variables and of input parameters on the resultant output of an analytical model was performed statistically (table 11).

Table 11: Statistics of single parameter sensitivity analysis

DRASTIC Parameter	Theoretical Weight	Theoretical Mean Weight %	Effective Mean Weight %	Min.	Max	Standard Deviation
Depth to water	5	21.74	4.94	3.8462	5.814	0.6762
Net Recharge	4	17.39	31.61	24.615	37.209	4.328
Aquifer media	3	13.04	18.12	13.846	24.242	3.3482
Soil media	2	8.7	7.26	5.3097	12.121	2.3275
Topography	1	4.35	4.72	1.1628	9.0909	2.5307
Impact of Vadose zone	5	21.74	17.96	13.274	27.273	4.794
Hydraulic conductivity	3	13.04	11.18	2.7273	23.077	8.7353

From table 11, the theoretical weight percent was calculated and compared with the effective weight percent. The "effective" weight is a function of the other six parameters as well as the weight assigned to it by the DRASTIC model. The "effective" weights of the DRASTIC parameters exhibited some deviation from the "theoretical" weight. The net recharge, **R**, tends to be the most effective parameter in the vulnerability assessment with an effective weight of 31.61% against the "theoretical" weight (17.39%). The "effective" weight of the aquifer media parameter, **A,** (18.12%) exceeds the "theoretical" weight assigned by DRASTIC (13.04%). Slight variation was observed in the topography, **T**, with effective weight of 4.72% against the theoretical weight of 4.35%. The soil media, **S**, the impact of the vadose zone, **I**, the hydraulic conductivity, **C**, and especially the depth of groundwater, **D**, reveal lower "effective" weights (7.26%, 17.96%, 11.18, and 4.94%), than the "theoretical" weights (8.7%, 21.74%, 13.04%, and 21.74%, respectively). Comparing the "theoretical" weights, with the "effective weights" (figure 14), the ones in which the effective weight is significantly larger than the theoretical weight, in the case of the net recharge and aquifer media has the highest impact on aquifer vulnerability. This pattern is due to the high recharge and permeable nature of the aquifer media (sandstone).

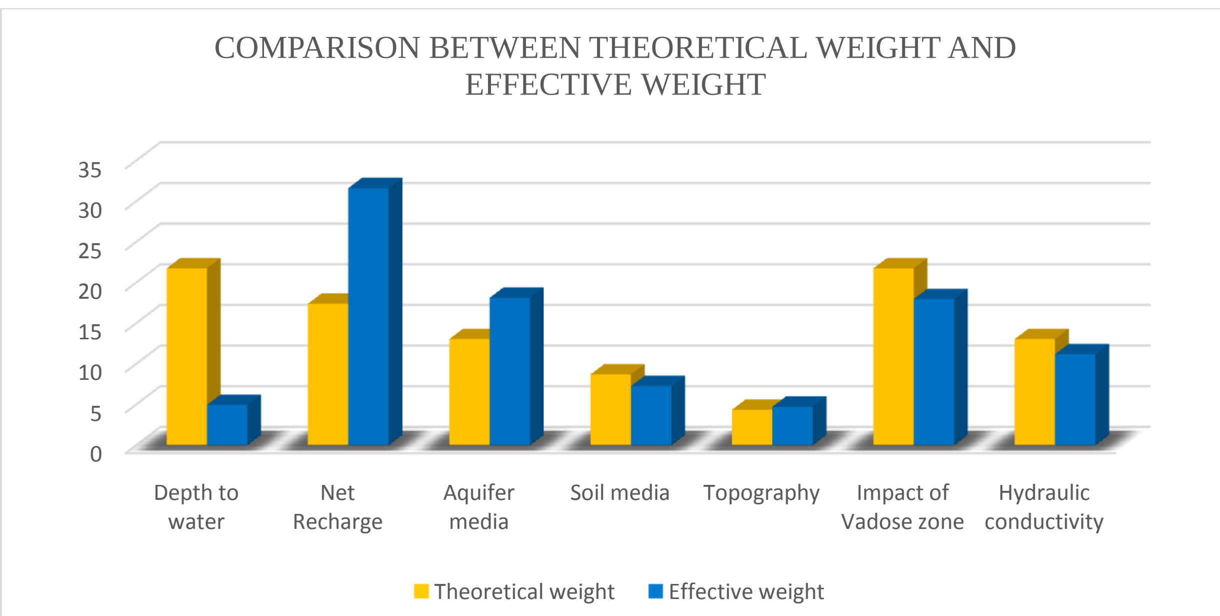

Fig. 14: Comparison of theoretical weight and effective weight

From figure 14, The larger variations are considered as the main factors that affect the distribution of vulnerability classes through the area, the net recharge has the highest impact on aquifer vulnerability follow by aquifer media.

