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Asseessment of Groundwater Vulnerability to Pollution in Kingsley Ozumba Mbadiwe University Ideato and Environs Using Drastic Method

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Abstract
The DRASTIC model was used to investigate the groundwater vulnerability to pollution in Kingsley Ozumba Mbadiwe University Ideato and environs, Nigeria. Twenty five soundings were probed within the study area to obtain data on the depth to water table, net recharge, aquifer media, soil media, topography, impact of vadoze zone and hydraulic conductivity. These seven parameters are denoted by the acronym, DRASTIC, a widely used technique for assessing groundwater vulnerability to pollution based on the hydrogeological settings of the area. The deduced DRASTIC parameters were used to compute the DRASTIC Index (DI) at the various VES points. The DRASTIC map shows that the locations Rochas Foundation College, Umuokwaraonure Ogboko and Staff Quarters 2 are areas of high vulnerability to pollution and the locations Library and JUPEB Center KOMU are areas of low vulnerability to pollution.. The rest of the locations within the study area have moderate vulnerability.
Keywords: *Aquifer, groundwater, vulnerability, parameters, pollution, DRASTIC*

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I. INTRODUCTION

Water is a vital resource for human development. It is the second most important basic need of man after oxygen which is the first. Water is used for a variety of purposes including domestic, industrial, and agricultural applications. The primary sources of water are surface water such as fresh water lakes, rivers, streams, etc. and groundwater such as borehole water and well water. Over the year, water especially in the form of rivers, stream and ocean has traditionally served as a mean of waste disposal of materials such as faeces and other domestic waste products all over the world. As human population increases with a parallel expansion in industrial and agricultural activities, water sources became receiver of wastewater along with contaminants both from home and industries. Groundwater is preferable to surface water because it is less contaminated and does not require extensive purification. However, due to the fact that surface water is not sufficiently available and is further worsen by pollution, urbanization, and industrialization, the majority of the populace in Nigeria's cities and rural areas depends on groundwater assets for drinking and other purposes. Monitoring of groundwater quality is therefore essential in any basin or population area which affects the fittings of water for household, industrial and agriculture use.

Groundwater vulnerability refers to the likelihood of groundwater contamination or pollution due to human activities or natural factors. Groundwater vulnerability depends on various geological, hydrogeological, and environmental factors that affects the susceptibility of groundwater to contamination. Assessing of groundwater vulnerability therefore helps to identify high-risk areas, prioritize protection and management efforts, develop targeted strategies for pollution prevention and remediation, and ensure sustainable groundwater resource management. In the present study, an effort has been made to calculate the groundwater vulnerability index of the study area for the aptness of groundwater resource for drinking.

II. THE STUDY AREA

The study area is Kingsley Ozumba Mbadiwe University Ideato and environs, defined by latitude 05°49.14'N to 05°50.64'N and longitude 07°4.02'E to 07°5.76′E. It is situated in the rainforest belt of Nigeria, with lush vegetation and dense forests. The area is predominantly a rural area used for farming, with crops like yams, cassava, maize, and palm trees being commonly cultivated. Some major communities within the study area include: Ogboko, Umuchima, Urualla, Obiohia and Ogume. The study area borders the Okigwe and Oru East LGAs to the east, Orlu LGA to the west, Nkwerre and Nwangele LGAs to the south. The area can be accessed with tarred and untarred roads, with high and low topography observed across it.

The study area is not well drained. The Orashi river flows along the boundary between Orlu LGA and the study area. On the Eastern part there are few tributaries of the rivers that drain the adjacent Local Government areas of Okigwe and Omuma which flow into the Imo River [1].

