Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v33(s).2024.252
Volume 33(S) 2024

Investigation of Aquifer Vulnerability under some Protective Measures in Ehime Mbano, South-Eastern Nigeria for Sustainable Groundwater Development

***[1]Ndubueze, D. N and [2]Igboekwe, M. U.**

[1]Department of physics, Kingsley Ozumba Mbadiwe University Ideato, Imo state Nigeria
[2]Michael Okpara University of Agriculture Umudike Umuahia Abia state, Nigeria

[*]Corresponding author's email: drdorisndubueze@gmail.com

ABSTRACT

This study focuses on assessing aquifer vulnerability to contamination in Ehime Mbano South-Eastern Nigeria by applying the DRASTIC model. The data was obtained using (VES) vertical electrical sounding technique by applying Schlumberger configurations with $^{AB}/_2$ = 400 m. The VES data were interpreted using state of the art soft wares e.g. IP12WIN and Surfer 12 to obtain the final model for each VES, groundwater vulnerability map was also developed while aquifer media was gotten by taking into account, the depth at which water was struck and correlating those depths with the lithological description of the VES results obtained. The hydraulic conductivity was calculated from apparent resistivity of the aquifer. However, the net recharge, soil media, and topography was obtained from research documentaries. Aquifer vulnerability assessment carried out revealed areas with high, low and moderate vulnerability based on the DRASTIC Index. Locations with high vulnerability rating of 126 -165 includes: Umuokiri Umunumo and Ikperejere. Locations with moderate vulnerability rating of 86-125 includes: Ikpem, Ikweii Nzerem while locations with low vulnerability rating of 70-85 includes: Umuokara Uzinomi and areas close to Umueze II. The findings of the study can be used to identify regions of contamination of groundwater in the study area.

Keywords:
Groundwater vulnerability,
Aquifer,
Contamination,
Sustainable,
DRASTIC model.

INTRODUCTION

Water as a massive forceful fluid form conveys with it occasionally toxins of fluctuating and unpredictable amounts thereby making quality groundwater availability be under severe threat due to anthropogenic causes. This has led to the contamination of ground and surface water. In Ehime Mbano for instance, there seem to be increased rate of water pollution or unhealthy groundwater drilled for consumption; water contamination are chiefly due to urban and agricultural activities. Such contaminated water when consumed gives rise to some diseases like cholera, diarrhea, dysentery, hepatitis A and typhoid fever (Nwachukwu *et al.*, 2010). In severe cases it can lead to fatalities with children and pregnant women being the most affected. This hampers their socio-economic development, stability and overall welfare of the community (Public Health Madison and Dane County, 2017). The Wisconsin Department of Natural Resources, Bureau of Drinking Water and Groundwater (2005) recommended that well water should be at least tested annually preferably at the end of raining season, and whenever a well is serviced including changing of submersible pump. Well water should also be tested whenever a change in taste, odor or color is noticed. In many parts of the world, groundwater vulnerability assessment is increasingly applied because it plays a very important role in making decision for proper groundwater management and protection. Aller *et al.* (1985); Aller, 1987), developed a standardized system for evaluating vulnerability of groundwater to contamination for the United State Environmental Protection Agency. The DRASTIC model was adopted for this research work. This DRASTIC model was used to develop the groundwater vulnerability map of the study area. The Point Count System Model (PCSM) known as DRASTIC, uses different seven parameters for the evaluation of groundwater vulnerability; and these parameters are: Depth to water table, Net recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and Hydraulic conductivity of the aquifer. The aim of this work is to investigate aquifer vulnerability under some protective measures in Ehime Mbano South eastern Nigeria for sustainable groundwater development.

Weights and Ratings for the Drastic Parameters

DRASTIC as an empirical groundwater model estimates groundwater contamination vulnerability of aquifer systems based on the hydrogeological settings of the area. A hydrogeological setting is defined as mappable unit with common hydrogeological characteristics (Engel *et al.*, 1996). The model employed a numerical ranking system that assigns relative weights to various parameters. Each DRASTIC factor was assigned a weight based on its relative significance in affecting pollution potential. The ratings range from 1 – 10 and weights from 1 – 5 as shown in the tables below. The final result for each hydrogeological setting is a numerical value, called DRASTIC Index. The DRASTIC Index [DI], is a measure of pollution potential, and is computed by the summation of the products of ratings and weights of each factor. The higher the value is, the more susceptible the area is to groundwater pollution. Thus,

$$DI = D_rD_w + R_rR_W + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \quad (1)$$

Where the subscripts r and w denote the rating and the weight of the factor being considered, respectively. The higher the value of DI the greater the vulnerability or relative pollution potential of the aquifer. Engel *et al.* (1996) converted the computed DRASTIC indices into qualitative risk categories of low, moderate, high and very high. This research tends to investigate aquifer vulnerability under some protective measures in Ehime Mbano South eastern Nigeria for sustainable groundwater development.

