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DRASTIC Index Mapping for Identifying Areas of High Aquifer Pollution Risk in a Mechanic Village: A Case Study of Reclaimed Nekede Mechanic Village Owerri, Imo State Nigeria

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ABSTRACT

The DRASTIC index mapping was used to investigate areas of high aquifer pollution risk in Reclaimed Nekede Mechanic Village Owerri, Nigeria. A total of six vertical electrical 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 map the groundwater vulnerability of the study area. The mapping shows that the location Near Otamiri River is an area of low vulnerability to pollution and the locations Along Church Road and Erosion Site are areas of moderate vulnerability to pollution. The rest of the locations within the study area have high vulnerability. The study concluded that the groundwater reserve is at a high risk of contamination due to the disposition of the hydrogeological environment of the area.

Keywords:
Aquifer,
Vulnerability,
Pollution,
DRASTIC,
VES.

INTRODUCTION

Water is a vital component of our planet, and its importance cannot be overstated (Nwaemene & Agbodike, 2024a). It is a clear, colourless, and odorless liquid that is essential for life. Water has unique chemical properties due to its polarity and hydrogen bonds which means it is able to dissolve, absorb, or suspend many different compounds (WHO, 2007). Thus, in nature, water is not pure as it acquires contaminants from its surrounding and those arising from humans and animals as well as other biological activities (Mendie, 2005). Water pollution occurs when contaminants or pollutants alter the physical, chemical, or biological properties of water, making it harmful to humans, animals, and the environment. Surface water in form of stream, rivers and ocean has long been polluted with human wastes and other domestic waste products all over the world while improper waste management, regulations and conservation practices increase pollution load in groundwater also. Therefore, monitoring of groundwater quality is essential in any population area as it affects it fittingness for household, industrial and agriculture use.

A mechanic village is an area or community where a high concentration of automotive repair shops, garages, and related businesses are located. These villages often have a large number of mechanics, technicians, and other workers involve in vehicle maintenance, repair, and serving. They indiscriminately drop solid and liquid wastes on the bare soil with no regard to possible groundwater pollution. The need to protect groundwater from pollution arising from such population area is an urgent task that calls for immediate attention. This is due to the fact that once contaminated, it becomes difficult to restore it back to its natural usable state (Nebo *et al.*, 2018).

Results obtained from the study area showed that over 1.4 million liters of spent engine oil was produced annually in the reclaimed village. About 60% of the mechanics disposed spent engine oil on the soil, within their immediate environment. Others used it for other purposes, such as pest control, sharpening of blades and reuse in heavy trucks among others. Another 88.3% of mechanics were ignorant of environmental impact of inappropriate spent engine oil disposal. It can be concluded that there was poor spent oil disposal attitudes and environmental practices among the automobile mechanics and such a practice may have led to serious contamination of the groundwater reserve in the reclaimed village. In the current study, an effort has been made to identify areas of high aquifer pollution risk in reclaimed Nekede mechanic village using DRASTIC index mapping.

MATERIALS AND METHODS

Description of the Study Area

The reclaimed mechanic village sited in Nekede, Owerri West Local Government of Imo State, provides a dramatic example of environmental impact due to anthropogenic activities. The automobile mechanic village site was set up in the year 1983 for the purpose of repairing and maintaining automobile vehicles used in the transportation of humans, animals and goods. The village was sited in an agricultural community, approximately one kilometer distance from Owerri, the major state capital city of Imo State. The agricultural land has humus soil showing a good area for agricultural practice.

The reclaimed village falls under the geographical coordinates of longitude 7.04 - 7.06˚E and latitude 5.24 - 5.27˚N. It lies on an area of flat agricultural land converted to mechanic workshops, shops and homes, where some of the mechanics and their families lived. This made the area very busy with human activities. The topography is relatively a level ground but towards the Otamiri River side that borders it to the West, it is strongly degraded. Its landscape has been sculpted by erosion forming deep gullies with elevations ranging between 71.5 and 44.1 meters in the North-West and central section and to about 65 meters on the East and South. The climate falls under type Aw in the Koppen-Geiger classification of wet and dry climate and zone B of the Nigeria's eco-climatologically zones (Ofomata, 1976). Given the close relationship between climate and vegetation, the location of the study area coincides with the rain-forest belt. The study area also showed a moderate to high population density, with average population density being about 104 people per 1km. This population density could be as a result of the activities of these labor force and their relatives (NPC, 2006).