This pattern is due to the high recharge and permeable nature of the aquifer media (sandstone).The single parameters' sensitivity shows the importance of the mapping parameters as follows, R>A>I>C>S>D>T, against the theoretical weight DRASTIC method, in the order of D>I>R>A>C>S>T. The significance of these factors highlights the importance of obtaining accurate, detail, and representative information about these factors.

4.0. Conclusion

This study utilized DRASTIC based-GIS technique to investigate the groundwater vulnerability in selected part of Oji River, Enugu state, Nigeria. This model provides a good tool to evaluate and manage the groundwater systems for its vulnerability to contamination. The DRASTIC index map shows that the principal aquifer is naturally protected from the source of contaminants occurs in the surface with vulnerability categories; Very low vulnerability' (risk index <90), 'Low vulnerability' (risk index 90 - 120) and 'Moderate' (risk index 120 - 160). These categories are function of the sensitivity of the DRASTIC parameters which directly depends on function of the weight assigned to the increased parameter. The very low vulnerability area may relate to the elevated topography, impact of vadose zone (shale) and the lower hydraulic conductivity of the aquifer. The class of low vulnerability extend over a large area of the study area (about 80 %). This is due to the soil media (Laterite sandy loam, Clayey laterite and Laterite sandy clay (coarse), variation values of topography and hydraulic conductivity of the aquifer. The moderate vulnerability area of the study area may relate to the variation on the impact of vadose zone (very fine sandstone), lower topography and high values of hydraulic conductivity. This is due to the convectional and orographic nature of the rains received by the aquiferous formation. The single-parameter removal sensitivity analysis test indicated the influence of each parameter on the final vulnerability measurement. The net recharge **R** has the highest impact on aquifer vulnerability assessment follow by aquifer media **A** and topography**T**. The significance of net recharge, aquifer media and topography emphasizes the importance of detailed, accurate, and representative information about these factors in aquifer vulnerability in the study area.

Although, the study area shows an acceptable aquifer vulnerability status, it is however important to note that the earth is in continuous modification due to environmental denudations and urbanization. To these effects, there would be erosion, continuous agricultural practices, overgrazing, wastewater leakage from industrial activities and other anthropogenic activities which degrades the environment and hence increases the aquifer vulnerability. Therefore, to maintain the low aquifer vulnerability status in the study area, and to protect groundwater reserve from future contamination, both preventive and protective maintenance measure must be ensured.

5.0 Recommendation

This study suggests that DRASTIC is useful tool for groundwater vulnerability assessment and can prioritize susceptible areas. Nevertheless, no area was free from contamination risk based on the DRASTIC index value. To avoid further contamination of groundwater resources, the following are therefore recommended:

1. Areas determined by the DRASTIC method should thus be given priority in research in terms of contamination.
2. Adequate controlling the domestic, agricultural, and industry activities in vulnerable areas. This is important in protecting the groundwater from pollution, in addition to monitoring the chemical, physical, and biological indicators that effects negatively in deteriorate the groundwater resources.
3. Regarding urban planning and organization of agricultural activities in the area, the vulnerability risk map prepared in the study could be most important when considering protection off groundwater quality.
4. Subsequent validation and evaluation of the sensitivity in the study, to test the consistency of the DRASTIC factors in the vulnerability assessment. This is because the results show that the effective weight for each factor is different from the theoretical weights assigned by the DRASTIC model. The lack or uncertainties in net recharge, aquifer media and topography are the highest factors that reduce the efficiency of the vulnerability index model.
5. Proper planning is required to solve the drainage problem in the study area to avoid further contamination of groundwater resources.
6. Surface water such as Oji river which can also be source of recharge to the borehole should be properly monitored.
7. This DRASTIC method results should be used in designing aquifer protection and management strategies for the area.

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References
Albinet, M and Margat, J. 1970. Groundwater Pollution Vulnerability Mapping. Bulletin du Bureau de Researches Geologicques et Minieres Bull BRGM 2nd Series, 3, 13-22.

Aller, L., Bennet, T., Lehr, J.H., Petty, R.J., and Hackett, G., 1987. DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeological Settings. US Environmental Protection Agency, Ada, OK, USA. EPA/600/2e87/035.

Al-Rawabdeh, A. M., Al-Ansari, N. A., Al-Taani, A. A. and Knutsson, S. 2013. A GIS-based Drastic model for assessing aquifer vulnerability in Amman-Zerqa Groundwater Basin, Jordan. Engineering 5, 490–504.