Location and Geology of the Study Area

The research area, Ehime Mbano, is located in the Anambra-Imo sedimentary basin in south-eastern Nigeria. Its latitude ranges from 5° 37N to 5° 46N, while its longitude ranges from 7° 14E to 7° 21E.

According to the geology of Ehime Mbano, the primary Formations in the study area are: the Benin Formation (–miocene – recent) (youngest), Ogwashi-Asaba Formation, Bende-Ameki Formation (Eocene), and Imo Shale Formation (Paleocene) (oldest) (Reyment 1965) (Fig. 1). The Benin Formation (Parkinson, 1907; http://www.sciencepub.net/rural) is the main water-bearing formation. This Formation is one of the present Tertiary Niger delta's subsurface stratigraphic components. It stretches from west to east over Nigeria's Niger delta region and beyond the country's current shore line in the south (Short and Stauble, 1978; Ehirim and Ofor, 2011). This Formation is coarse-grained, gravelly, locally fine-grained, poorly sorted, and sub-angular to well-rounded in shape, with lignite streaks and wool fragments. The Formation is a continental deposit of alluvial and upper coastal plain sands from the late Eocene to the recent. Overlying the Imo Shale Formation is the Bende-Ameki Formation, which makes up the majority of Eocene layers. A succession of highly fossiliferous grayish-green sandy-clay with calcareous concretions and white clay sandstones make up this Formation.