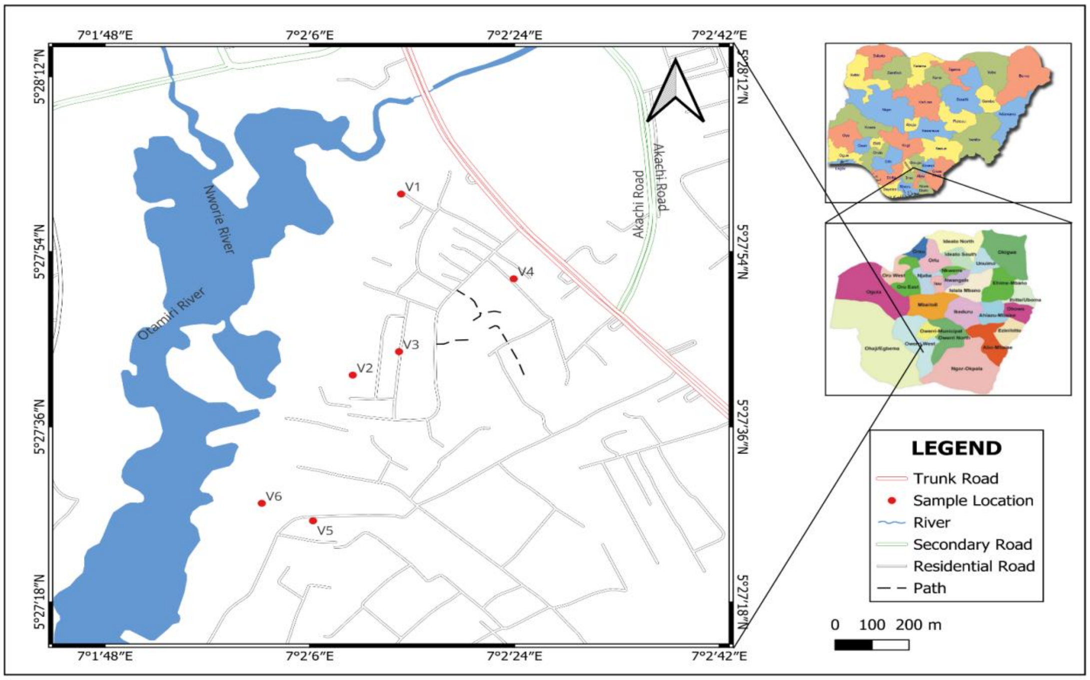


Figure 1: Location map of the study area

Geologic Setting of the Study area

The study area is underlain by the Benin Formation which is known as the 'coastal plain-sands' (Figure 2). It consists mainly of sands, sandstone and gravel with clays occuring in lenses. The sands and sandstones are coarse to fine partly unconsolidated with thickness ranging from 0 - 2100 m (Avbovho, 1978). The Benin Formation is composed mainly of high resistant fresh water-bearing continental sands and gravels with clay and shale intercalations (Onyeagocha, 1980). The environment of deposition is partly lagoonal and fluvio lacustrine/deltaic (Reyment, 1965). The formation which dips south westward starts as a thin edge layer at its contact with the Ogwasi-Asaba Formation in the northern part of the area, and thickness southwards to about 100m in the area (Ibe *et al.*, 1992). The sandy unit of which constitutes about 95% of the rock in the area is composed of over 96% of quartz (Onyeagocha, 1980).

The stratigraphic succession of rocks in the study area consists of Nsukka Formation, being the oldest formation and followed by Imo-Shale, Ameki Formation, Ogwashi-Asaba Formation while the youngest is the Benin Formation (Uma and Egboka, 1985). The coastal plain sand belonging to the Benin Formation extends to a considerable depth in the area and with a good hydraulic property for groundwater development (Amadi, 2009). The occurrence of groundwater is abundant in this Formation with a static water level ranging from 8-65 meters, which depends on the location and the time of the year. The Benin Formation is a good aquifer with an average annual replenishment of about 2.5 billion cubic meters per year (Onyeagocha, 1980).

