INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue VIII, August 2023

Homogeneity in Aquifer Vulnerability Index (AQI) and Water Quality Index (WQI) around some selected dumpsites in Imo River Basin Southeastern Nigeria

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DOI: **https://doi.org/10.51583/IJLTEMAS.2023.12801**

Received: 05 July 2023; Revised: 31 July 2023; Accepted: 08 August 2023; Published: 28 August 2023

Abstract: -This study was carried out using vertical electrical sounding data and geochemical data to determine if there is a relationship between the aquifer vulnerability index and the water quality index in the Imo River Basin Southeastern, Nigeria. Some vertical electrical sounding data were collected using OMEGA SAS1000 Terrameter, and sixteen (16) water samples were collected from, both surface and groundwater around the three selected dumpsites from Owerri, Orlu and Okigwe areas. These two sets of data were used to evaluate the water qualities in the vicinity of the three active dumpsites. The DRASTIC index ranged between 59 and 199, and the spatial variation showed that 8.8% of the aquifer in the study area is highly vulnerable. 81.2% of the aquifer has a low vulnerability index. The water quality index in the study area showed both good and poor water qualities. The geospatial distribution of water quality index showed that 80% of the study area had good water quality, and the remaining 20 % of the study area had poor water quality. The bivariate regression showed a curvilinear, relationship between the aquifer vulnerability index and the water quality index.

Keywords: Homogeneity, aquifer vulnerability, DRASTIC, Imo River basin, Vertical electrical soundings, Schlumberger, Terrameter.

I. Introduction

Water is one of the most valuable natural resources commonly used by both plants and animals. The quality and quantity of surface water and groundwater often depend on several human factors. The most accessible is the surface water which is more prone to the adverse effect of human activities. In recent times, with the advent of science and technology, groundwater is now easily accessible by drilling holes into the aquifer and using a mechanical or electrical water pump to lift water from the aquifer to overhead tanks. It is also seen that industrialization and urbanization to a large extent increase the rate of use of groundwater. The drilling of boreholes for water is a common practice in most cities in the developing world. Thus, there is generally a geometric increase in the usage of groundwater. According to Alexander et al. (2017), with the increase in groundwater usage, a decrease in the quantity and quality of water resources is inevitable. UNEP (2008) remarked that the quality of groundwater has been continuously deteriorating, and is worrisome to both the suppliers and users. Contaminated water is often characterized by an increase in the total salinity, an increase in the quantity of chemical and metallic harmful elements, and bacteriological species (Bear and Cheng, 2009). The toxic effects of these undesirable elements in water are found in the concentration range greater than 1000 mg kg-1 (Iwegbue et al. 2008). Globally, more than twenty-five thousand people die daily as a result of water-related diseases (PrussUstun et al. 2008). The WHO news report (2020) has it that some 829 000 people are estimated to die each year from diarrhea as a result of unsafe drinking water. Azizullah (2011) opined that water pollution is among the main threats to public health in Pakistan and is associated with the poor management of water resources.

There is an increasing dependence on groundwater as a source of potable water supply in the study area. The exponential growth in the sector of urbanization and industrialization is conspicuously seen in the environment. There is every reason that the water resources of the area have been compromised anthropogenically because, the more industries are sprouting, the more waste is generated. In the same manner the more the population of settlers increases, the more household waste generation will be recorded. Unfortunately, the common practice in the study area is open dumpsites. This demands that extra effort should be made by both governments and individuals towards protecting the quality of these limited natural resources. It is right to ascertain the current status of the aquifer so that proper protective measures will be employed. The knowledge of groundwater quality is very necessary for the general well-being of the citizens. The fact that the deadliest diseases are often contracted from drinking polluted water demands that the people’s aquifer should be constantly monitored and evaluated so that public health will not be compromised.

Hydrogeochemistry of the groundwater varies spatially and temporally, depending on the geology and chemical characteristics of the aquifer. The water quality can also be guided by Hydrogeochemical processes such as dissolution, precipitation, ion exchange processes, mineralogy of watershed and aquifer, climate, and topography (Luo and Zhang, 2018). Good knowledge of hydrogeochemistry and hydro-geological properties of an aquifer serves as a basis in an effort to monitor the quantity and quality of groundwater in a location.

The water quality analysis is one of the most important aspects of groundwater studies. The hydrochemical studies reveal the water quality suitable for drinking, agricultural, and, industrial purposes. Thus, in the characterization of an aquifer, there is a need for the hydrogeochemical analysis of well water, surface water, and leachate from the survey area. Water quality analysis exposes the particular contaminant element threatening the safety of the underground water. It also supplies information on the quantity of the contaminant present in underground water.

Groundwater vulnerability is the tendency of an aquifer to receive contaminants from anthropogenic or other surface sources. Chilton (2006) defined groundwater vulnerability as the intrinsic properties of the strata separating a saturated aquifer from the land surface which determines the sensitivity of that aquifer to being adversely affected by the contaminant loads applied at the land surface. It is a measure of the degree or extent the natural and manmade factors provide insulation barriers to keep pollution away from the groundwater. Assessing groundwater vulnerability is challenging (Abad et al. 2017). This is a result of numerous intrinsic factors that must be considered in estimating groundwater vulnerability. Vulnerability of the groundwater is a relative, non-measurable, and dimensionless property which is based on the concept that some land areas are more vulnerable to groundwater contamination than others (Chiedza and Kwazikwakhe 2013).

The maps showing the groundwater vulnerability assist with the identification of areas more susceptible to contamination than others. The vulnerability maps are useful in planning, policy formulation, and decision-making for groundwater management and protection. In assessing groundwater vulnerability, a lot of parameters are involved, and integrating all these parameters will amount to complex data management. But then, a comprehensive vulnerability model must include parameters to describe how likely it is that a site will be contaminated. It is important to note, that there is a need for regular assessment of the aquifer to devise strategies for protecting the groundwater since it is not easily accessible for treatment (Buofekane et al. 2013). Regular aquifer assessments and other actions that are not inimical to the safety of the groundwater are more effective ways than remedial strategies like cleaning the aquifer. Cleaning contaminated groundwater is very expensive (Machdar et al. 2018). Oroji (2018) opined that the prevention of aquifers pollution is considered an important factor in the management of groundwater resources. It is a difficult task to embark on cleaning an aquifer, thus there is a need to assess the pollution level of the people's aquifer.

