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Evaluation of Groundwater Vulnerability to Pollution Using Different Models in Njaba and Environs Southeastern Nigeria

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Abstract: *Evaluation of groundwater vulnerability to pollution using different models in Njaba and environs Southeastern Nigeria was carried out with the objective of evaluating groundwater vulnerability to pollution as a basis for developing measures capable of protecting groundwater resources including developing groundwater vulnerability map through application of the DRASTIC, GOD and Le Grand models; classifying the study area into different vulnerability classes; and comparing the results of the DRASTIC, GOD and Le Grand models. The methods adopted in the assessment involved integration of geological, geotechnical and geophysical data into Geographic Information System (GIS) software to generate groundwater vulnerability map. Techniques of the models generally involved parameters rating which are based on the evaluation of various parameters in relation to their capacity for enhancing or attenuating contaminants in the groundwater system. The study area generally occupies a nearly, flat to undulating topography with relatively high groundwater recharge. The area is underlain by predominantly clayey facies in the Northern area which grades into sandy sequences towards the south. Hydraulic conductivity ranges from* 8.4×10^{-4} *to* 1.6×10^{-3} ***m/sec****; with the upper limits reflecting coarse sands and gravelly units. Depth to water table decreases southwards while hydraulic head gradients vary between 0.004 and 0.356. Areas to south were classified as moderate and high vulnerabilities by GOD and DRASTIC models respectively; whereas the LeGrand model revealed that groundwater pollution in this area is possible but not likely to occur. The depth to water table ranges from 56 to 92 m with groundwater occurring in unconfined conditions in most places. The unsaturated zone material of these subareas is composed of sandy and gravelly facies with high hydraulic conductivity and low sorption, this area is not suitable for the location of waste dump. This area requires detailed site investigation and monitoring. Areas to the north were categorized into negligible and low vulnerability by GOD and DRASTIC models respectively; whereas the LeGrand model revealed that groundwater pollution in this area is very improbable. The northern part of the study area is underlain by sandy-clay and clayey facies with low hydraulic conductivity, high sorption capacities, and deep-seated water table in semi-confined to confined condition. This subarea has significant contaminant attenuation and retardation due to the properties of the overburden materials. The area requires a desk study to identify hazards and risk to groundwater. This area may be considered as potential waste disposal sites because of low aquifer sensitivity to human impacts. This research has provided data that will help the decision makers in the sustainable development of the study area in terms of land use and groundwater protection strategies.*

Key Words: *Groundwater Pollution, Vulnerability,LeGrand, DRASTIC, GOD and Njaba*

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I. Introduction

Water is an essential resource and forms the primary need of man in his environment (Ibeneme et al., 2013). It is available in form of groundwater which is very important to man because of its domestic and industrial usefulness to man. Groundwater is vulnerable because of its interaction with surface water and land use activities (Amadi, 2007). Hence, groundwater vulnerability to contamination is the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer (National Research Council, 1993).

DRASTIC, GODandLeGrandmodelswere employed in the evaluation of groundwater vulnerability because of their general applicability to available data as well as their computational ease. Models results are in the form of indices which provide relative measures of vulnerability of one area compared to others.

Evaluation of groundwater vulnerability to pollution using different models in Njaba and its environs was carried out to evaluate groundwater vulnerability to pollution in Njaba and environ. Groundwater contamination is one of the most serious global environmental problems facing human race.Groundwater is not easily polluted, but once polluted; its remediation becomes almost impossible.Uncontrolled sand mining, mechanical and manual dredging, indiscriminate siting of poorly engineered dumpsites and improper disposal of condemned engine oil from mechanic shops are some of the potential sources of groundwater contamination in the study area. Though, there is no record of groundwater pollution in the area investigated in this study. However, assessing groundwater quality and developing strategies to protect aquifers from future contamination are necessary in planning and designing water resources, making informed environmentally sound decisions regarding land-use and ensuring their sustainable development of the resources.Therefore, the objectives of the study are: (1) to develop groundwater vulnerability map using DRASTIC, GOD and LeGrand models (2) to compare the results of the different models (3) to classify the study area into different vulnerability classes; and (4) to determine the percentage of the area covered by each vulnerability class.

II. Study Area Description and Geology

The study area Njaba and its environs are in Imo State Nigeria and lies between latitudes 5°47’ and 6°00’ and longitude 6° 15’ and 7° 33’ (Figure 1). The area is underlain by Benin, Ogwashi, and Ameki Formations. Benin Formationwhich is the major stratigraphic unit in the Niger Delta Basin of Nigeria,comprises of sands, silts, gravel and clayey intercalations. The Ogwashi formation is characterized by alternation of clays, sands, grits and lignites (Bassey and Eminue, 2012). Ibeneme et al (2013) agreed that Ogwashi–Asaba formation apart from occurring mainly in Benin, Asaba and Onitsha, also occurs in Orlu areas.

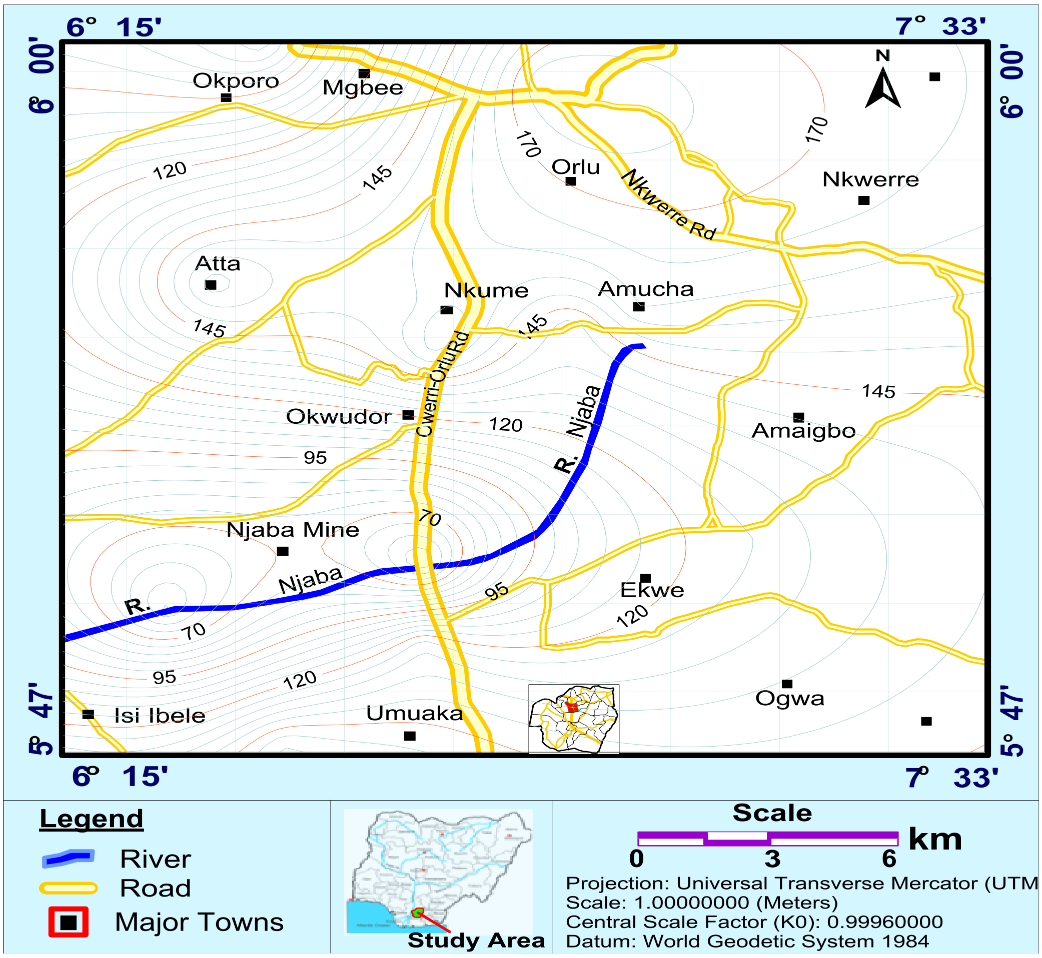


Figure1: Topographic Map Showing the Study Area.

III. Materials and Methods

The methods adopted in the assessment involved integration of geological, geotechnical and geophysical data into Geographic Information System (GIS) software to generate groundwater vulnerability map. DRASTIC, GOD and Le Grand models were employed in the study. Techniques of the models generally involve parameters rating which are based on the evaluation of various parameters in relation to their capacity for enhancing or attenuating contaminants in the groundwater system.