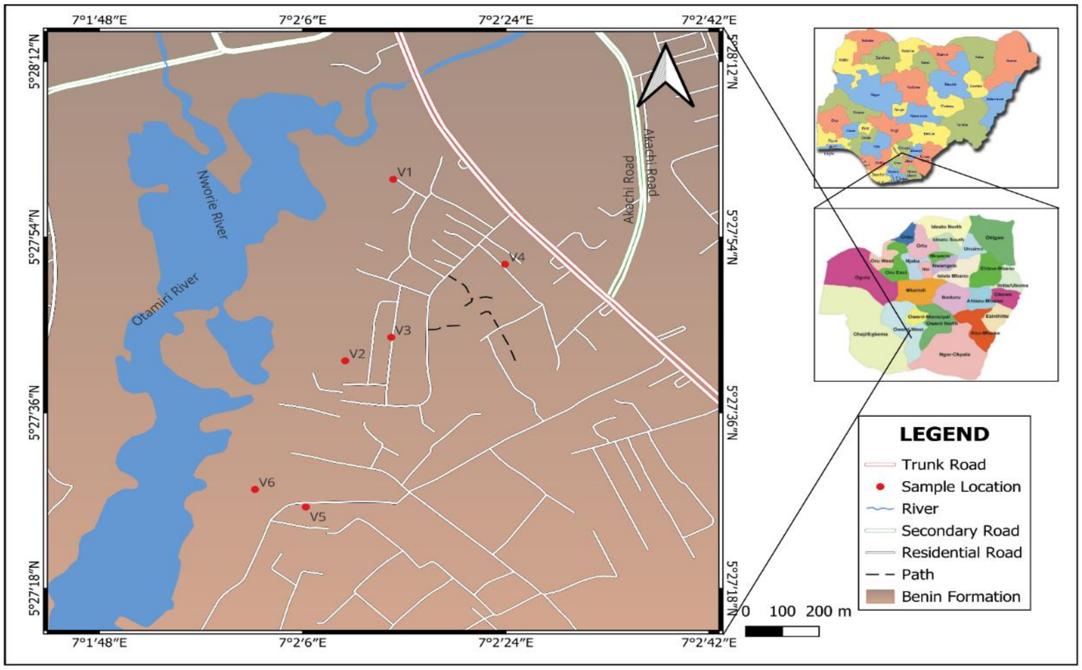


Figure 2: Geology map of the study area

Method

DRASTIC mapping is a technique used to visualize and communicate the results of a DRASTIC vulnerability assessment. It involves creating a map that shows the spatial distribution of vulnerability scores, allowing for easy identification of areas with high, moderate, or low vulnerability to groundwater contamination. The DRASTIC vulnerability assessment is a widely used method for assessing groundwater vulnerability to contamination. It was developed by the US Environmental Protection Agency in 1980s (USEPA, 1985). Groundwater vulnerability assessment evaluates the susceptibility of an aquifer or groundwater system to contamination or degradation. It considers factors such as hydrogeological characteristics, land use and land cover, climate and weather patterns, human activities and infrastructure, and geological and soil properties. DRASTIC is an acronym which stands for: depth to water table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and hydraulic conductivity (C).

The DRASTIC model assigns numerical values to each factor, ranging from 1 (low vulnerability) to 5 (high vulnerability). Each factor or parameter is assigned a subjective rating which vary from 1 to 10 based on their relative effect on the aquifer vulnerability (Nwaemene and Agbodike, 2024b). The scores are then combined to produce a final vulnerability index using the following equation:

DRASTIC INDEX= $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$

Where D, R, A, S, T, I, C are the seven factors or 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 (Aller *et al.,* 1987). Tables 8 shows the qualitative risk categories of low, moderate, high and very high vulnerability respectively (after Navulur *et al.,* 1996). Higher scores indicate greater vulnerability to contamination.

The DRASTIC scores are visualized on a map to better understand the spatial distribution of groundwater vulnerability and identify areas that require special protection or management to prevent groundwater contamination.

Table 1: Depth 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

Table 2: Net Recharge (R)

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

Table 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

Table 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

Table 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

Table 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

Table 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

Table 8 : DRASTIC Index ranges from qualitative risk categories (Navulur *et al.*, 1996)

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

Six VES were conducted at different points within the study area using the Schlumberger electrode configuration and the results were used to determine the model DRASTIC parameters. The geological mapping of the study area was also carried out to evaluate the hydrological and hydrogeological parameters of the area. This involved the use of geologic map, topographic map and physical investigation to acquire hydrogeological information of the area and description of the rock succession.