Various scholars devised several empirical indices for aquifer vulnerability. The aquifer vulnerability index (AVI) is a widely used method to assess the aquifer vulnerability to surface contaminants (Van- Stempvoort et al. (1992). This method quantifies the groundwater vulnerability by the hydraulic resistance to the vertical flow of wastewater through the unsaturated layers. The aquifer vulnerability index (AVI) is also known as integrated electric conductivity, to some scholars, it is longitudinal conductance. Obiora et al. (2016) also assessed the protective capacity of the aquifer using longitudinal conductance which is the sum of the ratio of the layer resistivities to the equivalent thicknesses of each layer above the aquifer layer. Other researchers have combined various geophysical and geochemical methods to assess how vulnerable the aquifers were by determining areas more susceptible to groundwater contamination than others (Davila Porcel et al. 2014; Ibeh et al. 2001;Sidhardhan et al. 2015). DRASTIC an acronym for seven parameters; depth to water, net recharge, aquifer media, soil media, topography, the impact of the vadose zone, and hydraulic conductivity is widely used in assessing aquifer vulnerability (Adnan, 2018;Machdar et al. 2018). Lobo Ferrari and Oliveira (2004) compared six (6) vulnerability index methods in assessing the aquifer vulnerability near Evora (Alentejo) in Portugal has it that the DRASTIC index gave a good picture of the aquifers of the study area characterized by metamorphic and igneous rocks.

Gogu and Darssargues (2000) opined that new research challenges in vulnerability assessment have been identified, especially the need for developing dynamic links between numerical models and index methods. Statistically, the quest to define the vulnerability status of groundwater is not left out (Javid *et al*., 2017; Fournier *et al*. 2007). Some studies used the water quality index to assess the degree of aquifer pollution (Rao and Latha, 2019; El-Fadel2014).

AtashiYazdi et al. (2020) used both the water quality index and intrinsic aquifer vulnerability assessment tools to evaluate theBahabad Yazd Plain aquifer. In their study, they found out that there is low vulnerability to contamination and that was in line with the WQI result within a significant portion of the northern and southern districts of their study area.

The study aimed at determining whether there is consistency between the result from the intrinsic aquifer vulnerability index (DRASTIC) and the water quality index (wqi) in the Imo River basin in southeastern Nigeria.

Location and geology of the study

The study was carried out in the Imo River Basin, Southeastern Nigeria. It is within the tropical, equatorial rainforest belt of West Africa. It lies between the longitude 6˚40ˈ- 7˚ 45ˈ E and latitude 4˚ 35ˈ - 6˚ 00ˈ N, with approximately an area of 120 Km × 170 Km (Fig 1). The Imo River basin is a 140 km north-south trending sedimentary syncline located in the upper Niger Delta within the middle of South-Eastern Nigeria and stretching across Imo state, and Abia state (Ejiogu et al. 2019). Two-thirds portion of the basin is in Imo State, comprising the upper and middle portions of the basin.

The Imo River basin is based on a bedrock of a sequence of sedimentary rocks about 5480m thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1989). The Imo starts from the hills of Okigwe, runs through Imo State, Rivers State, and empties into the Atlantic Ocean through Abia State via AkwaIbom State.

The climatic condition of the study area is characterized by uniformly high temperatures and seasonal distribution of precipitation. It has an average maximum temperature of 34˚C and an average minimum temperature of 25˚C. The study area is characterized by heavy rainfall of about 2400 mm/year. There are two prominent seasons; dry and rainy seasons. The rainy season runs from May to October and sometimes to November; probably due to the effect of climate change. The dry season runs between December and March.

Imo river basin covers six major geologic formations which include; the Nsukka Formation, Imo shale, Ameki, Ogwashi, Ajali, and Benin Formations. Its elevation ranges between 9 and 420 m above sea level (Figure 1)