3.1DRASTICModel

The DRASTIC model was designed as an easy-to-use model that wouldallow a user with basic knowledge of hydrogeology to assess the relative potential for groundwatercontamination. DRASTIC index (DI) is expressed as the sum of product of ratings and weights assigned to each of the parameter. That is, DRASTIC Index = $D_RD_W + R_RR_W + A_RA_W + S_RS_W + T_RT_W + I_RI_W + C_RC_W$. (1)

Where *D*, *R*, *A*, *S*, *T*, *I*, and *C* represent the seven parametersin the model: depth to-water table, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity, r is the rating, and w is the weight assigned to each parameter. These variables or parameters are utilized to define the hydrogeologic setting ofan area. These parameters are further subdivided into ranges or zones that represent various hydrogeologicsettings and are assigned different ratings on a scale of 1 to 10. The rating assigned to each range or zoneindicates the relative importance of each parameter within the zone in contributing to aquifer vulnerability.The resulting index is a relative measure of vulnerability to contamination. Shown in Figure 2 is the DRASTIC model evaluation approach.

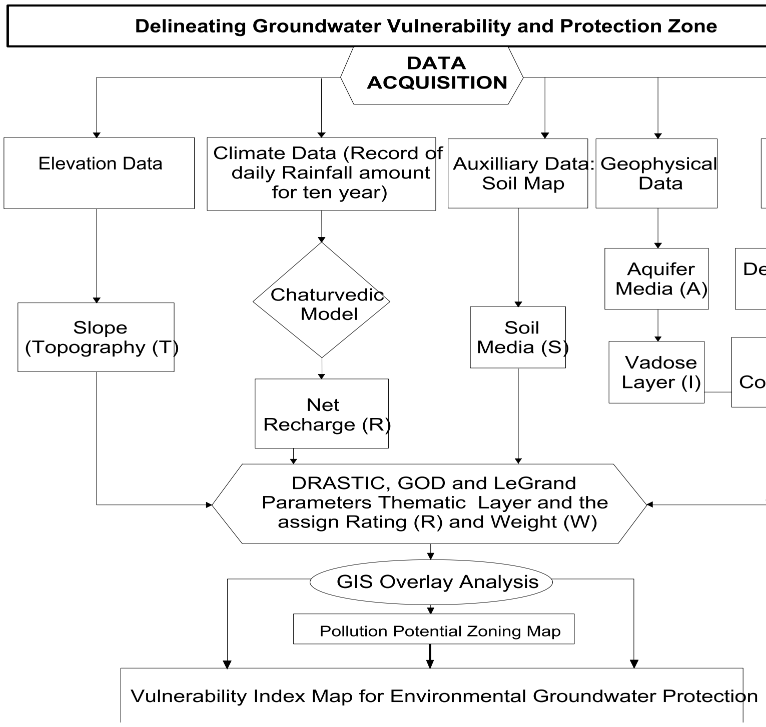


Figure 2: Conceptual Flowchart Representing the Methodology used in the study.

This study utilizedseveral data types, and the sources are presented in Table 1.

Table1: Information and sources of data used in the study

Data Type	**Data Source**	**Format**	**Parameter**
Borehole data	AIRBDA	Lithology log	Depth to water table D
Average annual rainfall	AIRBDA	Table	Recharge (R)
Geophysical Data	-	Lithology log/point	Aquifer (A)
Soil map	Ministry of Agriculture, Imo State	Map	Soil type
GPS/Remote sensing imagery	NASRDA(LP DAAC) Resolution 30m	Satellite image	Slope (T)
Geophysical Data	-	Point	Impact of Vadose Zone (I)
Borehole data	AIRBDA		Hydraulic Conductivity
Boreholes data	Anambra Imo River Basin Development Authority (AIRBDA)	Boreholes data	Groundwater Occurrence
Geological map 1/50 000		map	Overall Lithology of Aquifer
Wells Data		Lithology log	Depth to Water table

The depth-to-water table (D) is one of the most essential parameters in evaluating pollution potential because it provides a greater chance for natural attenuation in terms of dispersion, absorption, and biodegradation to occur as the depth to water increases(Ckakraborty, 2007).Depth to water table was computed based on the field data during 2017-2018.

Table 2: Probability Ratings and Weight for Depth to Water table after (Mogajiet al., 2014)

DRASTIC Parameters	Ranges (Classes)	Pollution potentiality for groundwater	Rating	Weight
Depth to water table	0-15	High	10	5
	15-30	Medium high	8	
	30-50	Medium	6	
	50-75	Low	4	
	75-100+	Very low	2	

Net Recharge (R). Net Recharge is the total quantity or amount of water which infiltrates and enters the aquifer. This study adopted 10 years daily records of precipitation between 2004 and 2013 to estimate net recharge in the area.

Table 3: Rainfall Intensity Duration (mm) from 2008 to 2017(Source: AIRBDA-Anambra Imo River Basin Development Authority)

MONTH	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
JAN	1.4	11.5	58.5	0	0	39.4	33	0	0	59.3
FEB	34	91.4	0	14.3	0	65.8	36	131.9	90.9	56.5
MAR	17	79.5	29.9	48.9	95.7	81.5	36.2	75	55.3	83.2
APRIL	183.1	139.8	95.5	178.2	186.9	237.8	125.5	99.2	187.4	198.7
MAY	268.2	555.3	390.5	368.3	234.5	250.2	382	413.3	306.1	330.7
JUNE	318.1	276.1	468.8	333.5	307.4	208.9	207.7	196.8	518.5	185.9
JULY	313.1	430.3	595.1	320.7	531.2	486.3	86.1	289.5	516	263.1
AUG	252.6	156.2	199.4	238.1	315.6	485.9	318.4	465.8	367.7	243.6
SEPT	352.9	514.1	429.6	402	409.9	558.1	382.2	283.8	493.9	254.2
OCT	311	215.5	264.4	108.4	235.3	207.2	398.8	257.9	211.8	159.9
NOV	52.9	20.4	6.7	89.7	61.1	111.8	108.6	69.8	86.2	56.5
DEC	0	13.2	0	9.9	10.3	0	0	130	0	84.1
Sum	2104.3	2503.3	2538.4	2112	2387.9	2732.9	2114.5	2413	2833.8	1975.7
Average	175.4	208.60	211.5	176	199.0	227.74	176.2	201.1	236.2	164.6
Average for 10 years			2371.58							

Aquifer and Soil Media

Table 4: Aquifer Media and Soil Media (After Ibe et al., 2001)

Aquifer material (Weight = 3)		Soil Media (Weight = 2)	
	Rating	Soil Material	**Rating**
Shale	1	Clay/organic soil	1
Till	3	Loamy clay	4
Silt	3	Clayey Loam	5
Schist	4	Loam	7
Sandstone	5	Sandy loam	8
Limestone	6	Loamy sand	9
Green rocks	6	Sand and gravel	10
Sand	8		
Sand and gravel	9		
Gravel	10		

Topography: The degree of slope, which varies from one place to another controls the likelihood that flood and the contained pollutants will have to run off or be retained in one area long enough to infiltrate it.

Table 5: Slope used in the evaluation of the slope layer after (After Ibe et al 2001)

Parameter	Ranges (Classes)	Rating	Pollution potentiality for groundwater	Weight
Slope	0 - 2 (Flat)	10	High	1
	2– 4	9		
	4 – 6 (Undulating)	8	Medium high	
	6 – 8	7		
	8 – 10 (Rolling)	6	Medium	
	10 – 12	5		
	12 – 14 (Moderately steep)	4	Low	
	14 – 16	3		
	16 – 18	2	Very low	
	> 18 (very Steep)	1	Very low	

Impact of Vadose Zone
The vadose zone influences the aquifer pollution potential depending on the permeability and attenuation characteristics of its soil cover media. The vadose zone thematic layer was generated using the ratings and weight assignment in Table 6.

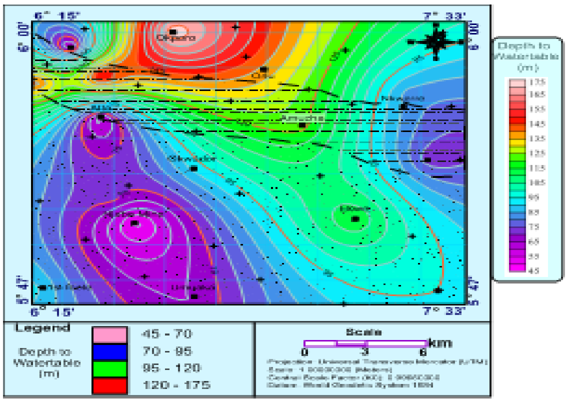
Hydraulic Conductivity. Hydraulic conductivity for each sample was subsequently computed from the sediment Granulometry data using the Hazen empirical formula (Freeze and Cherry, 1979):

$$K = A(d_{10})^2 \qquad (5)$$

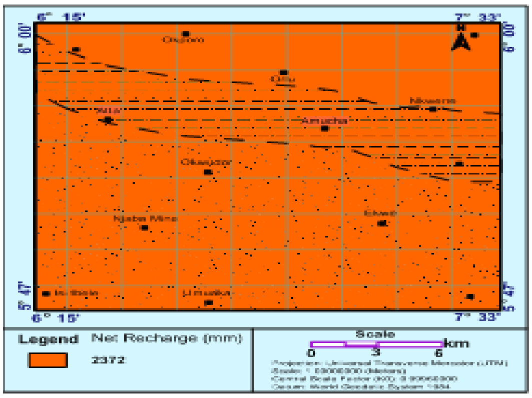
Where, K= the individual hydraulic conductivity values represent point values that govern groundwater flow within each lithological layer (parallel flow); d_{10} = the effective grain size value in (mm) at 10% passingread from the semi-logarithm graph. A is a dimensionless coefficient and its value is equal to 0.01. The bulk or effective hydraulic conductivity in the downward or vertical direction (K_z) governs groundwater flow across lithologic layers.