The depth to water table is the vertical distance from the land surface to the water table, which is the top of the saturated zone where the rock is completely saturated with water. Shallower water tables are more vulnerable. The depth to water table from the VES data was converted to feet using the conversion factor of 1 meter (m) = 3.2808 feet (ft). Net recharge is the net amount of water that enters an aquifer over a specific period, taking into account all sources of recharge and discharge. Higher recharge rates increase vulnerability. The net recharge was taken to be about 12% of the average annual rainfall (Navulur *et al.*, 1996). The annual rainfall for Nekede area is 2250mm which when converted to inches is 88.60 inches. The 12% percent of this is 10.63 inches. This was assumed as the recharge rate for all the locations in the study area. Aquifer media refers to the potential area that stores and transmits significant amounts of water. More permeable rocks or soils increase vulnerability. The soil media represents the uppermost and weathered part of the ground (Nwaemene and Agbodike, 2024b). Less protective soils (low ability to attenuate or filter out contaminants) increase vulnerability. Topography refers to the description of the shape and features of the land surface. Steeper slopes can increase runoff and contamination. The study area was found to be relatively flat with topography ranging from 2% - 4%. The vadose zone is the layer of soil and rock above the water table where the pores are not fully saturated with water. Thicker vadose zones can reduce vulnerability. The impact of the vadose zone was obtained by using the lithological or strata description resulting from the VES data analysis. Hydraulic conductivity is the ability of the aquifer system to transmit water. Higher conductivity increases vulnerability. In this work, a conversion factor for hydraulic conductivity of 1 m/day to 118.27 gpd/ft^2 was used in calculating hydraulic conductivity.

Aquifer Characteristics from VES Data

Vertical electrical sounding (VES) data obtained for the study area were used to calculate the electrical and hydraulic parameters to enable evaluation of groundwater potential and variation of the area. The data were analyzed with the IPI2WIN software to delineate the subsurface layers such as their depths, thicknesses and the resistivity values, and the curve signature or type. From these, qualitative deduction of the aquifer electrical parameters of depth, thickness and resistivity were made for each VES. The Dar-Zarrouk parameters of longitudinal conductance and transverse resistance at each VES were obtained from the relations:

R = (1)

$S = h/\rho$ (2)

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

Niwas and Singhal (1981) showed the relationship between hydraulic parameters and electrical parameters in a porous medium as:

$T = K\sigma R = KS\rho = Kh$ (3)

Where, T is the transmissivity, K is the hydraulic conductivity, σ the aquifer conductivity, R the transverse resistance, S the longitudinal conductance, ρ the aquifer resistivity and h the aquifer thickness respectively.

According to Niwas and Singhal (1981), in areas of similar geologic setting and water quality, the product $K\sigma$ remains fairly constant. Thus, knowing the K values from existing boreholes and σ values extracted from the sounding interpretation data, the determination of the aquifer hydraulic conductivity and transmissivity for the entire area can be made possible, including those without boreholes.

The storativity of the aquifer system which is the volume of water that an aquifer releases or takes in per unit drop or rise in hydraulic head (water level) per unit area was estimated from the rule of thumb equation given by Lohman (1972) and Todd (1980) as:

$\text{Storativity} = 3 \times 10^{-6}\, b$ (4)

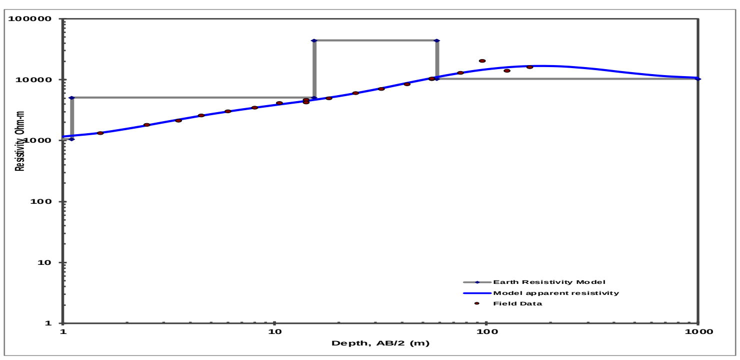
Where b is the saturated thickness of the aquifer

RESULTS AND DISCUSSION

Typical modelled VES results of the study area are shown in Figure 3. The aquifer parameters for the study area calculated from VES results are shown in Table 9. Hydraulic conductivity of 11.92 m/day obtained from the pumping test analysis of the existing borehole in a nearby town and Dar- Zarrouk parameters of electrical conductivity and transverse resistance obtained from sounding results were used to estimate the transmissivity of the aquiferous zone.