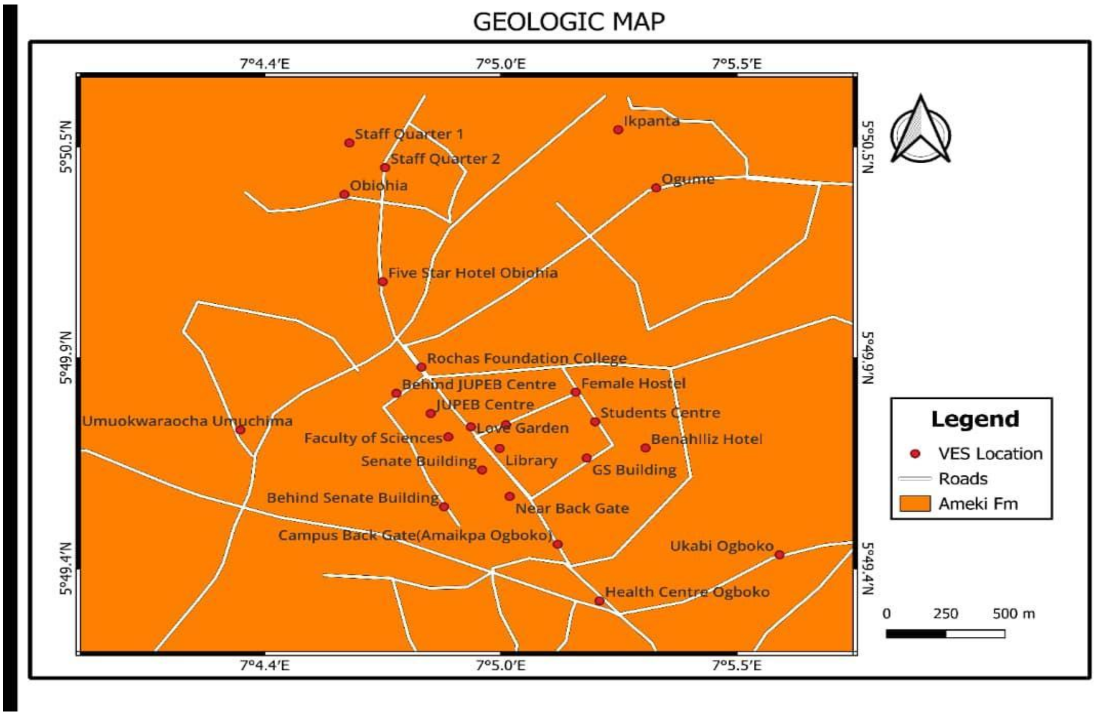

Figure 1: Accessibility map of the study area

III. GEOLOGY OF THE STUDY AREA

The regional geology of the study area is that of the Imo River basin (Figure 2). It is located in the southeastern Nigeria. The Imo River basin is situated within the Niger Delta basin, a sedimentary basin that covers much of southern Nigeria. The Imo River basin is characterized by six major stratigraphic units: The Benin Formation, the Ogwashi- Asaba Formation, the Bende-Ameki Formation, the Imo Shale group, Nsukua Formation and Ajali Sandstone Formation. The geological formation of the study area is Ameki Formation and it overlies the impervious Imo Shale group. The Ameki Formation is a sedimentary sequence of rocks deposited during the Paleocene to Eocene age, approximately 65-55 million years ago. The Formation consists of alternating layers of sand/sandstone, shale and clay. The Formation is estimated to be around 300-400 meters thick and was deposited in a shallow marine to coastal environment. The Ameki Formation contains fossils of marine organisms, such as plankton, benthic foraminifera, and mollusks. The formation’s sand and sandstone layers can act as aquifers, providing a source of groundwater.