Table 6: Vadose zone and Hydraulic Conductivity (After Ibe et al., 2001)

Impact of Vadose Zone Weight (W) = 5		Hydraulic Conductivity K(ms^{-1}) Weight (W) = 3	
	Rating (R)		Rating (R)
Clay	1	< E- 08	1
Shale	2	E- 08	2
Silt	3	E- 07	3
Schist	4	E- 06	5
Till	4	E- 05	6
Green rocks	5	E- 04	7
Sandstone	5	E- 03	8
Limestone	6	E- 02	9
Sand	8	E- 01	10
Sand and gravel	9		
Gravel	10		



(a)



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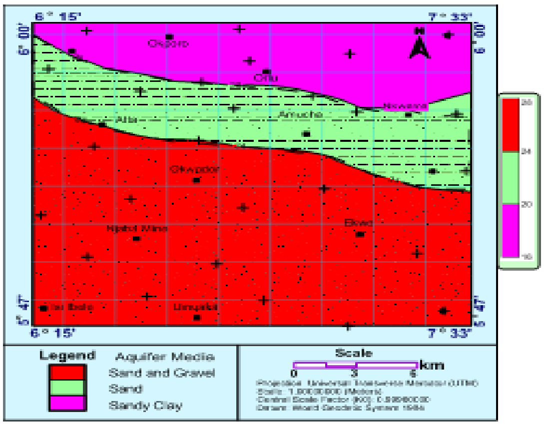

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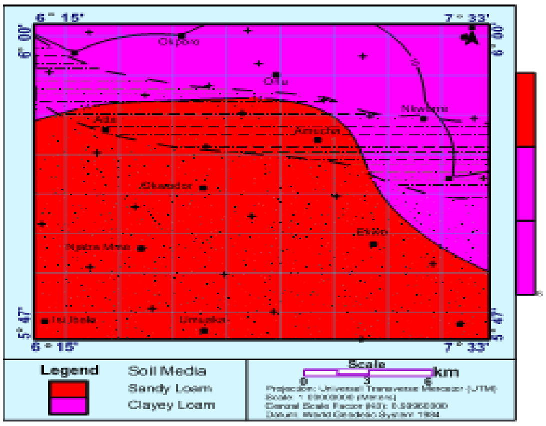

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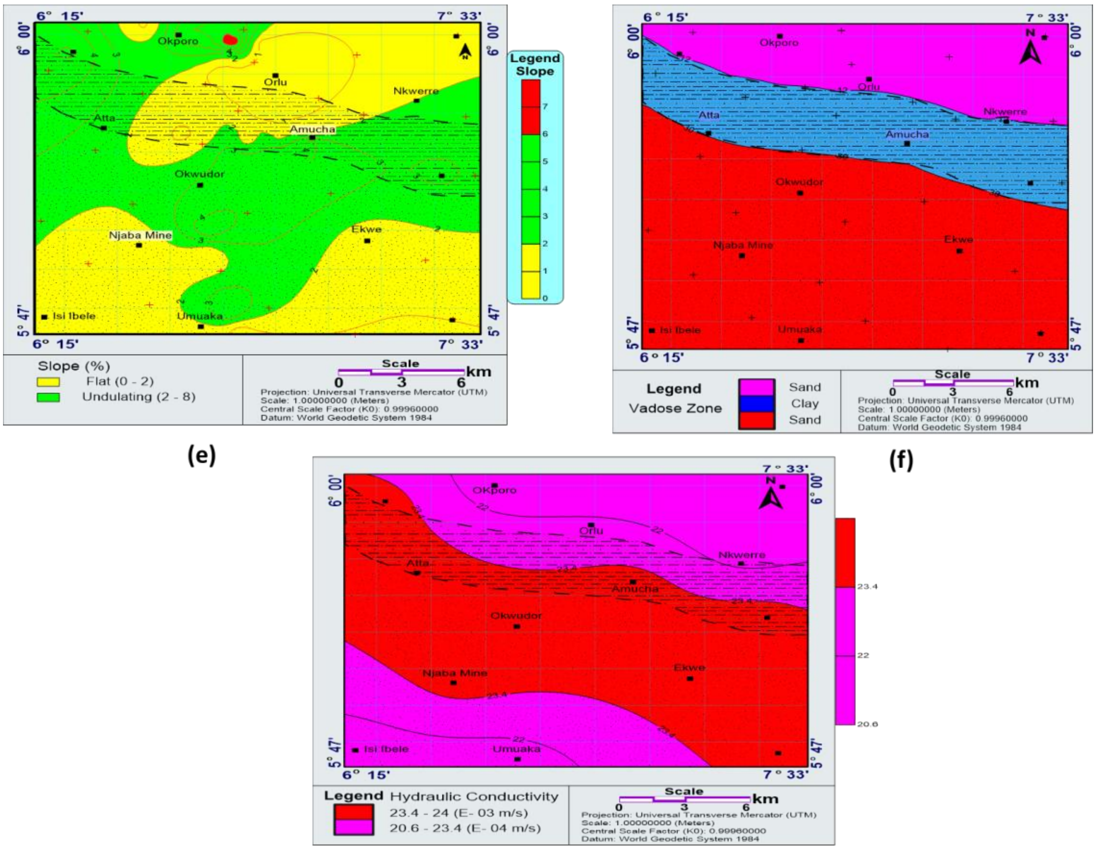

(e)

(f)

(g)

Figure 3: Groundwater pollution potential influencing factors used for DRASTIC model: (a) Depth to water table layer; (b) Rainfall data layer; (c) Aquifer media; (d) Soil media; (e) Topography/slope; (f) Vadose zone layer and (g) Hydraulic conductivity

3.3 Groundwater Vulnerability Assessment Using GOD Model

GOD model is alternative overlay and index approach, which considers the groundwater occurrence (G) (recharge), overall lithology of aquifer or aquitard (O), and depth to groundwater (D). The GOD method evaluates groundwater occurrence as the degree of confinement of the water table. overall lithology of aquifer or aquitard (O)was obtained from the digitization of the geological map of the study area. According to Foster et al. *(*2006) vulnerability indices are calculated by multiplying the rating values assigned to each of the three parameters of the method (see equation 4).

GOD vulnerability Index = $\mathbf{G} \times \mathbf{O} \times \mathbf{D}$ (4)

Table7 shows that for each parameter, the range of possible values varies from 0 (minimum vulnerability) to 1 (maximum vulnerability). GOD values were matched with a qualitative scale of vulnerability.

Groundwater Occurrence

Table 7: GOD Values and Corresponding Classes of Vulnerability (Adapted from Vogel, 2008)

Parameter	Range	Description
STEP I	0	None
Groundwater Occurrence		Overflowing
Rating	0.2	Confined
	0.3	Semi-confined
	0.5	Semi-unconfined (covered)
	1.0	Unconfined
	0.4	Residual soil
	0.5	Alluvial loose soil
	0.6	Aeolian sands
	0.7	Alluvial and fluvio glacial sands + gravel
	0.8	Colloidal gravel
	0.8 – 1.0	Unconsolidated (sediments)
STEP II	0.4	Residual soils

Overlying Lithology Rating	0.5	Alluvial soils
	0.6	Aeolian sands
	0.7	Alluvial and fluvio-glacial sands + gravels
	0.8	Colluvial gravels
	0.9 – 1.0	Unconsolidates (sediments)
STEP III	> 100	0.4
Depth to Water Rating (unconfined or confined)	50 -100	0.5
	20 – 50	0.6
	10 - 20	0.7
	5 – 10	0.8
	2 – 5	0.9
	< 2	1.0

The GOD vulnerability index was estimated using the evaluation procedure in Table 7.

(a) Groundwater Occurrence

The thematic map (Figure 4a) shows that the aquifer in the northern part of the study area is confined whereas aquifer in the southern part of the study area is generally unconfined.