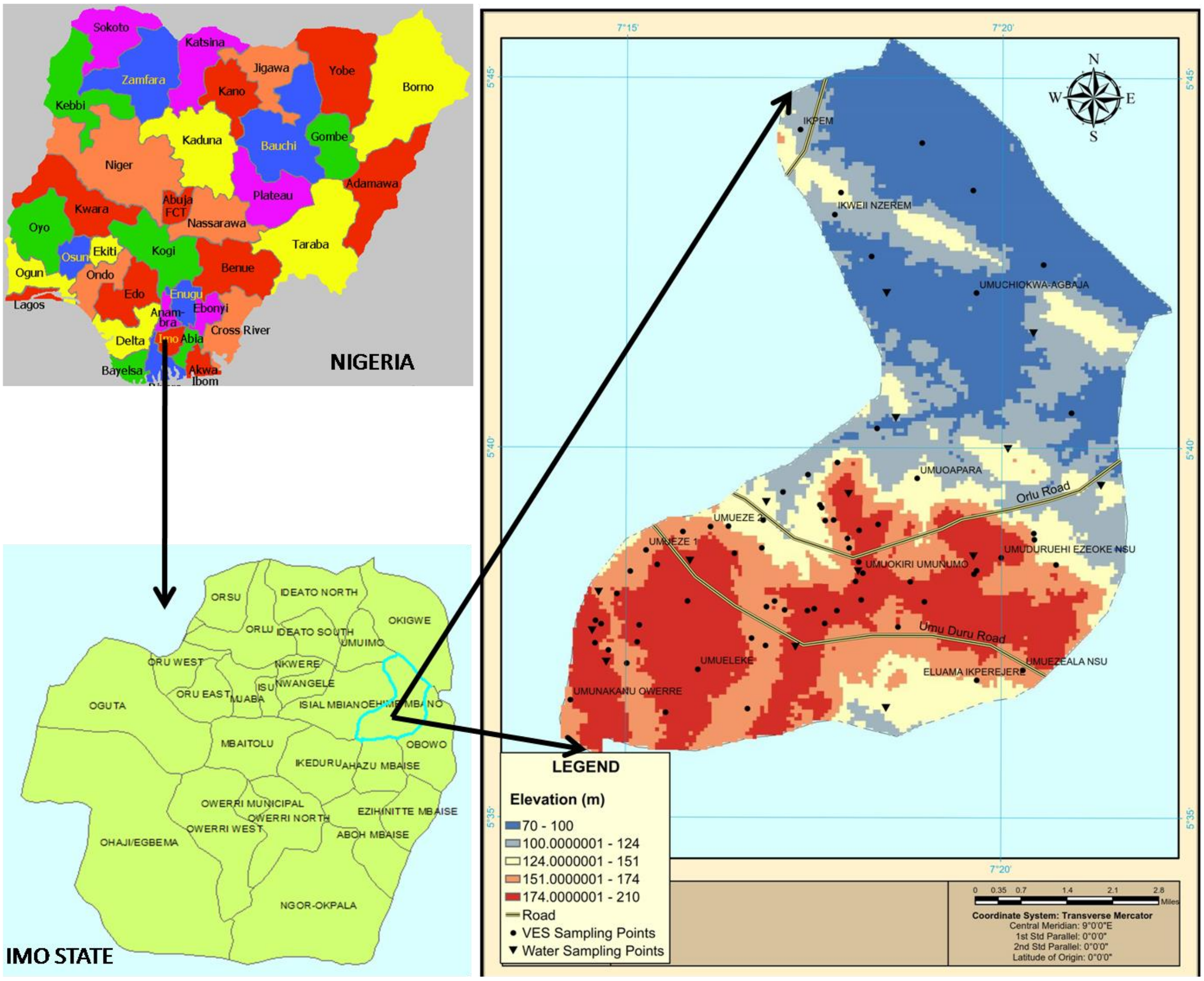

Figure 1: Location Map of the study area (Ehime Mbano)

MATERIALS AND METHODS

The two major phases of methodology in this study are:

Data collection (VES data) obtained using Schlumberger configuration and modelling applying DRASTIC method

Aller *et al.* (1985); Aller, (1987), developed a standardized system for evaluating vulnerability of groundwater to contamination for the United State Environmental Protection Agency. The DRASTIC model was adopted for this research work. This DRASTIC model was used to develop the groundwater vulnerability map of the study area. The Point Count System Model (PCSM) known as DRASTIC, uses different seven parameters for the evaluation of groundwater vulnerability; and these parameters are:

Depth to water table, Net recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and Hydraulic conductivity of the aquifer.

Depth to the water table

The depth to the water table is the distance from the ground to the water table. This determines the depth of material through which a contaminant must travel before reaching the aquifer. There is a greater chance for attenuation of force to occur as the depth to water increases because, deeper water levels imply longer travel distances.

Net recharge

Net recharge can be said to be a representation of the amount of water per unit area of land, which penetrates the land and reaches the water table. Recharge water is the means by which leaching and contaminants activities are transported vertically into the water table and horizontally or laterally within the aquifer zone. The greater the recharge rate, the greater the potential for groundwater to be polluted.

Aquifer media

Aquifer media represents the property that define the matrix like discharge and contaminations. The aquifer medium influences the amount of effective surface area of materials with which contaminants may come in contact. The larger the size of the particles of the grain, and the more the fractures or openings within the aquifer, the higher the permeability. Consequently, the rate of reducing the effect of the contaminants becomes lower. The aquifer media in question was gotten by taking into account, the depth at which water was struck and correlating those depths with the lithological description of the VES results obtained or even the strata description to identify the aquifer media.

Soil media

Soil media refers to the uppermost portion of the vadose zone characterized by significant biological activity. It was considered as the upper weathered zone of the earth, which averages a depth of one meter or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of contaminant to move vertically into the vadose zone.

Topography

Topography which is referred to as the variability of slope of the land surface helps to control the likelihood that a pollutant will run off or pool and remain on the surface in one area long enough to infiltrate.

Impact of the vadose zone

The vadose zone is defined as the zone above the water table that is unsaturated or even discontinuously saturated. This zone determines the attenuation characteristics of the material that is below any typical soil horizon and equally above the water table.

Hydraulic conductivity

Hydraulic conductivity means the ability or the capacity of the aquifer material to transmit water, when afterwards, controls the rate at which groundwater will flow under a given gradient or slope.

RESULTS AND DISCUSSION

Comparing the results of this work with DRASTIC index ranges for qualitative risk categories (After Engel *et al.*, 1996) as shown in tables 2 and 3 shows that the results fall within the acceptable range for low, high and moderate vulnerabilities.