Number of Layers		4	
Layer NO	Thickness (m)	Depth (m)	ρ (Ω-m)
1	1.10	1.10	1050.00
2	14.30	15.40	5060.00
3	43.00	58.40	44300.00
4	-		10300.00
-	-		
-	-		
-	-		
-	-		
-	-		
-	-		

FIELD DATA	
AB/2 (m)	ρa (Ω–m)
1.5	1336.40
2.5	1806.20
3.5	2142.10
4.5	2564.80
6.0	3015.30
8.0	3466.00
10.5	4165.50
14.0	4668.50
14.0	4271.10
18.0	4922.40
24.0	6023.90
32.0	7082.40
42.0	8441.60
55.0	10167.00
55.0	10505.40
75.0	13083.50
95.0	20484.00
125.0	13938.60
160.0	16022.20



VES NUMBER: VES 1 DIRECTION LAYOUT: DATE: September 15, 2024

LOCATION: MECHANIC VILLAGE, NEKEDE OWERRI WEST LGA, IMO STATE

COORDINATES: N05°27.999 E7°02.234 ELEVATION : 80m

PROJECT: RESEARCH WORK

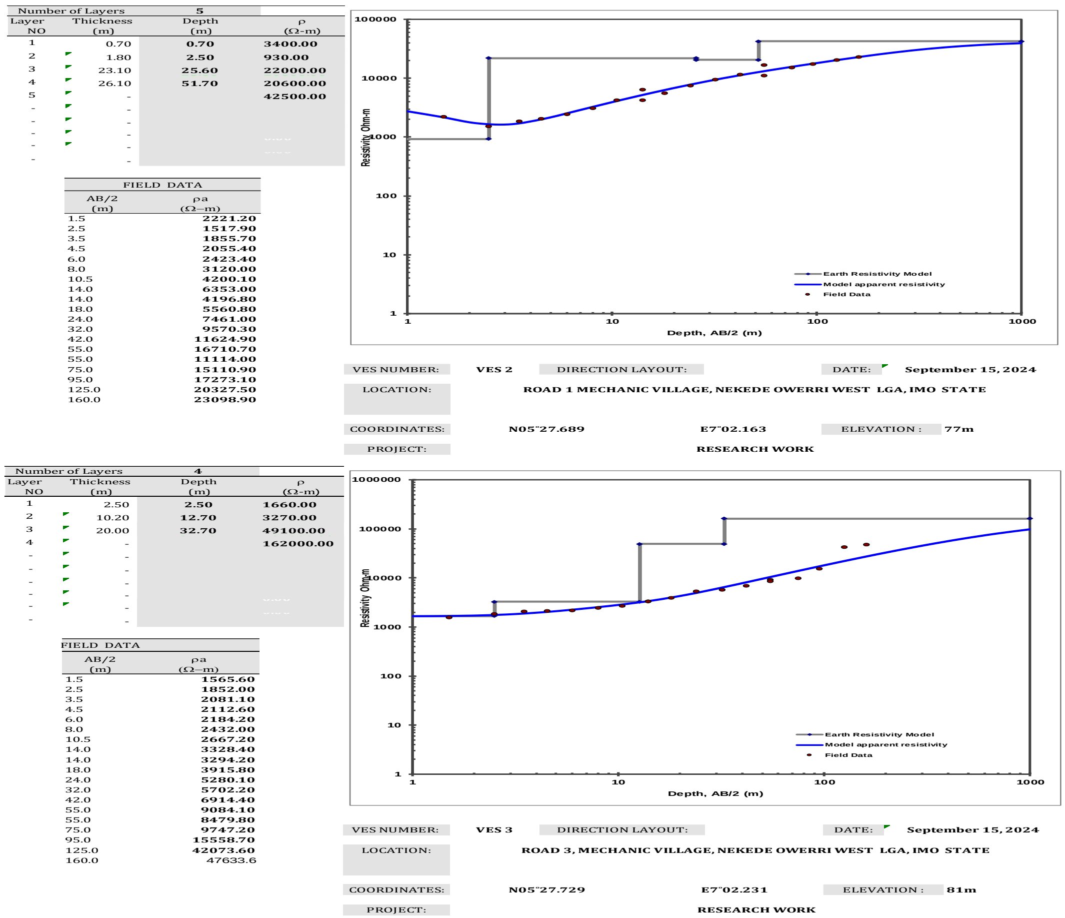


Figure 3: Representative inverse resistivity models of VES 1-3

The modelled VES results revealed that the study area is underlain by laterite, sands and gravel with some clay and sandy clay intermingled. The aquifer is delineated within the sand/gravel Formation. The study area is composed of three geoelectric layers which are: Topsoil, laterite/sand and gravel. The topsoil has resistivity values which range from 7.7 to 3400 Ωm and thickness that ranges from 0.4 to 2.5 m. It is composed of a mixture of sand, humus, and clay. The second layer is laterite in some and sand in most, with resistivity values ranging from 317 to 5060 Ωm and thickness ranging from 1.8 to 14.3 m. The laterite sometimes degrades into quartz sand. The third layer is the aquifer in the study area, its resistivity ranges from 1050 to 49100 Ωm. It is a composed of high resistivity sand and gravel with good water storage capacity and extends to a considerable depth in the area. The aquifer thickness ranges from 26.1 to 50.4 m. Below this thick aquifer is the basement complex which was not resolved in this study.

DRASTIC Mapping

The deduced DRASTIC parameters were used to compute the DRASTIC index at the various VES points and these are given in Table 10. This was then used to map the groundwater vulnerability of the study area (Figure 4). The DRASTIC mapping of the study area revealed that locations Along Church Road and Erosite Site are areas of moderate vulnerability to pollution and the location Near Otamiri River is an area of low vulnerability to pollution. The rest of the locations within