(b)Overall Lithology of Aquifer

The map shows that the study area contains heterogeneous geological formations. The area with red colour represents sands and gravel (Benin Formation); whereas the area with pink and light green colour represents clay and sand. This parameter represents the degree of consolidation of the strata above the water table

(c) Depth to Water table

The depth to water in the area designated with pink colour ranged from 45 to 70m, blue colour ranged from 70 to 95m; green colour ranged 95 from 130m; whereas the depth to water table in the area designated with red colour ranged from 130 to 175m.

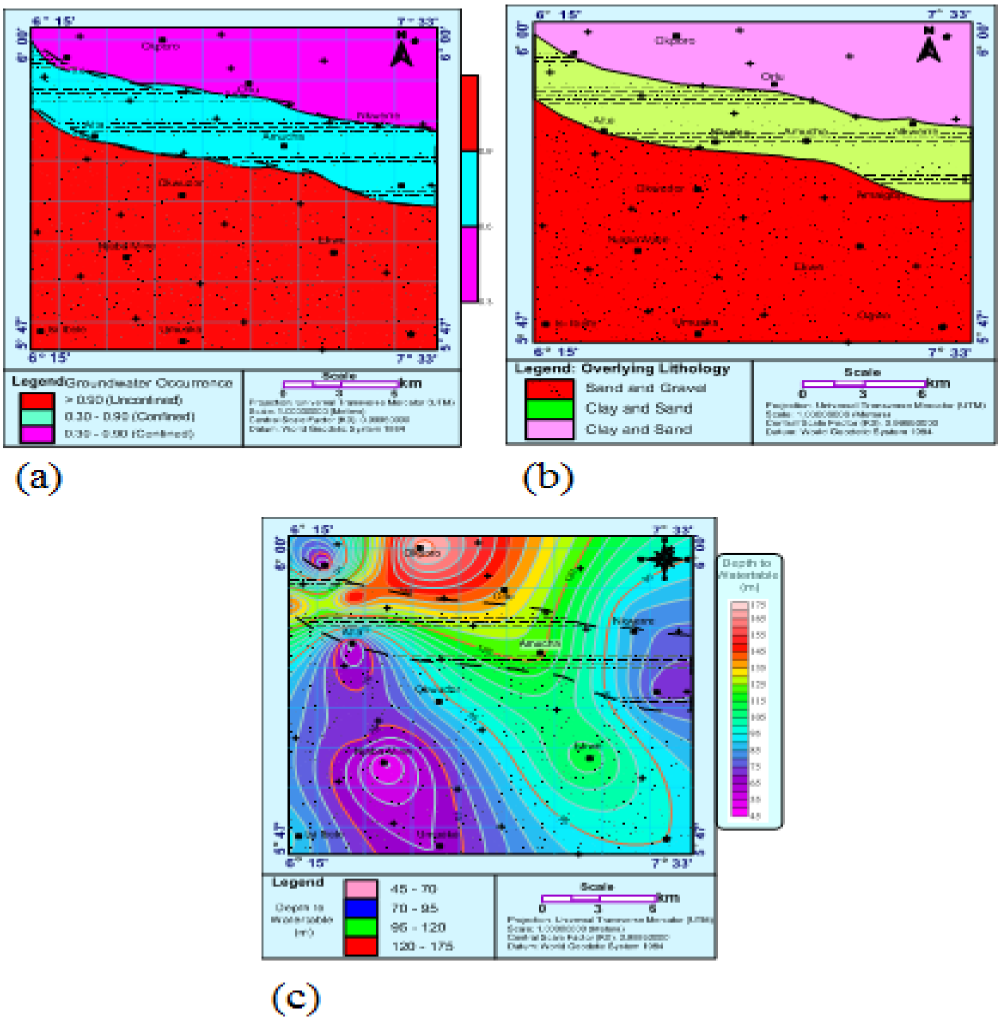

Figure 4: Groundwater pollution potential influencing factors used for GOD model: (a) Groundwater Occurrence;(b) Overall Lithology of Aquifer and (c) Depth to Water table

3.4 Groundwater Vulnerability Assessment Using Le Grand Model

The Le Grand Model is a rating system where a fixed range of values is assigned to parameters that are judged necessary and adequate for vulnerability assessment. Parameters of the model include: depth to water table, sorption above the water table, hydraulic conductivity, water table gradient, and horizontal distance to a pollution target.The rating charts (Figure5) illustrate the evaluation procedure for thesefactors.

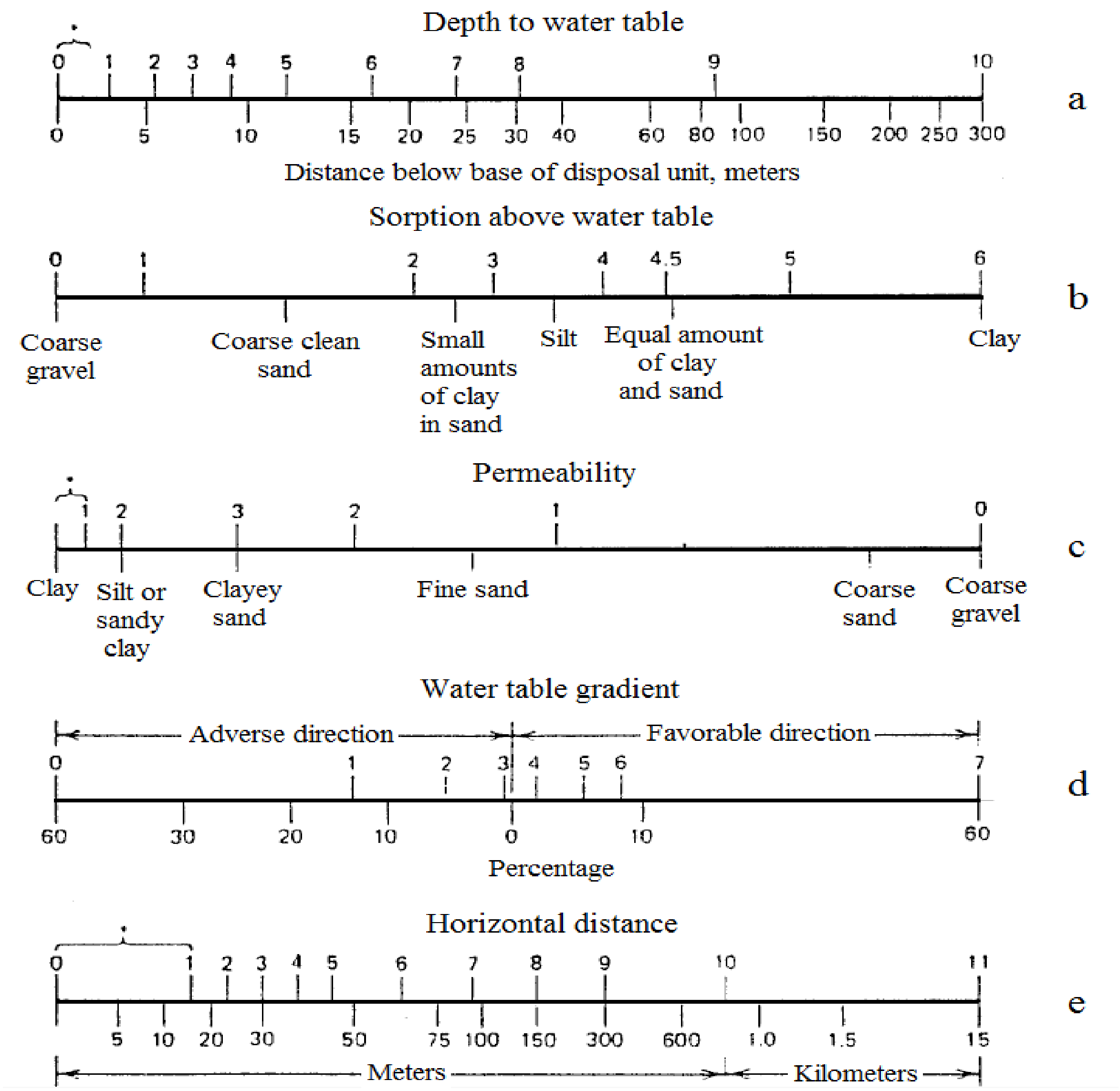

Figure 5: Groundwater Vulnerability Rating Charts for the LeGrand Model.

3.4.1 Static Water Level and Hydraulic Head Measurements

Static Water Level(s) measurements were delineated from the borehole lithologs while the elevations of the boreholes were measured with the aid of Geographic Positioning System (GPS). Hydraulic head (h) was determined as $h = E - s$ (5)

where E = elevation; s = depth to water table (Table 8).

The Hydraulic Gradient (I) was computed using the relation established by Freeze and Cherry (1979):

$$I = \frac{dh}{ds} \qquad (6)$$

where:dh = the difference in hydraulic head between two boreholes (piezometers);ds= the distance between the two boreholes (piezometers).