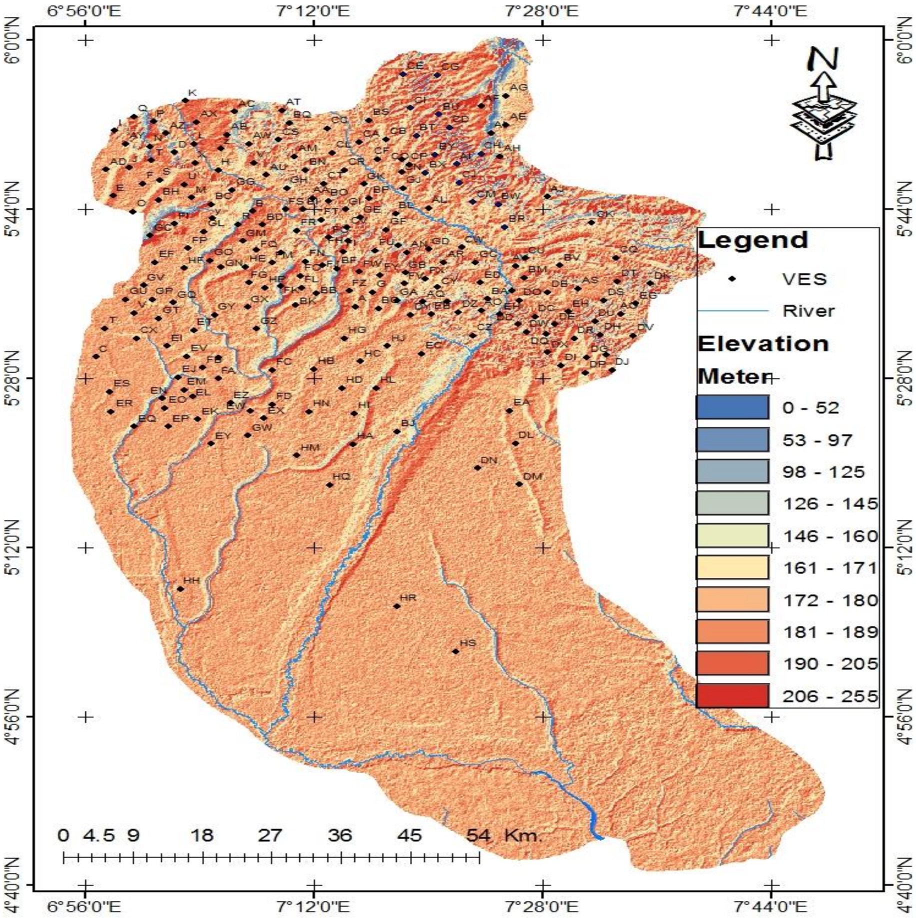


Fig 1 Map of the study area showing the VES points with there elevations.

II. Materials and methods

Two hundred and twenty-six (226) vertical electrical soundings (VES) were acquired. The ABEM™ SAS 4000 Terrameter was used. The Schlumberger electrode array with a maximum current electrode spacing of 1000m (Fig 2), was employed in the vertical electrical resistivity sounding. The vertical electrical soundings were heavily acquired within and around the selected dumpsites. Locations that were not close to the dumpsites were also acquired.

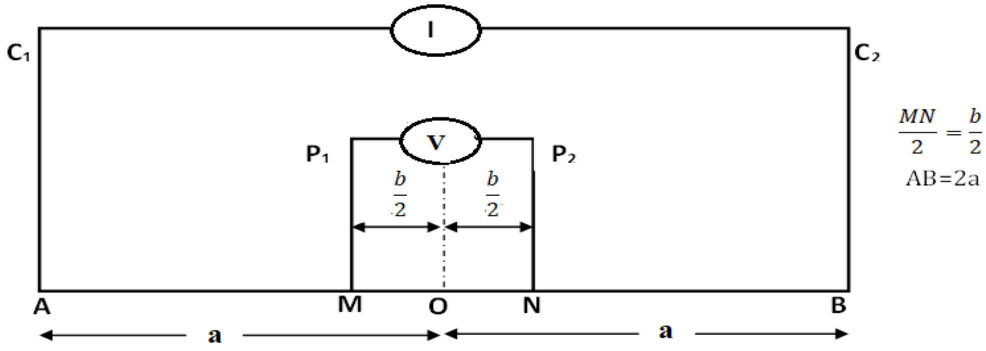


Figure 2 Diagram of Schlumberger electrode array used for the vertical electrical sounding

The observed field data (apparent layer resistance) was converted to apparent layer resistivity using the geometric factor (K).

For the Schlumberger array, the geometric factor is given by;

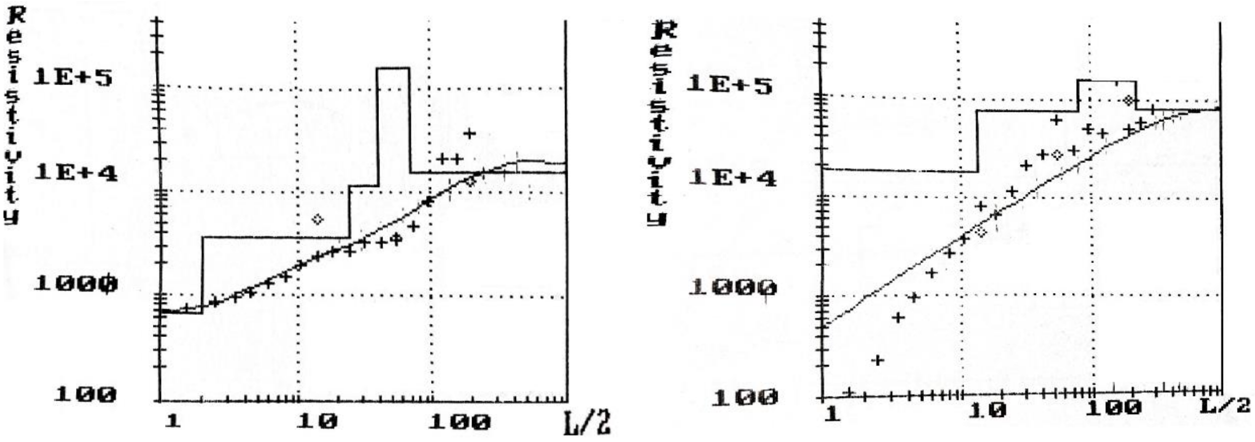
$$k = \left[\frac{a^2 - b^2}{2b}\right]\pi. \qquad (1)$$

Where 'a' is half current electrode spacing and 'b' is half potential electrode spacing.

The apparent resistivity (ρ) is given by the product of the apparent resistance (R) and the geometric factor (k) as shown in Eqn. 2 below.

$$\rho = \frac{V_{MN}}{I}k. \qquad (2)$$

Where V_{MN} is the potential difference across the two inner electrodes (potential electrodes). I, is the current in the circuit, and the ratio of potential across the two inner electrodes to the current in the circuit is the apparent resistance offered by the earth's layer. With the use of computer modeling techniques, the field data was reduced to their equivalent geological models (Zohdy et al. 1974). The apparent resistivity and the electrode distance parameters as the input data, the WinResist™ software which took care of the effects of lateral inhomogeneity and other forms of noisy signatures was used to generate smooth VES curves. The VES curves are log-log plots of the earth's resistivity versus the potential electrode spacing (Fig 3)