Anbazhagan, S. and Nair, A. 2004. Geographic Information System and Groundwater Quality Mapping in Panvel Basin, Maharashtra, India. Environmental Geology. Vol.45. Pg753-761. DOI 10.1007/s00254-003-0932-9.

Babiker, I. S., Mohammed, M. A. A., Hiyama, T. and Kato, K. 2005. AGIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, CentralJapan.ScienceoftheTotalEnvironment345,127–140.

Cronican A. E. and M. M. Gribb. 2004. Literature review: Equations for predicting hydraulic conductivity based on grain-size data. Supplement to Technical Note entitled: Hydraulic conductivity prediction for sandy soils. Published in Groundwater, 42(3):459-464

Eggleston, J., and Rojstaczer, S., 2001. The value of grain-size hydraulic estimates: comparison with high resolution in-situ field hydraulic conductivity, Geophysical Research Letters, v.28, 2855-2858.

Ewusi, A., Seidu, J., Ahenkorah, I., Eshemele, N. K., Asante-Annor, A., and Oti, D. 2016. "Evaluating the Mattru Jong Water Supply System in Seierra Leone" International Journal of Advanced Research, Vol. 4, No. 11, pp. 987-996.

Hazen, A., 1892. Experiments upon the purification of sewage and water at the Lawrence Experiment Station, Massachusetts State Board of Health 23rd Annual Report.

Jha Madan Kumar and Stefan Peiffer 2006. Application of Remote Sensing and GIS Technologies in Ground Water Hydrology: Past, Present and Future. Bayreuth: Bayreuth University Press.

Jha, Madan, Chowdhury Alivia, Chowdary, V. and Peiffer, Stefan. 2007. Groundwater Management and Development by Integrated Remote Sensing and Geographic Information Systems: Prospects and Constraints. Water Resources Management. 21.427-467.10.1007/s11269-006-9024-4.

Krogulec, E. and Trzeciak, T. 2017. DRASTIC assessment of groundwater vulnerability to pollution in the Vistula floodplain in central Poland. Hydrology Research 48 (4), 1088–1099.

Margat J 1968. Vulne´rabilite´ des nappes d'eausouterraine a` lapollution (vulnerability of groundwater to pollution). BRGMPublication 68 SGL 198 HYD, Orle´ans

Mendoza, J. A. and Barmen, G. 2006. Assessment of groundwater vulnerability in the Río Artiguas basin, Nicaragua. Env Geol 50:569–580.

Navulur, K.C.S., 1996. Groundwater Evaluation to Non-Point Source Nitrate Pollution for Large Areas Using GIS. Ph.D. thesis, Purdue University, West Lafayette, Indianapolis, USA.

Neh, A. V., Ako, A. A., Ayuk II, A. R. and Hosono, T. 2015. DRASTIC-GIS model for assessing vulnerability to pollution of the phreatic aquiferous formations in Douala-Cameroon. Journal of African Earth Sciences 102, 180–190.

Obi, G.C., Okogbue C.O. and Nwajide C.S. 2001. Evolution of Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure and Applied Sciences 7 (2), 321-330,2001.

Okonkwo, Austin and Ezeh, Chukwudi and Opara, Alexander. 2013. Estimates of Aquifer Transmissivity from specific capacity data in Sandstone Aquifer in Enugu state, Southeastern Nigeria. International Research Journal of Geology and Mining (IRJGM). 3.291-297.10.14303/irjgm.2013.037.

Okoli, F. U., Johnson, N. G. and Ejikeme J. O. 2017. Mapping Groundwater Potential Zones in Enugu State using Remote Sensing and GIS Techiques. Int.J. Innovative Environ. Studies Res. 5(1):33-46, 2017

Shirazi,S.M. ImranH.M. andShatirahAkib 2012. GIS-based DRASTIC method for groundwater vulnerability assessment: a review. Journal of Risk Research, 5:8, 991 - 1011. Faculty of Engineering, Department of Civil Engineering, University of Malaysia, Kuala Lumpur, Malaysia.

Saidi, S., Bouri, S. and Ben Dhia, H. 2010. Groundwater vulnerability and risk mapping of the Hajeb-jelma aquifer (Central Tunisia) using a GIS-based DRASTIC model Environmental Earth Sciences 59, 1579-1588.

Zghibi, A., Merzougui, A., Chenini, I., Ergaieg, K., Zouhri, L. and Tarhouni, J. 2016. Groundwater vulnerability analysis of Tunisian coastal aquifer: an application of DRASTIC index method in GIS environment. Groundwater for sustainable development 2, 169 – 181.