Table 8: ShowingHydraulic Head and Hydraulic Gradient

Location	Elevation (m)	Water table	Hydraulic Head, h = E – s	Change in hydraulic head, (*dh*)	Horizontal Distance (m)	Hydraulic Gradient
Njaba mine	126	72	54	4	300	0.013
	115	65	50			
Umuaka	161	108	53	0	200	0
	145	92	53			
Isi Ibele	155	92	63	17	500	0.034
	152	106	46			
Orlu	198	104	94	26	73	0.356
	182	114	68			
Okwudor	135	92	43	1	250	0.004
	120	76	44			
Amucha	195	122	73	33	420	0.079
	162	122	40			
Ekwe	155	115	40	22	126	0.175
	173	111	62			
Atta	151	59	92	23	650	0.035
	177	62	115			
Nkwerre	140	114	26	69	230	0.300
	162	67	95			

IV. Results and Discussion

Table 9: The Available Data of Depth to Water table in the Study Area

S/N	Location	Depth to water table (m)
1	Njaba mine site	65 – 72
2	Umuaka	58 – 65
3	Orlu	104 – 175
4	Okwudor	92
5	Ekwe	111– 115
6	Atta	56 – 65
7	Isi Ibele	92 – 105
8	Amucha	122
9	Nkwerre	98 –114

This silty-sand aquiferous unit in some localities is sandwiched between two sandy aquifers, an upper unconfined or confined aquifer, and a lower confined aquifer.From borehole lithologs, the depths to water table range from 56m (184ft) to 175m (574ft). In the southwest, the overburden consists of silt and sandstone and is about 48m thick, with aquifer thickness of 30m. Areas around the Njaba River mine site, the aquifer material is composed of coarse sand with thickness of 20m; whereas the overburden consists of silt and sand.

Information gathered from the lithologs of borehole in Atta reveals that the overburden material consists of sand, sandstone and clay, with overburden thickness of 30m whereas the aquifer thickness is 15m (Fig. 4.1).Similarly, borehole lithologs in Orlu reveals that the overburden material consists of clayey sand, clay and sand, with overburden thickness of 80m whereas the aquifer thickness is 25m.

Lithologs of borehole in Amucha reveals that the soil media comprises of lateritic sand with thickness of 15m. The overburden material consists of sandy clay, clay and sand, with thickness of 77m whereas the aquifer thickness is 30m.

(b) Net Recharge

The net recharge value of 327.75 was obtained using the modified version of the Chaturvedic (1973) formula (Equation 5).The net recharge was considered to be uniform within and around the study area and also represents the annual average amount of water that infiltrates the vadose zone and reaches the water table Alleret al.(1987). The higher the net recharge, the more vulnerable is the groundwater reservoir.

(c) Aquifer Media

The aquiferous material in the area covered by red colour is composed of sand and gravel. This type of aquiferous material is found within Benin Formation. The aquiferous material in the area covered by green colour is majorly of sand. This type of aquifer material is found across the three Formations; whereas the aquiferous material in the area covered by pink colour is composed of sandy clay. This type of aquifer material dominates the Ameki Formation. It suggests that the aquifer with sand and gravel is more permeable than sandy clay. It is the large pore spaces between aquifer materials that promote advection flow of contaminants (Figure 3c).

(d) Soil Media

The area with red colour represents area underlain by sandy loam. The soil type feels gritty but contains some silt and small amount of clay. The amount of silt and clay is sufficient to hold the soil particles together when moist. Besides, the surface soil colour is dark which indicate high organic matter content with relatively free movement of air and water in the soil mass. This area covers Njaba River mine site, Atta, Isi Ibele, Okwudor and Umuaka.

The area designated with pink colour represents clayey loam soil. This soil type is smooth when dry and silky when wet. Though silt and sand are present in appreciable amount but are dominated by clay. Also, the surface soil colour is yellow which indicate low organic matter content with high water content and not well, aerated in the soil mass. This area comprises of Orlu and Nkwerre (Figure3d).

The soil profile is somewhat uniform throughout the study area. Generally, the study area is underlain by intensely weathered and leached uniform sands, loamy sands and clays.

(e) Topography

The area with the yellow colour (Ekwe, Umuaka and Isi Ibele) are characterized by low slope degree (flat) and tend to retain water for longer time, hence providing greater chance for the infiltration of recharge water, which may contain a considerable amount of pollutants. Other areas have undulating slope on the account of having slope percentage above 2%. This implies that the pollution potential for groundwater is high (Figure 3e).

(f) Impact of Vadose Zone

The vadose zone in area to the southern part (red colour) of the study area Njaba River mine site, Okwudor, Ekwe, Umuaka, Atta and Isi Ibele axes is vastly permeable; hence, the probability of aquifer in such areas to be vulnerable to pollution is very high. The vadose zone in areas dominated with blue colour is permeable and porous, but there are lignite seam that overlay the friable sand. This area is underlain by Ogwashi Formation. Areas identified in this zone include Atta, Amucha, and Nkwerre. On the other hand, the vadose zone in areas to the northern part (pink colour) is less permeable (Fig. 3f). This area comprises of Orlu and Okporo.

(g) Hydraulic Conductivity (C)

A low transmissivity zone (1.0 E $^{-4}$ m/sec) exists towards eastern and western zones of the study area. The hydraulic conductivities of samples atOkwudor, Njaba sand mine and Amucha increase from top to bottom; whereas that of Orlu decrease from top to bottom. This implies that the lateritic soil seem to have high pore pressure build up due to its inability to allow water to infiltrate adequately.

Table 10: Effective Hydraulic Conductivity (K_Z) in the Downward Direction

Location	**Overall Thickness (b)**	**No. Layer**	**LithologicThickness (bi)**			**K = $A(d_{10})^2$ (m/sec) (ki)**			**Kz**
			Top	**Middle**	**Bottom**	**Top**	**Middle**	**Bottom**	
Njaba mine site	52	3	16	10	24	0.0004	0.0004	0.00102	0.000587
Umuaka	48	3	4	6	38	0.0001	0.001	0.01	0.000964
Orlu	95	5	15	17	58	0.0225	0.00014	0.0001	0.000136
Okwudor	66	6	26	19	8	0.00063	0.0012	0.0016	0.001063
Ekwe	68	4	5	27	36	0.0001	0.001	0.01	0.000844
Atta	44	4	4	7	30	0.00032	0.0012	0.00084	0.000814
Isi Ibele	66	3	8	26	32	0.0001	0.001	0.01	0.000604
Amucha	92	6	15	30	27	0.0004	0.00102	0.0014	0.001067
Nkwerre	66	5	26	22	7	0.0001	0.001	0.01	0.000233

The effective hydraulic conductivities of the area ranged from $1.36 \times 10^{-4}$to 1.067×10^{-3} m day^{-1}. The highest effective hydraulic conductivity was obtained at Amucha; whereas the least value was obtained at Orlu.

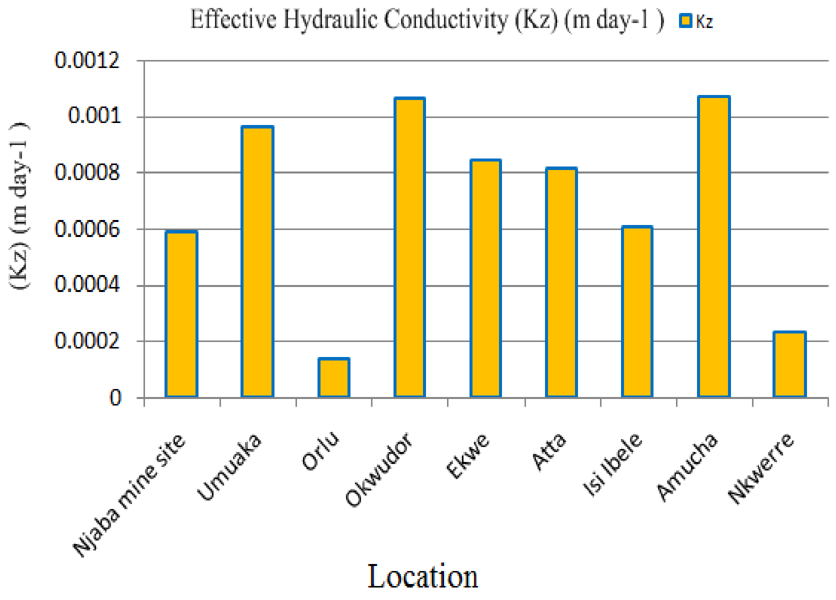

Figure 6: Effective Hydraulic Conductivity (K_z)

The result reveals that the hydraulic conductivity of the middle layer of the lithologic profile in Atta is highest followed by the bottom and the least is the top section (Table 10).
Therefore, the area (red colour) underlain by water bearing formation (aquifer) with high hydraulic conductivity is more vulnerable to potential contamination, relative to other areas (pink colour) with lower hydraulic conductivity.