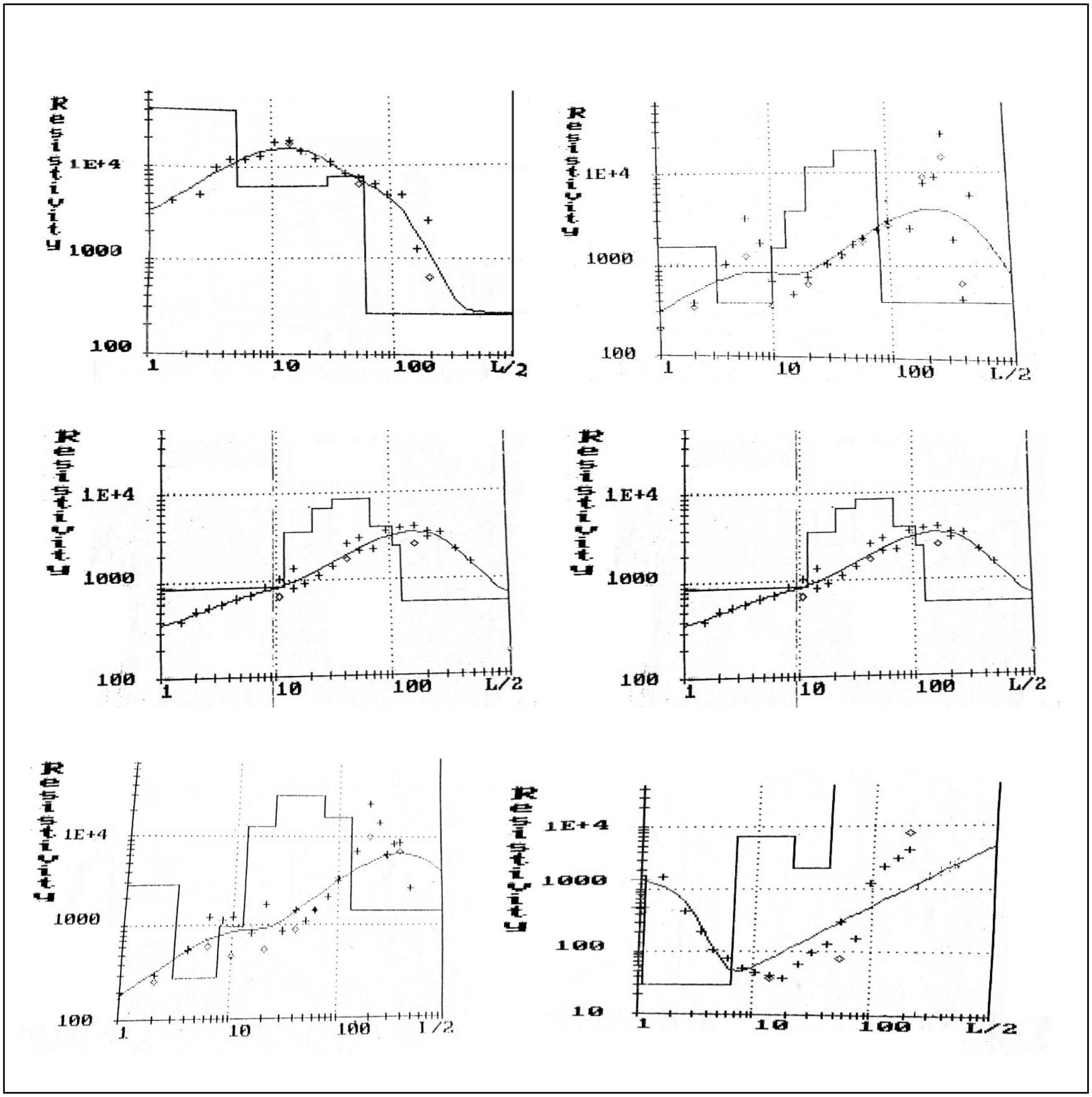


Fig 3 Some Samples of the VES curves selected from the locations of the three dumpsites.

The DRASTIC aquifer vulnerability assessment method is given by

$$\mathrm{DI} = \mathrm{D_r D_w} + \mathrm{R}_r \mathrm{R_w} + \mathrm{A_r A_w} + \mathrm{S_r S_w} + \mathrm{T_r T_w} + \mathrm{I_r I_w} + C_\mathrm{r} \mathrm{C_w} \quad (3)$$

Where;

DI is the DRASTIC index

D is the depth to aquifer media

R is rate of recharge

A is aquifer media

S is soil media

T is topography

C is Aquifer conductivity

'r' and 'w' are ratings and weights respectively, attached to individual parameters and. The higher the DI the more susceptible to contamination the groundwater of the area will be (Table 1).

Table 1 Classification of vulnerability for the DRASTIC model

Vulnerability class	low	Moderate	High	Very high
DRASTIC index	<101	100-140	141-200	>200

Source: (Engel et al., 1996).

Sixteen (16) water samples were collected in the study area and were analyzed for twenty-five (25) chemical parameters (Table 1). The samples were analyzed for both chemical presences using a combination of titrimetric, colorimetric, and atomic absorption spectroscopy. Conductivity was determined using a hand-held conductivity meter model H198302(HANNA). The conductivity meter was calibrated using a conductivity solution at 25^0C after which it was switched on and inserted into the 50ml water sample and the conductivity values were read and recorded in µs/cm. Salinity was determined with a hand-held Refractometer Model e-line refractometer. A drop of the digested water sample was placed on the refractive surface of the refractometer and the refractive index was read and recorded. The refractive index has been scaled as the salinity values recorded in mg/l. The refractive index was recalibrated using distilled water and has been scaled as the salinity values were recorded for each water sample recorded in mg/l

Alkalinity was determined by a combination of colorimetric and titrimetric methods using an H183200 multi-parameter bench photometer of wavelength 575nm. The heavy metals were determined using Atomic Absorption Spectrometer. The digested water samples were aspirated into the oxidizing air acetylene flame and the sensitivity for 1% absorption was observed. The amount of energy of the characteristic wavelength absorbed in the flame was recorded and is proportional to the concentration of the metal in the aspirated water samples.