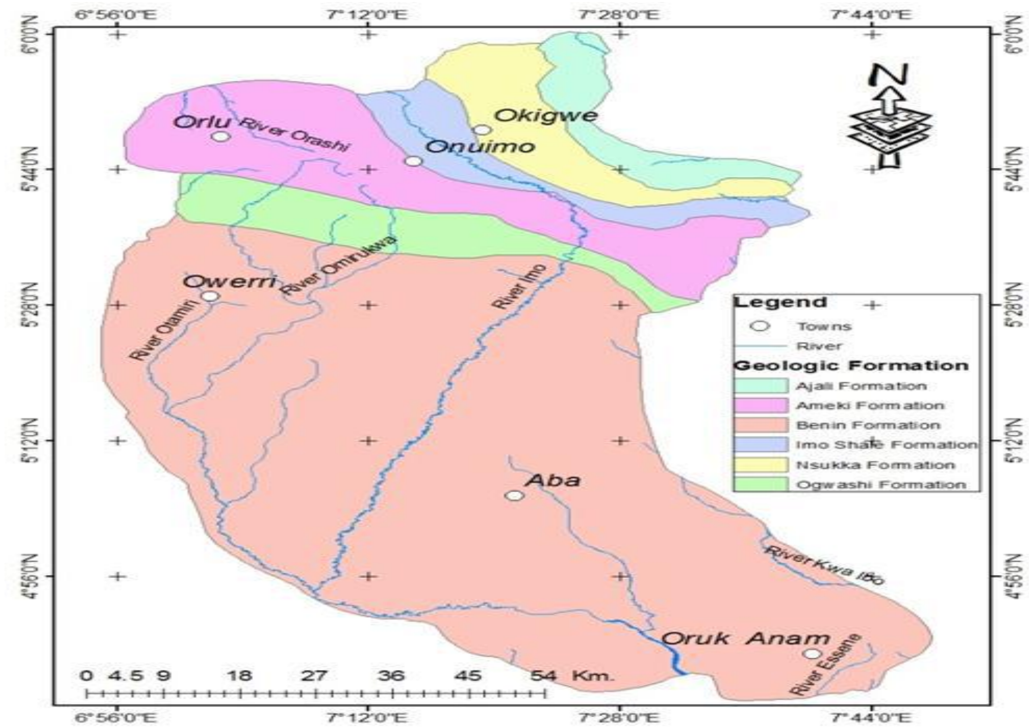

Figure 2: Geology map of Imo River basin [2]

IV. METHODOLOGY

The DRASTIC model has been the most commonly used aquifer sensitivity assessment method [3]. The model was developed by the US Environmental Protection Agency (EPA) to evaluate groundwater pollution potential for the entire United States [4]. This model is based on the concept of the hydrogeological setting that is defined as a composite description of all the major geologic and hydrogeologic factors that affect and control groundwater movement into, through and out of an area [4]. The acronym DRASTIC corresponds to the initials of the seven parameters used in the model which are: **depth of water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity**. Each of the seven (DRASTIC) parameters is mapped and classified into ranges or into significant media types which has an impact on pollution potential. Each factor or parameter is assigned a subjective rating which vary from 1 to 10 based on their relative effect on the aquifer vulnerability. Weight multipliers are then used for each parameter to balance and enhance its importance. Every parameter in the model has a fixed weight indicating the relative influence of the parameter in transporting contaminants to the groundwater. The parameter ratings are variable which allow the user to calibrate the model to suit a given region [5]. The final vulnerability map is based on the DRASTIC Index (DI) which is computed as the weighted sum overlay of the seven parameters using the following equation:

DRASTIC INDEX= $\mathbf{D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w}$

Where D, R, A, S, T, I, C are the seven parameters and the subscripts, r and w are the corresponding ratings and weights respectively. The Tables 1 to 7 show the weights and ratings assigned to the various DRASTIC parameters [4]. Tables 8 shows the qualitative risk categories of low, moderate, high and very high vulnerability respectively [6].

Table 1: Dept to Water Table (D)

Factor weight = 5	
Depth (ft)	Rating
100+	1
75 - 100	2
50 - 75	3
30 - 50	5
15 - 30	7
5 - 15	9
0 - 5	10

T able 2: Net Recharge (R)

Factor weight = 4	
Recharge (inches)	Rating
0 - 2	1
2 - 4	2
4 - 7	6
7 - 10	8
>10	9

Figure 3: Aquifer Media (A)

Factor weight = 3	
Aquifer material	Rating
Shale	1
Till	3
Silt	3
Schist	4
Sandstone	5
Limestone	6
Green rocks	6
Sand	8
Sand and gravel	9
Gravel	10

Figure 4: Soil Media (S)

Factor weight = 2	
Soil type	Rating
Clay/organic soil	1
Loamy clay	4
Clayey loam	5
Loam	7
Sandy loam	8
Loamy sand	9
Sand/gravel	10