4.2 Groundwater Vulnerability Assessment Using DRASTIC Model Map

Table 11: Calculations of DRASTIC Index (DI)

Location	D (W=5)		R(W=4)		A(W = 3)		S (W = 2)		T(W =1)		I(W= 5)		C(W=3)		DI
	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	R	R×W	∑ R×W
Umuaka	4	20	10	40	8	24	8	16	10	10	8	40	7	21	171
Mine Site	4	20	10	40	9	27	9	18	8	8	8	40	8	24	177
Okwudor	2	10	10	40	9	27	9	18	8	8	8	40	8	24	167
Atta	4	20	10	40	9	27	8	16	8	8	8	40	8	24	175
Ekwe	2	10	10	40	9	27	8	16	10	10	8	40	8	24	167
Isi Ibele	2	10	10	40	8	24	8	16	10	10	8	40	7	21	161
Orlu	2	10	10	40	8	18	5	10	9	8	1	5	7	21	111
Amucha	2	10	10	40	9	27	8	16	8	8	8	40	8	24	165
Nkwerre	2	10	10	40	8	18	5	10	9	9	1	5	7	21	111

The DRASTIC vulnerability index varied from 111 to 177. The resulted index was divided into three equal intervals and classified into three possible groundwater vulnerability zones.

Table12: Classification of Groundwater Vulnerability Zones using DI Values

DI Values	Classifications	Colour	Area Covered
155 – 177	High vulnerable (HV)	Red	67 %
133 – 155	Moderate vulnerable (MV)	Green	17.2%
111 – 133	Low vulnerable (LV)	Pink	15.8%

The result of groundwater vulnerability analysis using the DRASTIC model reveals that the high vulnerability zones are present in the southern region of the study area (red colour zone). This zone is classified as “High Vulnerability”. These areas have high vulnerability in respect to pollution. Soil media and impact of vadose zone are responsible for the high vulnerability. The unsaturated zone is highly permeable. This implies that urgent attention is required to protect groundwater resource within and around Njaba mining site, Okwudor and Amucha axis.

Consequently, this area is not suitable for siting waste dump because of the sensitivity of the area on the account of its high hydraulic conductivity and net recharge.The area with green code is classified as “Moderate vulnerability”. The vulnerability potential in respect to pollution is neither low nor high. The low vulnerability zones are present in the Northern part of the study area (pink colour). These areas includeOkporo, Orlu and Nkwerre etc. These areas indicate low vulnerability potential in respect to pollution (Figure9). High sorption and attenuation properties of the soil media and vadose zone are responsible for the low vulnerability. Hence, the higher the DRASTIC index, the greater the groundwater pollution potential.

The high, moderate and low vulnerability zones cover about 67 %, 17.2% and 15.8% of the total study area. It is apparently obvious from the vulnerability map that more than 50 % of the study area is dominated by high vulnerable zones followed by moderate zone respectively (Figure7). Consequently, the high vulnerability zones are highly susceptible to contamination AtiqurRahman (2008).

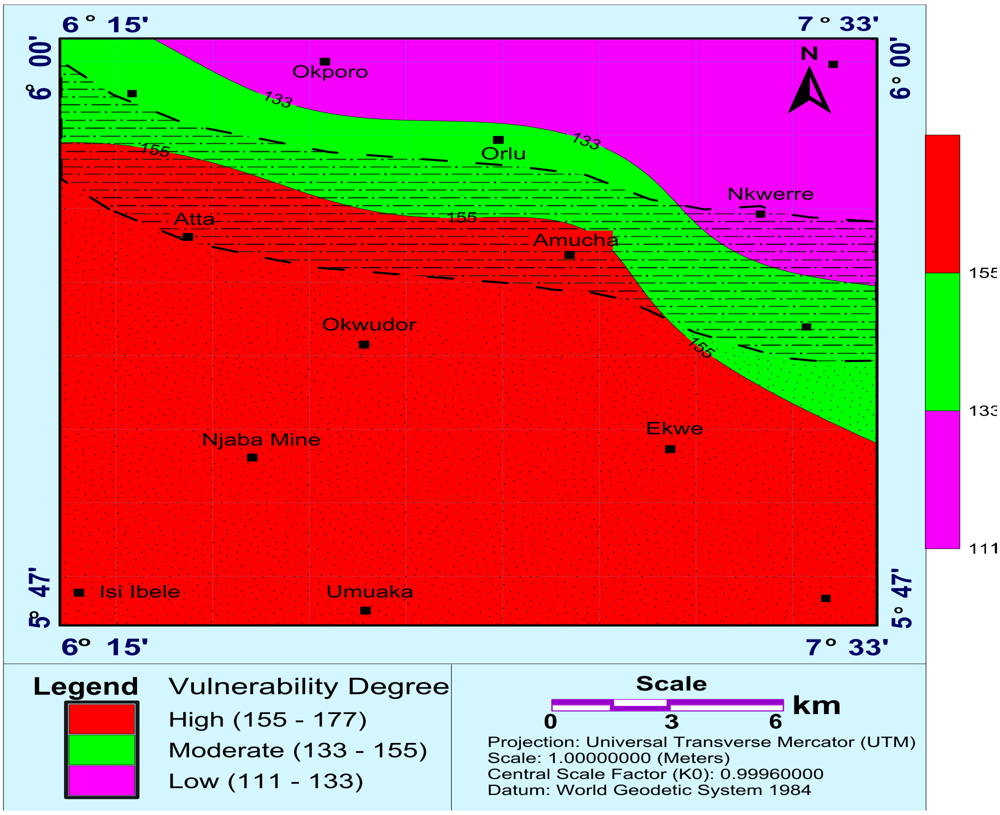

Figure 7: Vulnerability Map of the Study Area

4.3 The GOD vulnerability index ranges from 0.1 and 0.45 and are reclassified according to the categories of groundwater vulnerability assessment Table 14

Table 13: Groundwater Vulnerability Assessment Results Based on the GOD Model

Location	**Parameters**			**Rating**			**Total Score**	**Vulnerability**
	G	**O**	D	G	**O**	D		
Njaba mine site	Un-confined	Alluvial Sands	72	1.0	0.8	0.5	0.4	Moderate
Umuaka	Un-confined	Sands and gravels	65	1.0	0.7	0.5	0.35	Moderate
Orlu	Semi-Confined	Clay and sands	175	0.5	0.5	0.4	0.1	Negligible
Okwudor	Un-confined	Clay and sands	92	1.0	0.5	0.5	0.25	Low
Ekwe	Un-confined	Sands and gravels	115	1.0	0.7	0.4	0.28	Low
Atta	Semi-confined	Clay and sands	59	1.0	0.5	0.5	0.25	Low
Isi Ibele	Un-confined	Sands and gravels	92	1.0	0.7	0.5	0.35	Moderate
Amucha	Un-confined	Sands and gravels	122	1.0	0.7	0.4	0.28	Low
Nkwerre	Semi-Confined	Clay and sands	114	0.5	0.5	0.4	0.1	Negligible

Table 14: Final Vulnerability Rating

Final Vulnerability Rating	Class of Vulnerability
0- 0.1	Negligible
0.1- 0.3	Low
0.3-0.5	Moderate
0.5-0.7	High
0.7- 1.0	Extreme

The GOD index values in Tables 14 were classified into three possible groundwater vulnerability zones (Tables 14). The red colour zone with GOD index ranging from 0.24 to 0.40 was classified as "Moderate vulnerability" (Table 14). This zone includesNjaba mining site, Umuaka, Ekwe and Isi Ibele axis.The moderate vulnerabilityzoneis majorly underlain by the Benin Formation (southern region of the study area). The porous and permeable nature of the overlying lithologic profile is responsible for the moderate vulnerability. This suggests that groundwater in this zone could be vulnerable to pollutants, if pollutants are continuously discharged or leached. Also, the impact of human activities in this area could affect the groundwater table.

The green colour zonewith GOD index ranging from 0.14 to 0.24 was classified as "Low vulnerability" (Table 14). This area includesOkwudor Atta and Amucha.The low vulnerability zones are mostly underlain by Ogwashi Formation. Groundwater in this area could only be vulnerable to the most persistent pollutants in the long term, if the pollutants are continuously and widely discharged or leached.

The pink colour zonewith GOD index ranging from 0.04 to 0.14 was classified as "Negligible vulnerability" (Table 4.12). The areas include Orlu, Nkwerre, and Okporo. The Negligible vulnerability zones are mostly underlain by Ameki Formation. These areas have confining beds that prevent any significant vertical groundwater flow.