The result of the chemical analysis was used to calculate the water quality Index using Eqns. 4 - 7.

$$\mathrm{RW_i} = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (4)$$

$$\mathrm{q_i} = \frac{\mathrm{c_i}}{\mathrm{S_I}} \times 100 \qquad (5)$$

$$\mathrm{Sl_i} = \mathrm{RW_i} \times \mathrm{q_i} \qquad (6)$$

$$\mathrm{WQI} = \sum \mathrm{Sl_i} - \mathrm{n} \qquad (7)$$

where w_i is the weight of each chemical parameter

RW_i is the relative weight of the i^{th} chemical parameter,

q_i is a quality rating based on the i^{th} chemical parameter,

c_i is the concentration of each chemical parameter in each sample in mg/L,

S_i is the WHO drinking water standard for each chemical parameter,

Sl_i is the sub-index of the i^{th} parameter and

n is the number of chemical parameters.

The water quality index classifies water into 5 distinct groups (Table 2).

Table 2 Classification of water samples using WQI

WQI	Water Quality Description
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking

III. Results and discussions

The DRASTIC index in the study area ranged between 59 and 187, with VES HI recording the highest DRASTIC Index (Table 3). The shallow aquifers of the study area were characterized by a low to high aquifer vulnerability index.

Table 3 Selected VES locations with their corresponding DRASTIC Index

VES	Depth to aquifer			Recharge			Aquifer media			Soil media			Topography			Impact of vadose			Hydraulic conductivity			
	D			R			A			S			T			I			C			
	D_R	D_W	D_RD_W	R_R	R_W	R_RR	A_R	A_W	A_RA_W	S_R	S_W	S_RS_W	T_R	T_W	R_RT_W	I_R	I_W	I_RI_W	C_R	C_W	C_RC_W	DI
AE	1	5	5	8	4	32	10	3	30	10	2	20	4	1	4	8	5	40	2	3	6	137
AF	1	5	5	6	4	24	8	3	24	8	2	16	4	1	4	3	5	15	1	3	33	121
AJ	1	5	5	6	4	24	8	3	24	9	2	18	2	1	2	3	5	15	1	3	3	91
AN	9	5	14	6	4	24	8	3	24	8	2	16	7	1	7	3	5	15	1	3	3	103
AP	1	5	5	6	4	24	8	3	24	9	2	18	4	1	4	3	5	15	1	3	3	93
BA	1	5	5	6	4	24	8	3	24	7	2	14	5	1	5	6	5	30	1	3	3	105
BL	1	5	5	6	4	24	2	3	6	7	2	14	4	1	4	6	5	30	2	3	6	89
BR	1	5	5	6	4	24	8	3	24	8	2	16	7	1	7	3	5	15	1	3	3	94
C	1	5	5	8	4	24	6	3	18	10	2	20	4	1	4	8	5	40	1	3	3	114
CA	1	5	5	6	4	24	8	3	24	7	2	14	4	1	4	3	5	15	2	3	6	92
CB	1	5	5	6	4	24	8	3	24	10	2	20	5	1	5	6	5	30	1	3	3	111
CF	1	5	5	6	4	24	6	3	18	8	2	16	4	1	4	3	5	15	1	3	3	85
CG	1	5	5	6	4	24	2	3	6	8	2	16	4	1	4	3	5	15	1	3	3	73
CI	1	5	5	6	4	24	8	3	24	7	2	14	6	1	6	6	5	30	1	3	3	106
CJ	1	5	5	6	4	24	8	3	24	7	2	14	6	1	6	3	5	15	1	3	3	91
CL	1	5	5	6	4	24	2	3	24	1	2	2	4	1	4	3	5	15	1	3	3	77
CV	1	5	5	6	4	24	8	3	24	8	2	16	4	1	4	3	5	15	1	3	3	91
D	1	5	5	8	4	32	8	3	24	1	2	2	6	1	6	3	5	15	2	3	6	90
E	1	5	5	8	4	32	8	3	24	10	2	20	2	1	2	6	5	30	2	3	6	119
EG	1	5	5	9	4	36	8	3	24	10	2	20	4	1	4	6	5	30	1	3	3	122
F	1	5	5	8	4	32	8	3	24	10	2	20	4	1	4	3	5	15	2	3	6	106
G	1	5	5	8	4	32	8	3	24	10	2	20	6	1	6	3	5	15	2	3	6	108
GS	1	5	5	9	4	36	8	3	24	10	2	20	4	1	4	8	5	40	2	3	6	135
HL	1	5	5	9	4	36	8	3	24	10	2	20	5	1	5	3	5	15	2	3	6	111
HM	3	5	15	9	4	36	8	3	24	7	2	14	4	1	4	8	5	15	2	3	6	114
IH	2	5	10	8	4	32	8	3	24	7	2	14	4	1	4	5	20	100	1	3	3	187

Forty-two percent (42%) of the VES locations showed a low aquifer vulnerability index, fifty-seven percent (57%) showed a moderate aquifer vulnerability index and only one percent (1%) showed a high vulnerability index. There is a need for proper waste management in the study area so that the DI of the study area in the nearest future will not increase.

The spatial variation map of DRASTIC (Figure 4) showed three levels of aquifer vulnerability in the study area.

The higher the DRASTIC index, the greater the groundwater contamination potential is. The green colour showed a low aquifer vulnerability index, the yellow colour showed a moderate aquifer vulnerability and the orange colour showed a high aquifer vulnerability. A small portion of the study area representing 8.8% of the study area was found to be highly vulnerable. Two out of the three selected dumpsites in the study area (Orlu and Owerri dumpsites were located within this area of high aquifer vulnerability character.

69% of the study area was moderately vulnerable and 22.2 % was classified as a low vulnerability area. The dumpsite at the Okigwe was identified as being located within the area of a low aquifer vulnerability. The Orlu dumpsite was described as being located within the area of moderate aquifer vulnerability. TheOwerri dumpsite was identified as being located within the high aquifer vulnerability area.