Figure 5: Topography (T)

Factor weight = 1	
Slope (%)	Rating
>18	1
16 - 18	2
14 - 16	3
12 - 14	4
10 - 12	5
8 - 10	6
6 - 8	7
4 - 6	8
2 - 4	9
0 - 2	10

Figure 6: Impact of vadoze zone (I)

Factor weight = 5	
Unsaturated material	Rating
Clay	1
Shale	2
Silt	3
Schist	4
Till	4
Green rocks	5
Sandstone	5
Limestone	6
Sand	8
Sand and gravel	9
Gravel	10

Figure 7: Hydraulic conductivity (C)

Factor weight = 3	
Hydraulic conductivity (gpd/ft^2)	Rating
1 - 100	1
100 - 300	2
300 - 700	4
700 - 1000	6
1000 - 2000	8

Figure 8 : DRASTIC Index ranges from qualitative risk categories [6]

	DRASTIC qualitative category			
	Low	Moderate	High	Very high
Drastic Index (DI)	1 - 100	101 - 140	141 - 200	>200

Twenty five vertical electrical sounding results along side the geology of the study area were used to determine the DRASTIC parameters. The depth to water table is the distance from the ground to the water table. It represents the thickness of material through which infiltrating water must travel before reaching the aquifer-saturated zone. The deeper the table water, the smaller the assigned rating. Net recharge is the amount of water per unit area that penetrates the ground and reaches the water table. The greater the recharge rate, the greater the potential for groundwater pollution. The net recharge was taken to be about 12% of the average annual rainfall [6]. The annual rainfall for Ideato area is 2526.2mm which when converted to inches is 99.53in. The 12% of this is 11.94in. This was assumed as the recharge rate for all the locations in the study area. Aquifer media refers to the potential area for water storage. The contaminant attenuation of aquifer depends on the amount and sorting of fine grains. In general, the larger the grain size, the higher the permeability and lower the attenuation capacity; consequently the greater the pollution potential. So coarse media were assigned a high rating value compared to fine media. The soil media represents the uppermost and weathered part of the ground. The characteristics of soil influence the amount of recharge infiltrating the ground surface, the amount of potential dispersion, the purifying process of contaminants, etc. Coarse soil media have high rating in comparison to fine soil media. Topography refers to the slope or steepness of the land surface. It dictates whether the runoff will remain on the surface to allow contaminant percolation to the saturated zone. The study area was found to be relatively flat with topography ranging from 0-2%. The vadose zone is defined as the zone above the water table which is unsaturated or discontinuously saturated. The impact of the vadose zone was obtained by using the lithological description or strata description resulting from the VES data analysis. Aquifer hydraulic conductivity is the ability of the aquifer to transmit water. Hydraulic conductivity controls the rate at which groundwater flow under a given gradient and hence contaminant migration and dispersion. In this work a conversion factor for hydraulic conductivity of 1m/day to 118.27gpd/ft^2 was used in calculating hydraulic conductivity.

V. ESTIMATION OF AQUIFER PARAMETERS FROM VES

VES data obtained for the study area were used to calculate the aquifer parameters to enable evaluation of the groundwater potential of the study area. Using equations 1, 2, and 3 the Dar-Zurrouk parameters of transverse resistance and longitudinal conductance, and aquifer hydraulic conductivity and transmissivity were computed.

The Dar-zarrouk parameters are obtained using Equations 1 and 2

$$R = h\rho \qquad (1)$$

$$L = h/\rho \qquad (2)$$

Where, R = transverse resistance, h = aquifer aquifer thickness, ρ = aquifer resistivity, and L = longitudinal conductance

The aquifer hydraulic conductivity, K and transmiisivity, T are obtained using Equation 3

$$T = K\sigma R = KL/\sigma = Kh \qquad (3)$$

In areas of similar geologic setting and water quality, the product Kσ remains fairly constant [7, 8, 9]. Thus knowing the K values for existing boreholes and σ from VES interpretation for the aquifer at borehole locations, the determination of transrnissivity and its variations from place to place is made possible, including those without boreholes.