the study area have high vulnerability to pollution. The high vulnerability may be attributed to shallow water tables, permeable soils and high recharge rates or precipitation. This implies increased risk of contamination. There is a greater likelihood of pollutants entering the groundwater system, leading to contaminated drinking water sources. Areas with moderate vulnerability to pollution have some risk of contamination, but mitigating factors present. There is possible pollution impacts, but less severe than high vulnerability areas. The area with low vulnerability is less susceptible to pollution or has a high resilience to pollution. This implies that it is better protected from surface activities and natural processes (Nwaemene & Agbodike, 2024b).

Table 9: Summary of aquifer parameters of the study area

VES NO	Aquifer Resistivity (Ωm)	Depth to water table (m)	Aquifer Thickness (m)	Aquifer Conductivity $(\Omega m)^{-1}$	Aquifer Transverse Resistance (Ωm^2)	Longitudinal Conductance (Ω)	Storativity	Diagnostic Parameter Kσ	Hydraulic Conductivity N & S Model (m/day)	Estimated Transmissivity (m^2/day)
1	44300	58.4	43.0	0.0000226	1904900	0.000971	0.000129	0.000269	11.9167	512.42
2	20600	51.7	26.1	0.0000485	537660	0.001267	0.000078	0.000578	11.9068	310.77
3	49100	32.7	20.0	0.0000204	982000	0.000407	0.000060	0.000243	11.9313	238.63
4	32000	55.3	50.4	0.0000313	1612800	0.001575	0.000151	0.000373	11.9360	601.57
5	1050	80.2	48.1	0.0009524	50505	0.045810	0.000144	0.011353	11.9207	573.39
6	5980	50.0	39.0	0.0001672	233220	0.006522	0.000117	0.001993	11.9181	464.81

Table 10: Deduced DRASTIC mapping of the study area

VES NO	Location	Latitude N (Degree)	Longitude E (Degree)	D		R		A		S		T		I		C		Index	Mapping
				w	r	w	r	w	r	w	R	w	r	w	r	w	r		
1	**Free Zone - Aba Road**	05˚27.999'	07˚02.234'	5	1	4	9	3	5	2	8	1	9	5	8	3	8	**145**	**High**
2	**Road 1**	05˚27.689'	07˚02.163'	5	1	4	9	3	8	2	8	1	9	5	8	3	8	**154**	**High**
3	**Road 3**	05˚27.729'	07˚02.231'	5	1	4	9	3	5	2	8	1	9	5	8	3	8	**145**	**High**
4	**Along Church Road**	05˚27.854'	07˚02.399'	5	1	4	9	3	5	2	8	1	9	5	2	3	8	**115**	**Moderate**
5	**Near Otamiri River**	05˚27.439'	07˚02.105'	5	1	4	9	3	3	2	1	1	9	5	1	3	8	**90**	**Low**
6	**Erosion Site**	05˚27.469'	07˚02.030'	5	1	4	9	3	8	2	1	1	9	5	8	3	8	**140**	**Moderate**