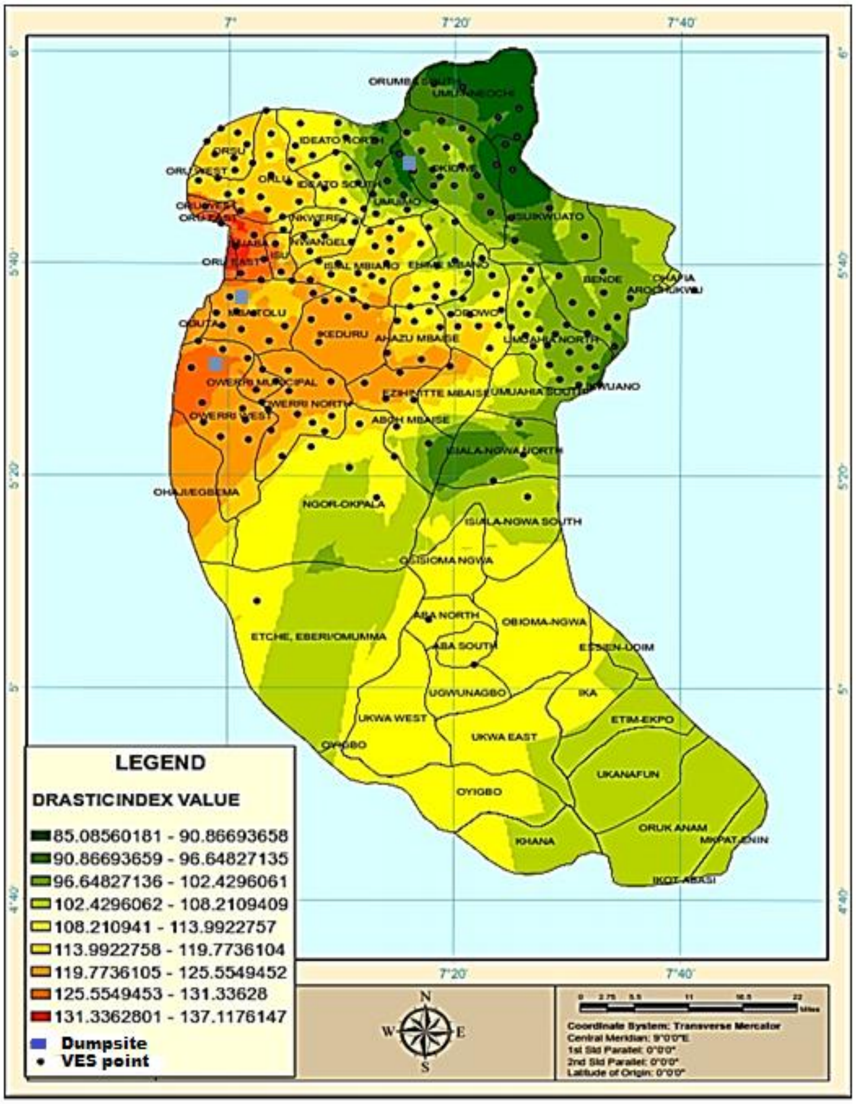


Fig 4 The vulnerability map of the study area with the DRASTIC model

Table 4 Physico-chemical analysis of water samples around the dumpsite

S/N	PARAMETER	WHO STD.	1	BHW 2	SW 1	SW 2	SW 3	BHW 3	SW 4	BHW 4	SW 5	BHW 5	SW 6	BHW 6	BHW 7	BHW 8	BHW 9	BHW 10
1	PH	6.5 – 8.5	7.39	6.92	7.22	7.5	7.14	6.7	6.65	6.62	6.57	6.66	6.91	6.1	5.9	6.1	6.3	5.2
2	Conductivity, us/cm	100	81	40	3	79	39	42	55	48	56	37	10	70	68	149	219	40
3	Dissolved Oxygen, mg/l	>4	4.8	4.3	4.1	4.2	4.3	4.1	4.1	4.5	4	4.4	4.4	4.3	4.5	4.2	4.4	4.3
4	BOD, mg/l	10	1.28	0.48	2.08	1.6	1.6	0.32	0.43	0.48	0.3	0.2	0.3	1.2	0.1	0.4	1.2	1.4
5	COD, mg/l	15	2.05	0.77	3.33	2.56	2.56	0.51	0.77	0.77	0.48	0.32	0.48	1.92	0.16	0.64	1.92	2.24
6	TDS, mg/l	250	52.65	26	1.95	51.35	25.35	27.3	35.8	31.2	36.4	22.1	6.5	31.2	33.15	29.9	31.2	30.96
7	Salinity, mg/l	-	2936.2	1738.1	822.9	427.9	987.5	460.9	856	526.6	263	3555.1	1580	303.6	220.2	209	97.3	62.7
8	Alkalinity($CaCO_3$), mg/l	500	252	358	178	156	392	204	174	356	270	200	204	5	10	60	5	50
9	Carbonate, mg/l	350	132	280	88	72	268	116	96	146	134	96	110	127	76	70	47	49
10	Bi-Carbonate, mg/l	380	120	78	90	84	124	88	78	210	136	104	94	42	32	24	16	16
11	Nitrate(NO^-_3), mg/l	40	83.3	11.9	47.5	68.4	55.6	15.3	25.8	0.04	7.8	90.3	13.7	137	343	257	322	243.2
12	N), mg/l	15	18.8	2.7	8.2	15.7	10.4	3.5	5.8	0.01	1.8	204	3.2	29.5	73.8	57	71.4	54.1
13	Phosphate (PO^{3-}_4), mg/l	5	3.3	1.2	4.2	0.2	0	1	1	0.7	0.5	1.6	1.2	0.1	1.4	4.4	0.1	19.5
14	Phosphorus (P), mg/l	0.3	1.1	0.4	1.4	0.1	0	0.3	0.3	0.2	0.2	0.5	0.4	0	0.4	1.4	0	6.4
15	Phosphate(P_2O_5), mg/l	-	2.5	0.9	3.2	0.1	0	0.8	0.7	0.5	0.4	1.2	0.9	0.1	0.9	3.3	0.1	14.6
16	Sulphate(SO^{2-}_4), mg/l	400	164.6	288.1	82.3	205.8	123.85	329	534	41.15	453	164.6	124	55	0	0	5	5
17	Chloride, mg/l	600	1625.3	962.1	455.5	236.9	546.6	255.1	474	291.5	146	1967.9	875	0.43	184	133.5	127	59
18	Sodium, mg/l	100	12.63	10.211	4.136	2.452	6.22	3.165	4.21	3.362	2.2	11.28	7.12	3.02	2	1.64	0.03	0
19	Potassium, mg/l	10	20	30	25	60	30	10	40	80	30	40	20	0.06	0.11	0.03	0	0.02
20	Calcium, mg/l	200	140	145	160	120	185	80	10	100	90	120	100	80	24.4	10	19.4	18
21	Magnesium, mg/l	150	30	25	30	30	0	20	15	75	10	20	25	10	0	0	0	0
22	Iron, mg/l	0.3	0.12	0.18	0.11	0.05	2.2	1.12	0.26	0.12	0.23	0.33	0.18	0.55	0.4	0.31	0.19	0.2
23	Copper, mg/l	1	0.1	0.06	0.13	0.17	0.08	0.2	0.18	0.1	0.13	0.04	0.16	0.2	0.05	0.05	0	0.08
24	Lead, mg/l	0.05	0.06	0.08	0.12	0.46	0.02	0	0.14	0.06	0	0	0	0.151	0.125	0.032	0.001	0.012
25	Tot. Bact Cnt, cfu/100ml	30	14	39	1700	1600	3400	59	54	1200	42	52	29	76	210	54	39	21
26	Tot Coli. Cnt, cfu/100ml	5.0-10.0	3	14	870	520	920	8	7	850	12	14	7	30	143	17	11	14
27	Tot. Fae. Cnt, cfu/100ml	0	0	4	80	60	210	0	1	780	2	3	2					
28	cfu/100ml	0	0	2	48	30	80	0	1	240	1	1	0	24	57	5	4	12