VI. RESULTS AND DISCUSSION

The aquifer parameters for the study area calculated from VES results are shown in Table 9. With hydraulic conductivity of 4.06m/day obtained from the pumping test analysis of the existing borehole in a nearby town, electrical conductivity and transverse resistance (Dar- Zarrouk parametres) obtained from sounding results, the transmissivity of the aquiferous zone was calculated.

Table 9: Summary results of the aquifer parameters in the study area

VES NO	Aquifer Resistivity (Ωm)	Depth to Aquifer Table (m)	Aquifer Thickness (m)	Aquifer Conductivity (Ωm)$^{-1}$	Aquifer Transverse Resistance	Aquifer Longitudinal Conductance	Diagnostic Parameter Kσ	Estimated Hydraulic Conductivity (m/day)	Estimated Transmissivity (m^2/day)
1	211460	94.5	115.5	4.72903E-06	24423630	0.000546	0.0000192	4.060032	468.93
2	11740	82.7	127.3	8.51789E-05	1494502	0.010843	0.0003458	4.059692	516.80
3	6235	102	108	1.60385E-04	673380	0.017322	0.0006512	4.060232	438.50
4	1148	70.7	139.3	8.7108E-04	1599160	0.121341	0.0035366	4.060017	565.56
5	130186	65.9	144.1	7.68132E-06	18759803	0.001107	0.0000312	4.061803	585.31
6	273502	54.6	155.4	3.65628E-06	42502211	0.000568	0.0000148	4.047830	629.03
7	15456	41.4	168.6	6.46998E-05	2605882	0.010908	0.0002627	4.060291	684.57

8	98012	94	116	1.02028E-05	11369392	0.001184	0.0000414	4.057697	470.69
9	77843	87	123	1.28464E-05	9576689	0.001580	0.0000522	4.063404	499.80
10	191647	89.4	120.6	5.21793E-06	23112628	0.000629	0.0000212	4.062916	489.99
11	145000	63	147	6.89655E-06	21315000	0.001014	0.0000280	4.060000	596.82
12	91912	109	101	1.088E-05	9283112	0.001099	0.0000442	4.062510	410.31
13	450000	108	102	2.22222E-06	45900000	0.000227	0.0000090	4.050000	413.10
14	2109	87	123	4.74158E-04	259407	0.058321	0.0019251	4.060036	499.38
15	15764	81.6	128.4	6.34357E-05	2024098	0.008145	0.0002575	4.059230	521.21
16	389540	99.7	110.3	2.56713E-06	42966262	0.000283	0.0000104	4.051216	446.85
17	9954	91	119	1.00462E-04	1184526	0.011955	0.0004079	4.060237	483.17
18	390	6.5	4.7	2.56410E-03	1833	0.012051	0.0104102	4.059978	19.08
19	2370	21.5	49.6	4.21585E-04	117651	0.020928	0.0017116	4.056492	201.20
20	1674	76.6	133.4	5.97372E-04	223312	0.079689	0.0024253	4.059952	541.60
21	222701	91	119	4.49033E-06	26501419	0.000534	0.0000182	4.053158	482.33
22	36446	91	119	2.74379E-05	4337074	0.003265	0.0001114	4.060084	483.15
23	404656	76	134	2.47123E-06	54223904	0.000331	0.0000100	4.046560	542.24
24	44747	86.1	88.9	2.23479E-05	3978008	0.001987	0.0000907	4.058553	360.81
25	14750	41.9	83	6.77966E-05	122425	0.005627	0.0002753	4.060675	337.04