Aquifer Vulnerability Ratings

The determination of the groundwater vulnerability index of the study area was done using the DRASTIC model as shown in Table 1 as derived from the relations:

D R A S T I C

RW rw Rw Rw rw rw Rw

Drastic Index (DI) =DrDw +RrRw +ArAw + SrSw + TrTw + IrIw + CrCw (2)

The Aquifer Vulnerability Index Map shown in Fig 2 reveals that a range from 69/70 to 165/164. Highest values (126 – 165) are seen in the southern part of the study area where communities such as Ikperejere, Umuokiri and Umunumo are located. These areas represent communities that could be most affected by pollution such as leaching of fertilizers, spillage/leakage of pipeline. It also represents areas with lowest structural resistance to anomalous incursion. The northern area has a moderate vulnerability rating with values range from 86 to 125. However, these values are also observed in the South Western region with patches very low vulnerability (70- 85). Communities with moderate vulnerability include Ikpem, Ikweii Nzerem and Umueleke. Areas close to Umueze II have the lowest vulnerability Index showing stronger protective zones that resist pollution and promote potable groundwater.

Results of the DRASTIC analysis shows that only 16.7%, 58.3% and 25% of the study area have low, medium and high vulnerability to groundwater pollution respectively. Therefore, areas like Umuezeala-Ama, Umuezeala-Ogwara, Agbaja and Umuduru Ikpeafor with low susceptibility to groundwater pollution will have quality ground water while Umuihie Orieagu, Umuihim Umualumaku, Umuokiri Umunumo, Lowa, Umuduru-Nsu and Okpu Uzinomi will most likely have contaminated groundwater due to their high susceptibility to groundwater pollution.