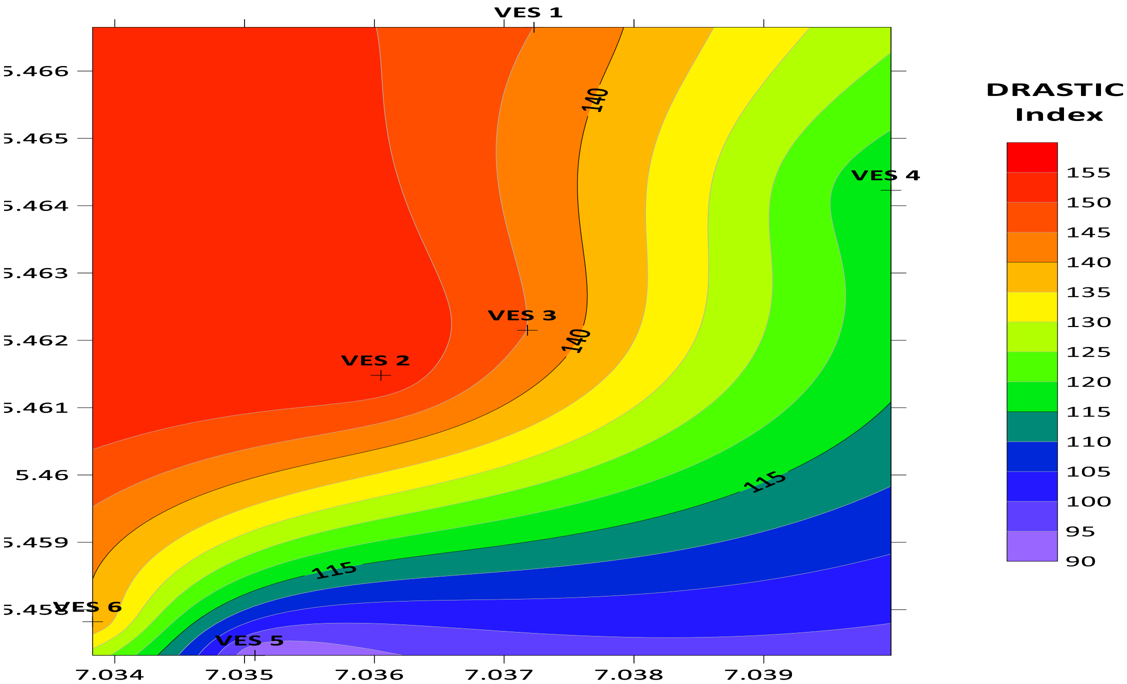


Figure 4: DRASTIC mapping of the study area

CONCLUSION

Six vertical electrical soundings were probed using the Schlumberger array to obtain the DRASTIC parameters used to compute the DRASTIC mapping of the study area. The DRASTIC mapping of the study area showed that locations Along Church Road and Erosion Site are areas of moderate (close to high) vulnerability to pollution. These areas have moderate potential for pollution impacts and health risks, especially for sensitive population. To manage moderate vulnerability, best management practices for pollution control should be implemented and regular monitoring of water quality should be carried out. Locations Free Zone - Aba Road, Road 1 and Road 3 have high vulnerability to pollution. Pollutants could migrate to the groundwater system with relative ease and contaminate the drinking water sources due to the various hydrogeological factors that make it very susceptible to pollution. Consequences of inaction include: long-term environmental damage, health problems and medical costs. To mitigate high vulnerability, implement pollution prevention measures, monitor water quality regularly, and enforce regulations and standards. Near Otamiri River is an area of low vulnerability to pollution. So, the aquifer is at a minimal risk of contamination. There is a reduced risk of environmental degradation and safe drinking water sources. Overall, it can be concluded that the study area is at a high risk of aquifer pollution. Therefore, this study recommends regular monitoring and reassessment, investment in remediation and cleanup efforts, education of stakeholders and promotion of best practices to ensure the protection of the groundwater system of the area.

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