VII. DRASTIC INDEX

The deduced DRASTIC parameters were used to compute the DRASTIC Index (DI) at the various VES points and these are given in Table 10. This was then used to generate the groundwater vulnerability map for the study area (Figure 3). The map shows that the locations Rochas Foundation College, Umuokwaraonure Ogboko and Staff Quarters 2 are areas of high vulnerability to pollution and the locations Library and JUPEB Center KOMU are areas of low vulnerability to pollution. The rest of the locations within the study area have moderate vulnerability. The high vulnerability implies that the area has hydro-geological factors that make it conductive to pollution, hence the aquifer is more susceptible to contamination. The pollutants from the surface such as agricultural chemicals, domestic waste and stormwater runoff can easily infiltrate the soil and reach the aquifer, posing a risk to groundwater quality. It is not a function of population. Areas with low vulnerability may be attributed to deep water tables, which imply that the aquifers are at low risk of contamination (better protected) from surface activities and natural processes. The integrated vulnerability model however shows the high risk imposed on the areas with moderate and high vulnerability rates, which suggests that the aquifer of the study area is at a moderate to high risk of contamination, and measures should be taken to protect it, such as implementing best management practices for land use, monitoring groundwater quality, conducting regular vulnerability assessments and developing protection and remediation strategies.

Table 10: Calculated DRASTIC Index for the study area

VES NO	Location	Northings	Eastings	D		R		A		S		T		I		C		DI	Classification
				w	r	w	r	w	r	w	r	w	r	w	r	w	r		
1	Senate Building KOMU	5.82721	7.08228	5	2	4	9	3	5	2	9	1	10	5	5	3	4	**126**	**Moderate**
2	Faculty of Science KOMU	5.82862	7.08100	5	2	4	9	3	8	2	9	1	10	5	5	3	4	**135**	**Moderate**
3	Library KOMU	5.82812	7.08295	5	1	4	9	3	8	2	1	1	10	5	1	3	4	**94**	**Low**
4	Female Hotel KOMU	5.83052	7.08585	5	2	4	9	3	8	2	9	1	10	5	5	3	4	**135**	**Moderate**
5	Students Center KOMU	5.82927	7.08660	5	3	4	9	3	5	2	1	1	10	5	8	3	4	**130**	**Moderate**
6	Back of Senate Building	5.82563	7.08083	5	3	4	9	3	5	2	1	1	10	5	5	3	4	**115**	**Moderate**
7	University Backgate (Amaikpa Ogboko)	5.74070	7.08517	5	5	4	9	3	5	2	1	1	10	5	5	3	4	**115**	**Moderate**
8	Beside Stadium KOMU	5.82162	7.08677	5	2	4	9	3	5	2	1	1	10	5	5	3	4	**110**	**Moderate**
9	Health Center Ogboko	5.82359	7.09363	5	2	4	9	3	5	2	9	1	10	5	5	3	4	**126**	**Moderate**
10	G.S. Building KOMU	5.82772	7.08628	5	2	4	9	3	5	2	9	1	10	5	5	3	4	**126**	**Moderate**
11	Love Garden	5.82905	7.08186	5	3	4	9	3	8	2	1	1	10	5	8	3	4	**139**	**Moderate**
12	JUPEB Center KOMU	5.82962	7.08033	5	1	4	9	3	5	2	1	1	10	5	5	3	4	**108**	**Moderate**
13	Medical Center KOMU	5.82608	7.08334	5	1	4	9	3	5	2	1	1	10	5	5	3	4	**105**	**Moderate**
14	Benaillz Hotel Ogboko	5.82615	7.08852	5	2	4	9	3	8	2	9	1	10	5	5	3	4	**135**	**Moderate**
15	Umuduruanyanwu Ogboko	5.83897	7.07695	5	2	4	9	3	8	2	9	1	10	5	2	3	4	**120**	**Moderate**
16	Rochas Foundation College Ogboko	5.82771	7.08290	5	2	4	9	3	5	2	9	1	10	5	8	3	4	**141**	**High**
17	Ikpanta Urualla	5.84915	7.08425	5	2	4	9	3	8	2	1	1	10	5	8	3	4	**134**	**Moderate**
18	Ogume	5.80798	7.06822	5	9	4	9	3	1	2	9	1	10	5	2	3	4	**134**	**Moderate**
19	Umuokwaraonure Ogboko	5.81593	7.08700	5	7	4	9	3	8	2	1	1	10	5	5	3	4	**144**	**High**
20	Ukabi Ogboko	5.82359	7.09363	5	2	4	9	3	8	2	10	1	10	5	1	3	4	**117**	**Moderate**
21	Staff Quarters 1 KOMU	5.84117	7.07723	5	2	4	9	3	8	2	9	1	10	5	1	3	4	**115**	**Moderate**
22	Staff Quarters 2 KOMU	5.84012	7.07859	5	2	4	9	3	8	2	10	1	10	5	8	3	4	**152**	**High**
23	Behind JUPEB KOMU	5.83525	7.07850	5	2	4	9	3	5	2	1	1	10	5	1	3	4	**90**	**Low**
24	5 Star Hotel Ogboko	5.83048	7.07902	5	2	4	9	3	5	2	9	1	10	5	5	3	4	**126**	**Moderate**
25	Umuokwaraocha Umuchima	5.82892	7.07307	5	5	4	9	3	5	2	10	1	10	5	1	3	4	**123**	**Moderate**