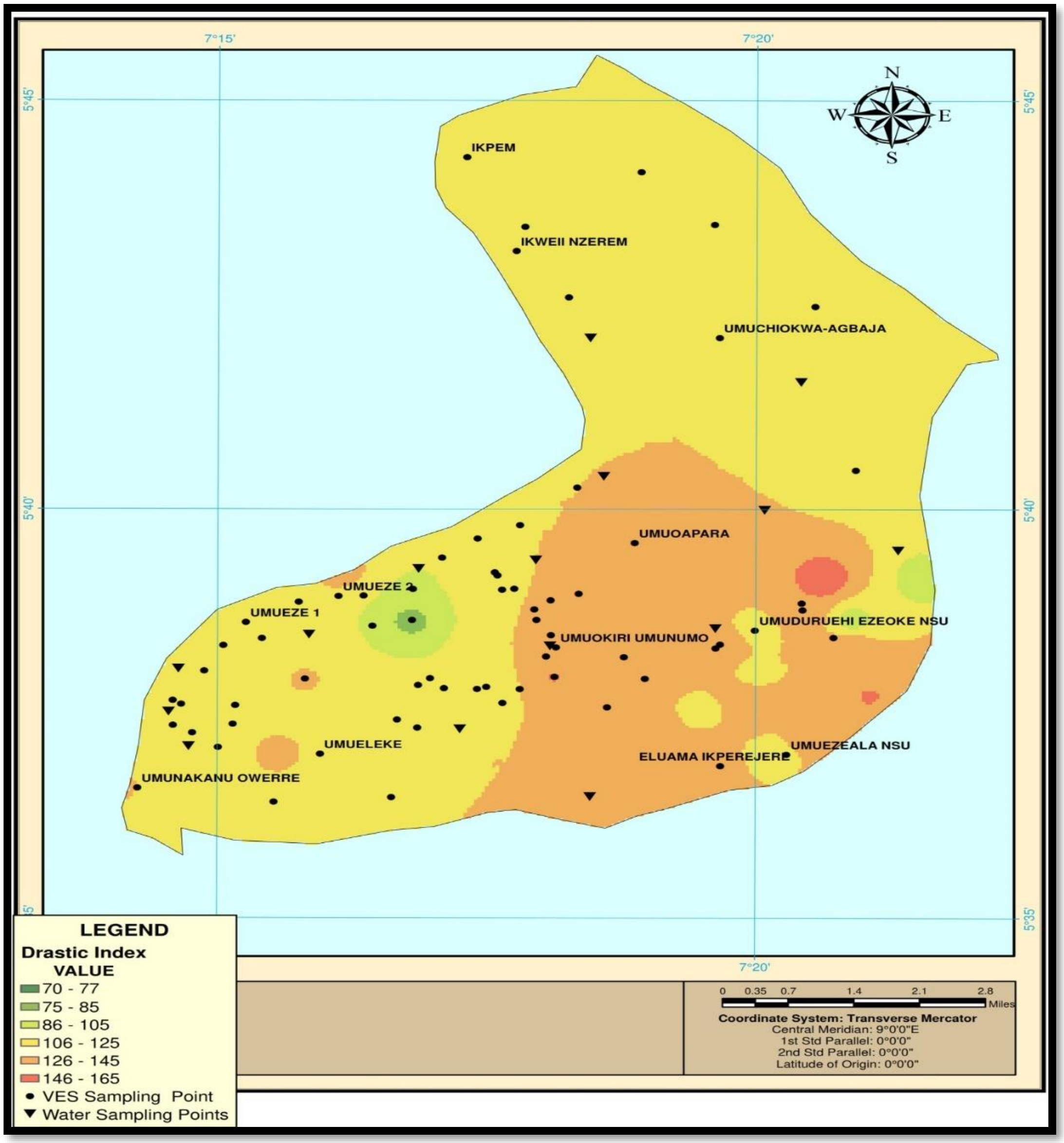

Figure 2: Aquifer vulnerability index map of the study area

Table 1: Aquifer vulnerability obtained from DRASTIC index

VES NO.	D		R		A		S		T		I		C		D	R	A	S	T	I	C	DRASTIC INDEX	VULNERABILITY
	r	w	r	w	r	W	r	w	r	w	r	W	R	W									
1	1	5	9	4	8	4	8	2	8	1	8	5	1	3	5	36	32	16	8	40	3	140	M
2	1	5	9	4	3	4	4	2	8	1	8	5	1	3	5	36	12	8	8	40	3	112	M
3	1	5	9	4	1	4	4	2	8	1	1	5	1	3	5	36	4	8	8	5	3	69	L
4	7	5	9	4	9	4	9	2	8	1	1	5	1	3	35	36	36	18	8	5	3	141	H
5	1	5	9	4	8	4	7	2	8	1	1	5	1	3	5	36	32	14	8	5	3	103	M
6	5	5	9	4	3	4	9	2	8	1	1	5	1	3	25	36	12	18	8	5	3	107	M
7	1	5	9	4	8	4	8	2	8	1	8	5	1	3	5	36	32	16	8	40	3	140	M
8	1	5	9	4	8	4	4	2	8	1	1	5	1	3	5	36	32	8	8	5	3	97	L
9	1	5	9	4	8	4	1	2	8	1	1	5	1	3	5	36	32	2	8	5	3	91	L
10	1	5	9	4	3	4	4	2	8	1	1	5	1	3	5	36	12	8	8	5	3	77	L
11	1	5	9	4	9	4	8	2	8	1	8	5	1	3	5	36	36	16	8	40	3	144	H
12	1	5	9	4	9	4	9	2	8	1	8	5	1	3	5	36	36	18	8	40	3	146	H
13	1	5	9	4	8	4	4	2	8	1	3	5	1	3	5	36	32	8	8	15	3	107	M
14	1	5	9	4	3	4	1	2	8	1	8	5	1	3	5	36	12	2	8	40	3	106	M
15	1	5	9	4	8	4	8	2	8	1	5	5	1	3	5	36	32	16	8	25	3	125	M
16	1	5	9	4	3	4	9	2	8	1	1	5	1	3	5	36	12	18	8	5	3	87	L
17	1	5	9	4	8	4	4	2	7	1	8	5	1	3	5	36	32	8	7	40	3	131	M
18	1	5	9	4	3	4	1	2	8	1	8	5	1	3	5	36	12	2	8	40	3	106	M
19	1	5	9	4	8	4	1	2	8	1	8	5	1	3	5	36	32	2	8	40	3	126	M
20	1	5	9	4	8	4	9	2	8	1	8	5	1	3	5	36	32	18	8	40	3	142	H
21	7	5	9	4	8	4	8	2	8	1	3	5	1	3	35	36	32	16	8	15	3	145	H
22	1	5	9	4	3	4	4	2	8	1	8	5	1	3	5	36	12	8	8	40	3	112	M
23	1	5	9	4	8	4	8	2	8	1	8	5	1	3	5	36	32	16	8	40	3	140	M
24	1	5	9	4	8	4	10	2	7	1	8	5	1	3	5	36	32	20	7	40	3	143	H
25	5	5	9	4	3	4	10	2	9	1	2	5	1	3	25	36	12	20	9	10	3	115	M
26	1	5	9	4	9	4	4	2	9	1	2	5	1	3	5	36	36	8	9	10	3	107	M
27	1	5	9	4	9	4	10	2	8	1	8	5	1	3	5	36	36	20	8	40	3	148	H
28	5	5	9	4	8	4	9	2	8	1	2	5	1	3	25	36	32	18	8	10	3	132	M
29	10	5	9	4	8	4	10	2	8	1	3	5	1	3	50	36	32	20	8	15	3	164	H
30	1	5	9	4	8	4	9	2	8	1	2	5	1	3	5	36	32	18	8	10	3	112	M
31	1	5	9	4	9	4	4	2	8	1	2	5	1	3	5	36	36	8	8	10	3	106	M
32	1	5	9	4	9	4	1	2	9	1	2	5	1	3	5	36	36	2	9	10	3	101	M
33	1	5	9	4	9	4	9	2	8	1	2	5	1	3	5	36	36	18	8	10	3	116	M
34	2	5	9	4	1	4	9	2	8	1	2	5	1	3	10	36	4	18	8	10	3	89	L
35	1	5	9	4	8	4	4	2	8	1	8	5	1	3	5	36	32	8	8	40	3	132	M
36	1	5	9	4	8	4	9	2	8	1	8	5	1	3	5	36	32	18	8	40	3	142	H