The complex water quality data (Table 4) was made more understandable by computing the water quality index (Table 5). Generally, there were good and poor water qualities in the study area. 43.75% of the water samples were classified as having excellent water quality, 12.5% of the water samples were classified as poor water quality and 43.7% were identified as having very poor water quality. BHW 6, BHW7, and BHW10 have WQI values of 234.88, 208.86, and 278.28 respectively.

Table 5 The locations and water quality index of water samples in the study area

water sample	LONGITUDE	LATITUDE	WQI
BHW 1	E007° 02ˈ 21.5	N05° 28ˈ18.6″	137.4
BHW 2	E007° 02ˈ 47.2″	N05° 28ˈ29.2″	131.18
SW 1	E007° 02ˈ 30.6″	N05° 28ˈ18.6″	175.39
SW 2	E007° 02ˈ29.1 ″	N05° 28ˈ17.4″	37.429
SW 3	E007° 02ˈ 11.0″	N05° 28ˈ05.2″	56.779
BHW 3	E007° 02ˈ 30.6″	N05° 47ˈ54″	30.05
SW 4	E007° 02ˈ40.6″	N05° 48ˈ01.4″	56.45
BHW 4	E007° 02ˈ 37.0″	N05° 47ˈ51.11″	7.911
SW 5	E007° 20ˈ09.4″	N05° 50ˈ51.2″	24.45
BHW 5	E007° 02ˈ 34.4″	N05° 51ˈ28.4″	24.89
SW 6	E007° 20ˈ13.5″	N05° 50ˈ51.25″	23.454
BHW 6	E 007°01ˈ3.7″	N05˚27’ 37.5″	234.88
BHW 7	E 007˚02ˈ38.9″	N05˚28ˈ 032″	208.86
BHW 8	E 007˚02.419ˈ	N05˚27.988ˈ	114.147
BHW 9	E 007˚02.245ˈ	N05˚28.277ˈ	11.316
BHW 10	E007^0 02ˈ 395ˈ	N05˚28.487 ˈ	278.28

Water Type	Excellent water quality	Poor water quality	Very Poor water quality	Total
Water Quality Index	0-50	51-100	101	
No. of water samples	7	2	7	16
% of water samples	43.75	12.5	43.75	100

All these samples were from Owerri which geologically is within Benin Formation. This is the same location identified with DRASTIC as a high aquifer vulnerability area (Figure 4).