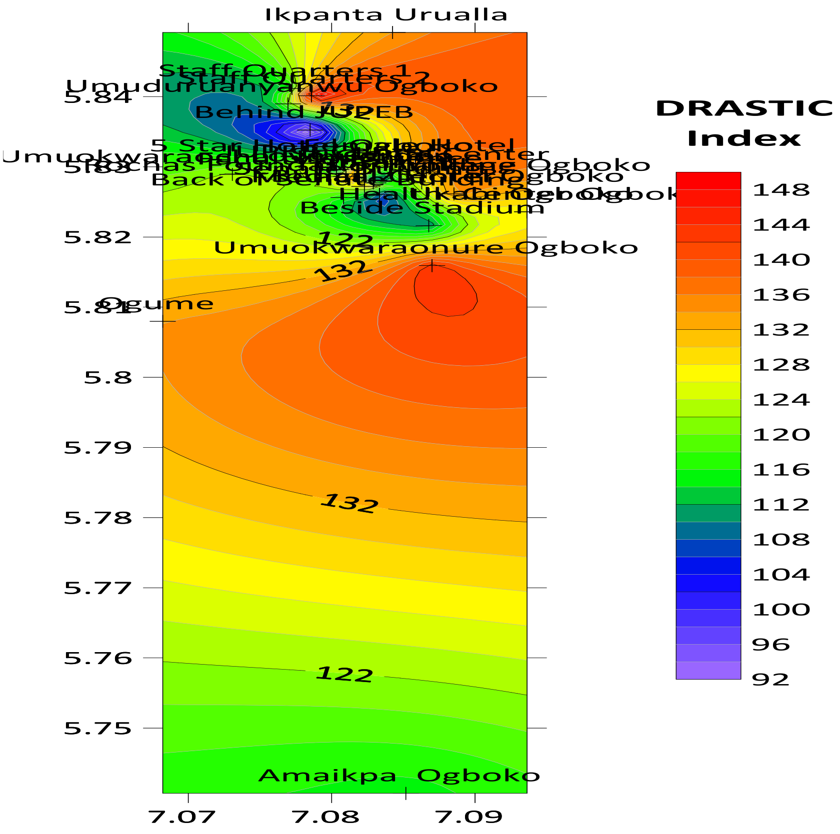

Figure 3: Groundwater vulnerability map of the study area

VIII. CONCLUSION

Twenty five soundings were probed using the Schlumberger array to obtain the DRASTIC parameter used to compute the DRASTIC Index at the various VES points in the study area. The results of the study showed that most of the locations in the area are characterized with moderate vulnerability to pollution while Rochas Foundation College, Umuokwaraonure Ogboko and Staff Quarters 2 are characterized with high vulnerability to pollution, which implies that the aquifer is at a moderate to high risk of contamination. Contaminants could migrate to the water table with relative ease due to the various hydrogeological factors that make it susceptible to pollution. Library and Behind JUPEB KOMU are areas of low vulnerability. So the aquifer is at a low risk of contamination and better protected from surface activities and natural processes.

The outcomes obtained from the study will be helpful in identifying high-risk areas, prioritizing protection and management efforts, developing targeted strategies for pollution prevention and remediation and ensuring sustainable groundwater resource management.

Disclosure statement

No potential conflict of interest was reported by the authors

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