37	1	5	9	4	8	4	9	2	8	1	8	5	1	3	5	36	32	18	8	40	3	142	H
38	10	5	9	4	8	4	8	2	9	1	2	5	1	3	50	36	32	16	9	10	3	156	H
39	1	5	9	4	8	4	5	2	8	1	3	5	1	3	5	36	32	10	8	15	3	109	M
40	1	5	9	4	8	4	5	2	9	1	8	5	1	3	5	36	32	10	9	40	3	135	M
41	1	5	9	4	8	4	9	2	8	1	8	5	1	3	5	36	32	18	8	40	3	142	H
42	1	5	9	4	8	4	4	2	8	1	5	5	1	3	5	36	32	8	8	25	3	117	M
43	1	5	9	4	3	4	5	2	9	1	2	5	1	3	5	36	12	10	9	10	3	85	L
44	1	5	9	4	3	4	5	2	9	1	2	5	1	3	5	36	12	10	9	10	3	85	L
45	1	5	9	4	3	4	10	2	8	1	2	5	1	3	5	36	12	20	8	10	3	94	L
46	1	5	9	4	8	4	9	2	9	1	3	5	1	3	5	36	32	18	9	15	3	118	M
47	1	5	9	4	8	4	4	2	8	1	8	5	1	3	5	36	32	8	8	40	3	132	M
48	1	5	9	4	5	4	9	2	8	1	8	5	1	3	5	36	20	18	8	40	3	130	M
49	1	5	9	4	9	4	9	2	8	1	8	5	1	3	5	36	36	18	8	40	3	146	H
50	1	5	9	4	8	4	9	2	8	1	3	5	1	3	5	36	32	18	8	15	3	117	M
51	1	5	9	4	8	4	9	2	9	1	3	5	1	3	5	36	32	18	9	15	3	118	M
52	5	5	9	4	3	4	10	2	9	1	2	5	1	3	25	36	12	20	9	10	3	115	M
53	5	5	9	4	3	4	10	2	9	1	2	5	1	3	25	36	12	20	9	10	3	115	M
54	5	5	9	4	3	4	10	2	9	1	2	5	1	3	25	36	12	20	9	10	3	115	M
55	5	5	9	4	3	4	10	2	9	1	2	5	1	3	25	36	12	20	9	10	3	115	M
56	1	5	9	4	8	4	9	2	8	1	8	5	1	3	5	36	32	18	8	40	3	142	H
57	10	5	9	4	8	4	8	2	9	1	2	5	1	3	50	36	32	16	9	10	3	156	H
58	1	5	9	4	8	4	1	2	8	1	8	5	1	3	5	36	32	2	8	40	3	126	M
59	1	5	9	4	8	4	1	2	8	1	8	5	1	3	5	36	32	2	8	40	3	126	M
60	1	5	9	4	8	4	1	2	8	1	1	5	1	3	5	36	32	2	8	5	3	91	L

Table 2: DRASTIC index ranges for qualitative risk categories (After Engel *et al.*, 1996)

	DRASTIC Qualitative Category			
	Low	**Moderate**	**High**	**Very high**
DRASTIC Index [DI]	1 – 100	101 – 140	141 - 200	>200

Details of communities within the various vulnerability categories and their associated map colours are shown in Table 3.