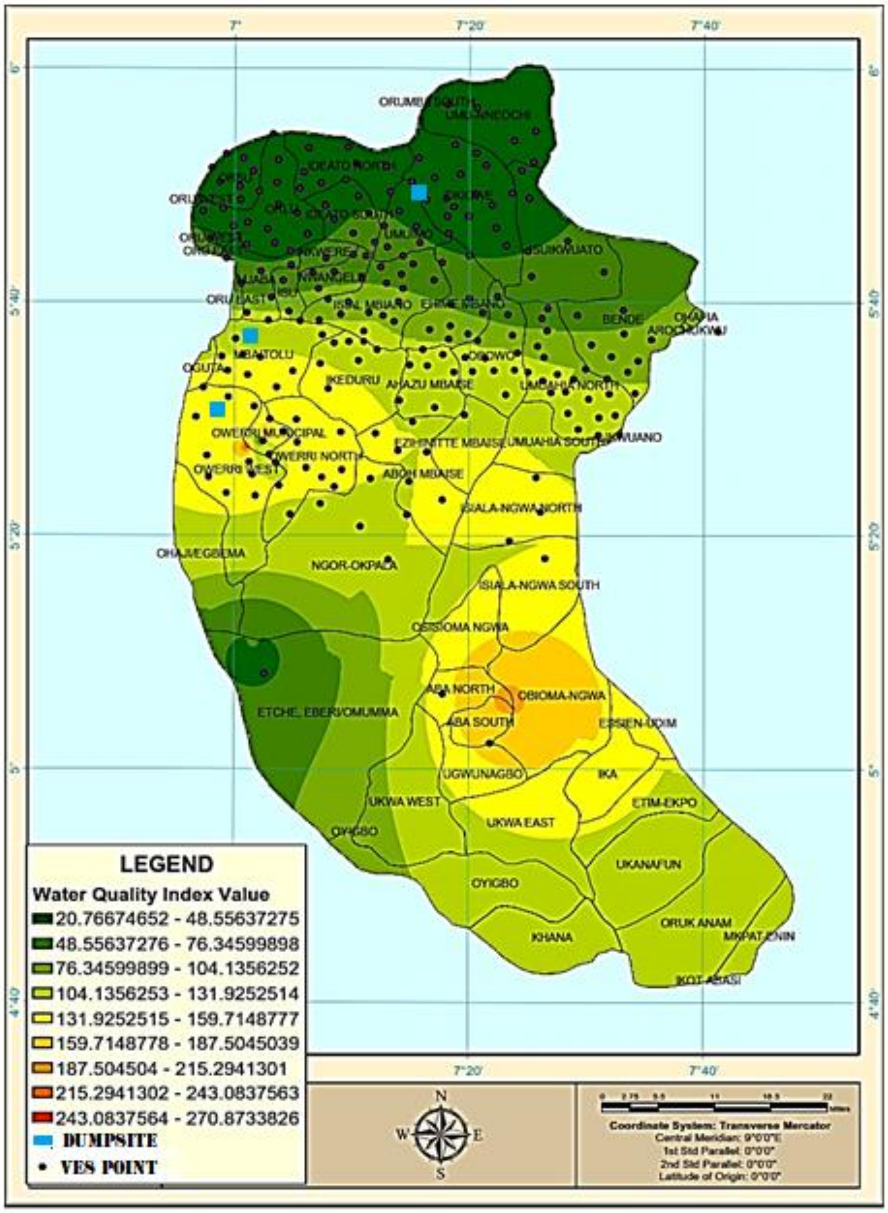


FIG 5 Spatial variation of water quality index of the study area

The spatial variation of the aquifer vulnerability as delineated by the DRASTIC (Figure 4) was compared with the spatial variation of the water quality index (Figure 5). The areas with a moderate aquifer vulnerability in the drastic model also have moderately polluted water quality. This result was not in line with Leal *et al.,*(2012)that opined that there were some inconsistencies between the groundwater vulnerability and the water quality index. The study found out that, while some highly vulnerable areas had water with good water quality, in some locations it was not the same.

The bivariate regression analysis (Fig 6) showed that there is a non-linear relationship between the DRASTIC index and the water quality index. The curvilinear relationship is given by;

$$D = 0.009Q^2 - 1.462Q + 83.137 \qquad 8$$

where D IS THE DRASTIC index (DI)

Q is the water quality index (WQI)

Recall that, Chiedza and Kwazikwakhe (2013) showed that the DRASTIC vulnerability result was consistent with the water quality index in their study carried out in South Africa.

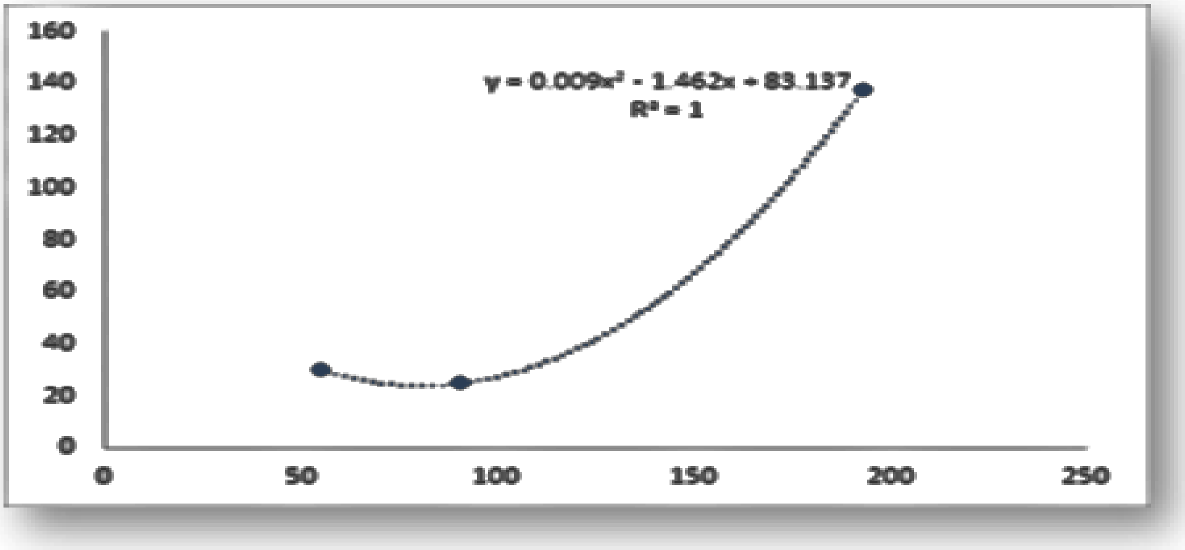


Fig 6 Bivariate regression plot of the DRASTIC Index versus the water quality index

IV. Summary, conclusion, and recommendation

The vulnerability index of the aquifer and the water quality index of surface and groundwater in the Imo River basin were compared and contrasted. Consistency was established in the results gotten from the geophysical and geochemical surveys. The DRASTIC index revealed that areas within Ajali, Ameki, and Imo Shale Formations have low aquifer vulnerability and in the same manner the water samples within these formations, Ajali, Ameki, and Imo shale were characterized by a good to excellent water quality. The areas within Benin Formation and Ogwashi Formation have a moderate to high aquifer vulnerability, similarly, the water quality in this geologic formation was delineated as a poor to very poor water quality. Finally, from the spatial map of the water quality index, the northern part of the study area made up of Ajali Formation and Nsukka Formation was delineated as an area with good-quality water. Also in the southwestern part of the study area was identified areas with good water quality. The aquifers in Benin Formation and Ogwashi Formation are highly vulnerable to contamination. This suggests that more care should be taken in waste management and other environmental and agricultural practices that may be inimical to the portability of groundwater in the study area. The commercial drinking water producers located within the Benin Formation of the study area should take make sure they treat the water to conform with SON drinking water standards before distributing the sachet and bottled water to the public.

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