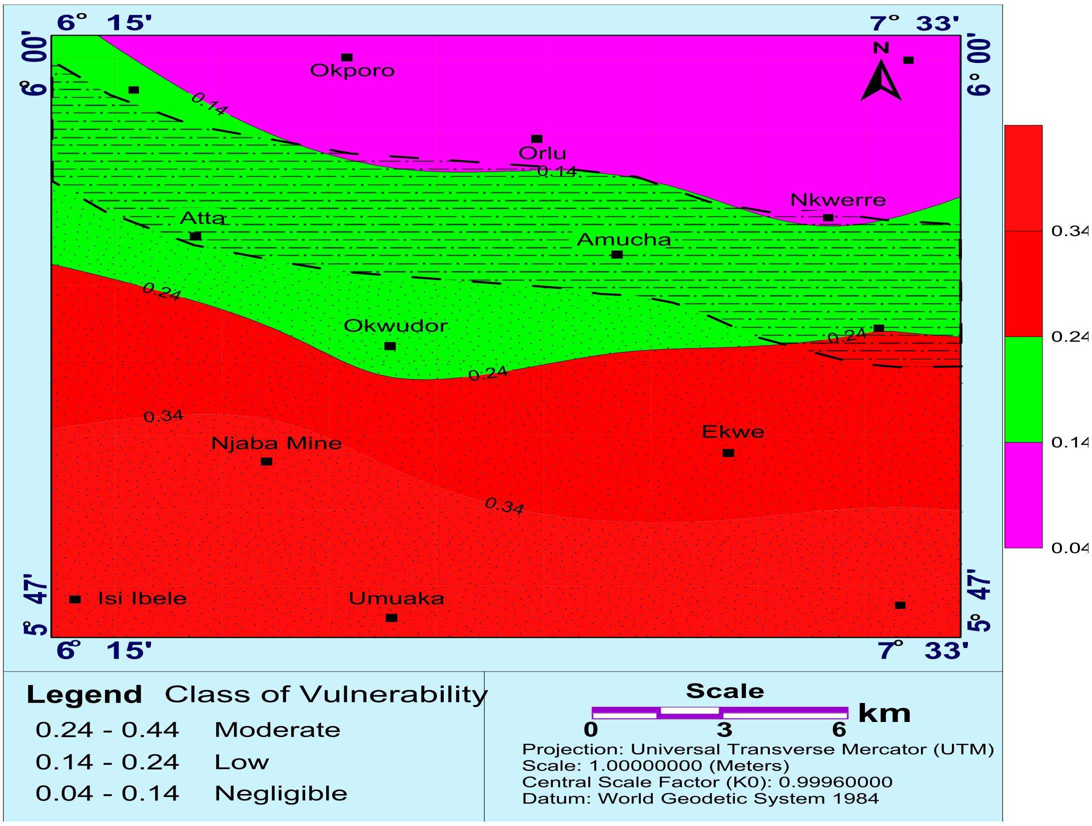

Figure 8: GOD Model showing Vulnerability Map of the Study Area

Besides, the analysis of the Figure 4.14 reveals that negligible, low and moderate vulnerability zones account for 21 %, 53% and 26% of the study area respectively.

4.4 Groundwater Vulnerability Assessment Using Le Grand's Model

A vulnerability index was obtained as the sum of the numerical rating of the five parameters in each location Table 15.

Table 15: Result of Vulnerability Assessment Based on Le Grand's Model

Parameter	Depth to water table	Sorption	Permeability	Water table gradient	Distance (m)	Total points
Njaba River mine site	8.1	1.5	0.3	0.013	19.5	11.41
Umuaka	8.7	2.5	0.3	0.0	4000	22.20
Orlu	9.5	6	3	0.356	28	21.36
Okwudor	9.1	2.5	0.3	0.004	3000	22.6
Ekwe	9.2	1.0	0.3	0.175	3000	21.38
Atta	8.6	2.5	0.3	0.035	6000	22.24
Isi Ibele	9.1	2.5	0.3	0.034	2600	22.53
Amucha	9.2	2.5	0.3	0.079	122	17.58
Nkwerre	9.2	6	3	0.300	5000	29.30

The total points or index for each location was then expressed in words in terms of possibility of pollution according to the Le Grand's classification shown in Table 16.

Table 16: Possibility of Pollution

Total Points	Possibility of Pollution
0 – 4	Imminent
4 – 8	Probable/Possible
8 – 12	Possible but not likely
12 – 25	Very Improbable
25 – 35	Virtually Impossible

The result of groundwater vulnerability analysis using the Le Grand model reveals that the possibility for groundwater pollution exists within and around red colour zone (Njaba mine site); but it is not likely to occur. This area is underlain by Benin Formation.However, groundwater pollution is very improbable (impossible)in other areas designated with green and pink colours. Thesezonesareunderalain by Ogwashi and Ameki Formations respectively comprise of Orlu, Nkwerre and Okporo. It suggests that area dominated with red colour has higher susceptibility than areas dominated with green and pink colour (Figure9).

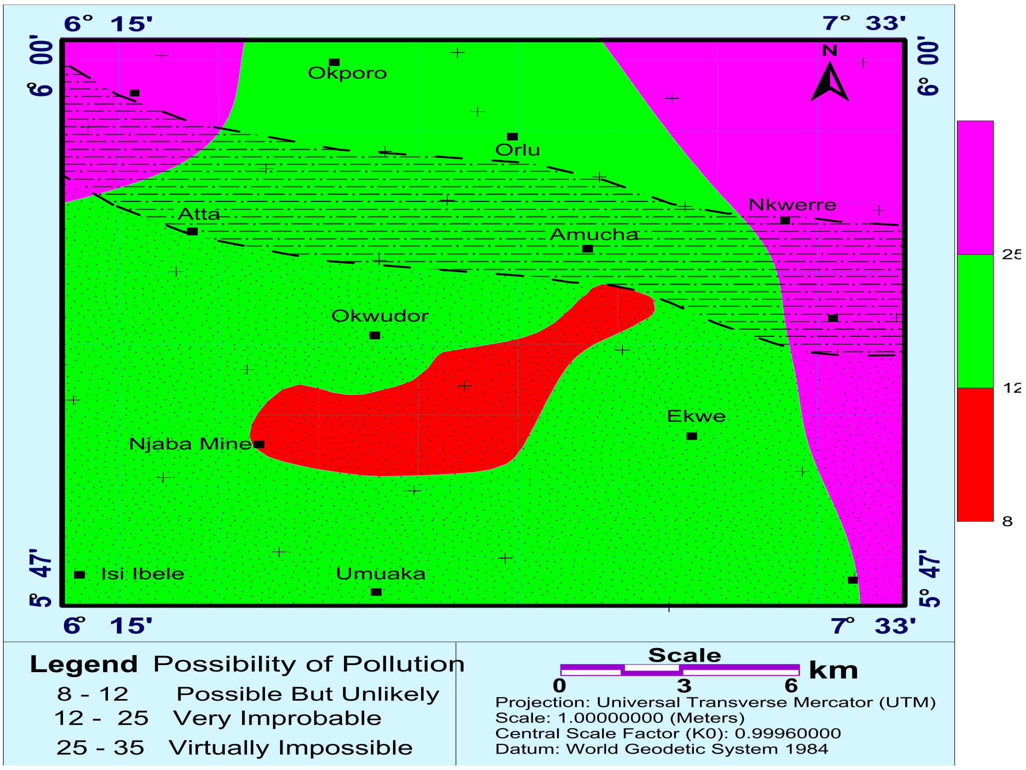

Figure 9: Le Grand Model ShowingVulnerability Map of the Study Area

4.5 Subsurface Geology of the Study Area

One major geologic cross-section taken along A – A' (Figure 10) and correlation studies of borehole litho-logs outside the line of section were employed to evaluate subsurface geology of the study area. The geologic cross-section reveals that the southwestern part of the area is mostly underlain by sands. The sand facies grades into a gravelly sequence toward the Njaba River. The northeastern part is distinguished by a thick clayey facies that thins out towards the Njaba River. The formation in the northeastern part of the study area is characterized by alternation of clays, sands, grits and lignites (Bassey and Eminue, 2012). The observed facies changes were consistent with the characteristics of the coastal plain sand and Ogwashi-Asaba Formations according toBassey and Eminue, (2012) and Ibeneme et al. (2013).

The sand unit in the southern part of the study area is overlain by thick lateritic layer and underlain by few lenses of clay and thick sandy gravel. The sand unit thins out towards the north (Figure13). The fractured shale in the northeastern part of the study area is overlain by a thicker lateritic layer and underlain by sandy unit. The sandy layer is underlain by shale and fractured shale as the aquiferous media.