Table 3: Location of different aquifer vulnerability categories and their associated colours ramp

Location	Vulnerability Values	Remarks	Colour Ramp
UmezealaOgwara, UmuokaraUzinomi,	70 – 85	Low	Green/Deep Green
Umueze 1, Umueze 2, Umuosu Alike Nzerem, Umumanu Umuezeala, Umudimezeji, Ikwem, Ikweii Nzerem, Umueleke, Umunakanu Owerre	86 – 125	Moderate	Light Green/ Yellow
Umuokiri Umunumo, Ikperejere, Lowa, UmuduruNsu, Nkumeato, Umuoapara	126 – 165	High	Brown/Red

CONCLUSION

Aquifer vulnerability assessment carried out revealed areas with high, low and moderate vulnerability based on the DRASTIC Index. Locations with high vulnerability rating of 126 -165 include: Umuokiri Umunumo and Ikperejere. Locations with moderate vulnerability rating of 86-125 include: Ikpem, Ikweii Nzerem while locations with low vulnerability rating of 70-85 include: Umuokara Uzinomi and areas close to Umueze II. The vulnerability of the area is in line with the description of the subsurface lithology. The areas with high resistivities are interpreted especially from the ground surface are more vulnerable than places with low resistivities which are regarded as shale/clay units are less vulnerable.

REFERENCES

Aller, L., Bennet, T., Leher, J. H., Petty, R. J. and Hackett, G. (1987). *DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings*. EPA 600/2-87-035, p. 622. Retrieved from https://www.researchgate.net/figure/DRASTIC-Index-and-vulnerability-class-Aller-et-al-1987_tbl2 on 12th March, 2022.

Aller, L., Bennett, T., Lehr, J.H. and Petty, R.J. (1985). *DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings*. Ada, OK: United States Environmental Protection Agency, Robert S. Kerr Environmental Research laboratory. EPA/600/2-85/0108. Retrieved from https://www.google.com/url?sa=t&source=web&rct=j&url=https://nhess.copernicus.org/preprints/nhess on 12th March, 2022.

Ehirim, C. N. and Ofor, W. (2011). Assessing aquifer vulnerability to contaminants near solid waste landfill sites in a coastal environment, Port Harcourt, Nigeria. *Trends in Applied Sciences Research*, 6:165 – 173. Doi:10.3923/tasr.2011.165.173.

Engel, B., Navulur, K., Cooper, K. and Hahn, L. (1996). Estimating groundwater vulnerability to non-point source pollution from nitrates and pesticides on a regional scale. *Application of Geographic Information Systems in Hydrology and Water Resources Management*, 235:521–526. Retrieved from http://hydrologie.org/redbooks/a235/iahs_235_0521.pdf on 13th March, 2022.

Nwachukwu, M. A., Huan, F., Maureen, I. A. and Umunna, F. U. (2010). The causes and the control of selective pollution of shallow wells by coliform bacteria, Imo River Basin Nigeria. *Water Quality Exposition Health;* 2:75-84. Retrieved from https://link.springer.com/article/10.1007/s12403-010-0025-4 on 22nd February, 2022.

Parkinson, F. (1907). The post cretaceous stratigraphy of southern Nigeria. *Journal of Geological Survey*, London, 63:320. Doi:10.1144/GSL.JGS.1907.063.01-04.19

Public Health Madison and Dane County (2017). Water quality in Dane Country: Overview, current challenges and recommendations. Retrieved from http://www.publichealthmdc.com on 10th August, 2021.

Reyment, A. (1965). *Aspects of the geology of Nigeria.* Ibadan University Press, 145 p. Retrieved from google.com on 22nd February, 2022.

Short, A. and Stauble, E. (1978). *Adaptation options for climate change impacts on groundwater resources.* Victoria. Australia. Retrieved from https://openknowledge.worldbank.org/handle/10986/27857 on 22nd February, 2022