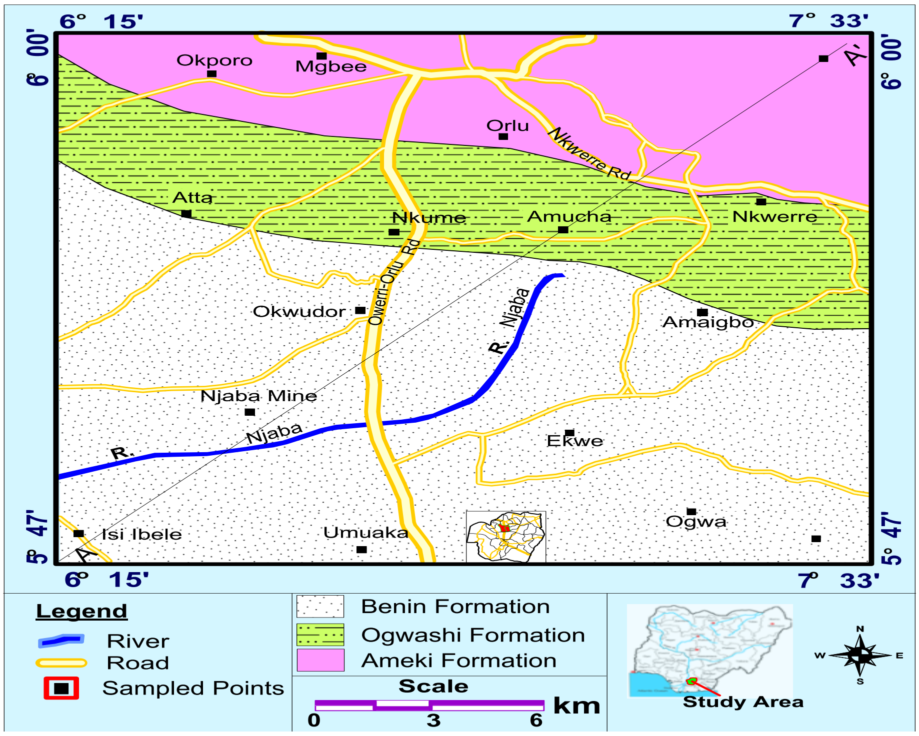

Figure 10: Geologic Cross-section of the Study Area taken along AA'

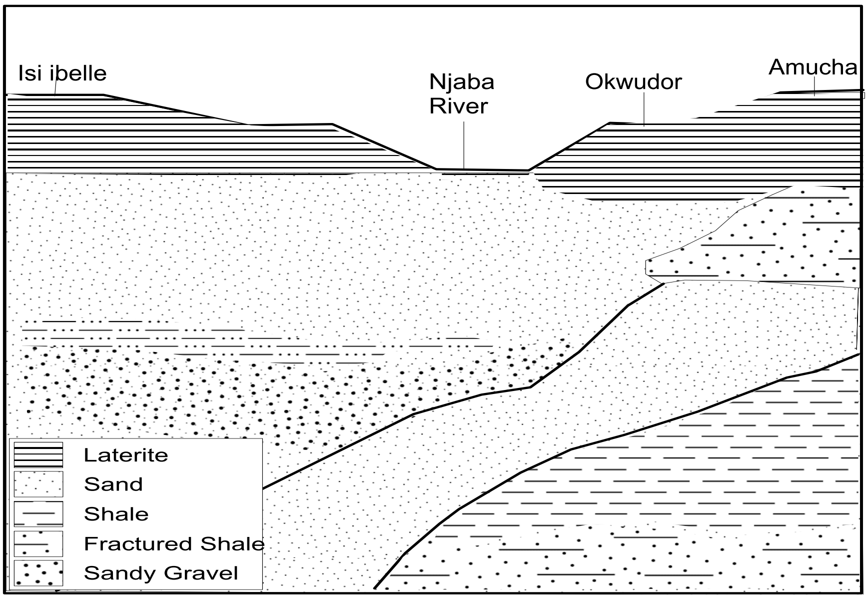

Figure11: Showing Subsurface Geology of the study area along AA'

4.6 Groundwater Flow Direction

The dominant direction of groundwater flow is northeast southwest.Contaminants usually travel alongside with groundwater movement. It appears from the flow map that Orashi and Njaba Rivers are at risk in the event of pollution of groundwater system from waste disposal and spillage sites.

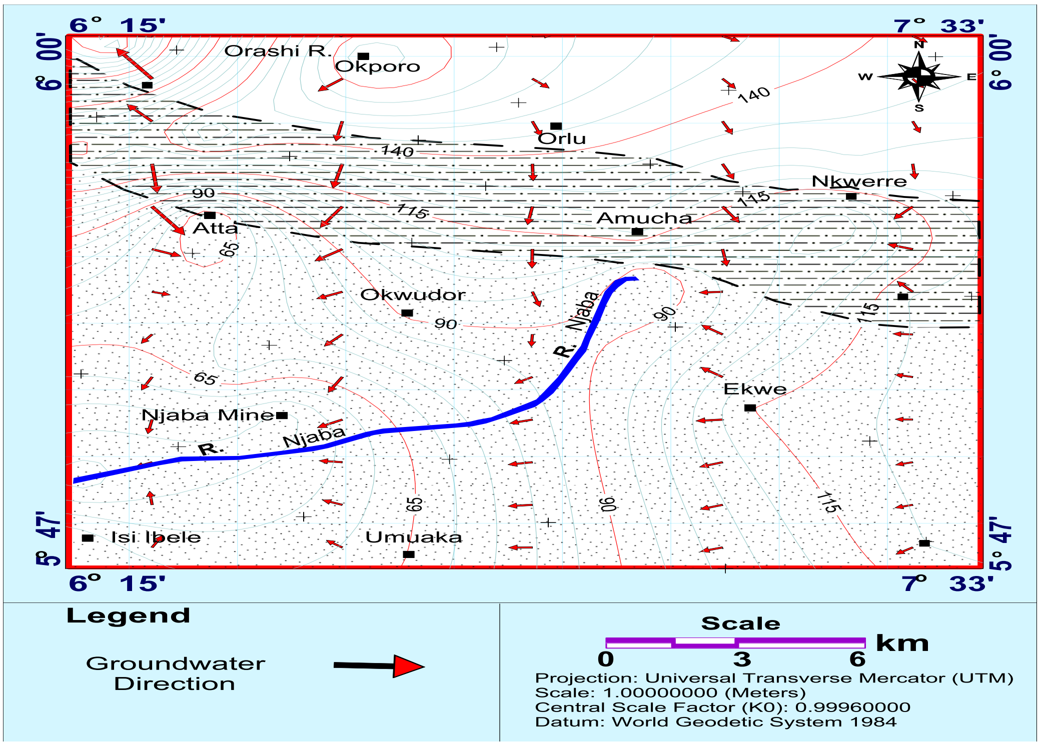

Figure 12: Map Showing the Direction of Groundwater Flow

V. Conclusion

The study area was categorized into three (3) groundwater vulnerability zones, namely, Low Vulnerability (LV), Moderate Vulnerability (MV), and High Vulnerability (HV).

Area shown to have high groundwater vulnerability by DRASTIC model were indicated to have low to moderate groundwater vulnerability by GOD model; whereas areas shown to have low groundwater vulnerability by DRASTIC model were indicated to have negligible groundwater vulnerability by GOD model. The DRASTIC model reveals that the high groundwater vulnerability zone covers more than 50% of the total study area.Areas to the north were categorized into negligible and low vulnerability by GOD and DRASTIC models respectively; whereas the Le Grand model revealed that groundwater pollution in this area is very improbable. It suggests that areas to the north have negligible to low groundwater vulnerability.

Areas to south were classified as moderate and high vulnerabilities by GOD and DRASTIC models respectively; whereas the Le Grand model revealed that groundwater pollution in this area is possible but not likely to occur. It suggests that areas to the south have moderate to high groundwater vulnerability. These areas comprise of Umuaka, Okwudor, Njaba River mine site and Isi Ibele.

Open dump waste disposal, sand mine, dredging and severe gullies are common in areas of moderate to high groundwater vulnerability. These site conditions and contaminant sources are expected to have adverse effects on groundwater quality. It is therefore, imperative that such waste dumping and mining activities in the southern areas should be controlled and managed sustainably in order to forestall further groundwater degradation.

VI. Recommendations

It is recommended that vulnerability assessment mapping as a visual analysis tool should be carried out before developing any area in order to help decision makers and town planners to know where to site waste dumps, mechanic workshops and other activities that may introduce contaminants into the groundwater system. Also, groundwater vulnerability studies should be a prerequisite for land-use planning, or at least employed to identify areas where stringent protection measures should be applied.The northern part of the study area withlow groundwater vulnerability requires a desk study to identify hazards and risk to groundwater or the environment. Site specific monitoring schemes should also be evolved in these subareas depending on the groundwater flow direction, nearness to surface water bodies, potential pollution targets and landfill design. While the southern part of the study area withmoderate to high groundwater vulnerabilityrequires urgent attention in terms of government policies, political will and resources to forestall further deterioration of the groundwater system.

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