Application of Entropy Model to Geophysical and Satellite Data for Groundwater Vulnerability in a Typical Basement Complex.

[1]Adewuyi Akeem Ademola and [2]Olisa Benson

[1]akeemadewuyi302@mail.com

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[1,2] Department of Applied Geophysics, The Federal University of Technology Akure, PMB 704, Ondo State, Nigeria.

ABSTRACT

Groundwater Vulnerability of Ogbese Area Southwestern Nigeria, have been evaluated using the integration of Geophysical and Satellite Data. Five (5) parameters were considered in achieving this aim; namely Topsoil Resistivity (TSR), Hydraulic Conductivity (HC), Longitudinal Conductance (LC), Topographic Slope (TS) and Drainage Density (DD). Multi-criteria decision analysis technique was employed to assign weight to each of the parameters using the concept of Entropy model. In order to evaluate the groundwater vulnerability of Ogbese, twenty eight (28) Vertical Electrical Sounding (VES) points were occupied. Three (3) curve types were delineated in the study area; the curve types vary from three layers A and H type curves to four layers KH. Four (4) subsurface geo-electric sequences of topsoil, lateritic clay, partially weathered/fractured basement and the fresh basement were delineated in the area. With the help of Entropy technique, different weight have been assigned to all the conditioning factors; (TSR=0.25, LC=0.38, HC=0.0082, TS=0.15, DD=0.20) with the Longitudinal Conductance (LC) having the highest weight of all the five parameters. The maps of all the parameters were generated and synthesized to producing the Vulnerability Map, which shows that the area is characterized by four zones; very low, low, moderate and high vulnerability zones. Validation of the model from well information suggests 66.7% agreement.

Key words: Entropy, Groundwater Vulnerability, Geographic Information System

1 INTRODUCTION

Water is an indispensable requirement that sustains life. Most human activities such as agriculture, industries and domestic needs depend upon the availability of water resources (Awomeso *et al.*, 2010). The increasing rate of groundwater contamination most especially in the developing countries has become a problem that has gained the attention of both academic scholars and stakeholders in the management of groundwater resources in recent times. Groundwater is naturally susceptible to contamination from both natural and anthropogenic sources. The generation of solid wastes is an intrinsic element associated with human existence as the day to day activities of man cannot be possible without producing unwanted materials or by-products (WHO, 1971). Solid wastes can be grouped into two: (i) Hazardous waste which includes toxic chemicals, radioactive materials, flammable and explosive wastes and (ii) Non-Hazardous wastes like agriculture, commercial and industrial wastes that are not lethal by nature or contain toxic materials. The disposal of these wastes is undertaken through many ways which include landfill, incineration, compositing and open dumps. Polluted groundwater has elevated microbal, ionic and volatile organic content, resulting to hazardous effects on public health and poor groundwater quality (Olafisoye *et al*., 2013). Wastes generated from agricultural farmland and industries have contributed immensely to water pollution when contaminant percolates into the groundwater (Adigun *et al*., 2017). Drinking contaminated water could result into a variety of water borne diseases such as Diarrhoea, Cholera, Dysentery and Typhoid.

Geophysical methods have been found very relevant in the investigation of environmental and groundwater pollution. It has two major advantages which make it a suitable tool for environmental impact assessment. Firstly it is non-intrusive, non-destructive and it can give continuous subsurface information along a profile. Hydrochemical analysis involving the determination of physiochemical parameters of water samples is also essential in area(s) of suspected groundwater contamination (Adigun *et al*., 2017). Electrical resistivity method is a versatile, fast, cost effective and non-destructive geophysical technique; it is useful in mapping continuous subsurface information along a profile.

In Ogbese community (Fig 1.1) cassava processing is their major source of livelihood because of its wide usage when processed into garri, akpu, starch e.t.c. Cassava is normally processed before consumption as a means of detoxification, preservation and modification due to the presence of toxic cyanogenic glycosides in unfermented roots and leaves. This processing generates solid and liquid residues that are hazardous in the environment (Ehilenboadiaye *et al*., 2018). Leachate plumes generated from cassava effluents can be inorganic chemicals similar to those inorganic contaminants from landfills, open waste disposal sites, salt brines, acid spills and natural salt water intrusions (Ehilenboadiaye *et al*., 2018). Inorganic contaminants from cassava effluents, cemeteries, open waste disposal sites as well as salt brines, acid spills and natural salt water intrusion are detectable by electrical methods because of their high values of specific conductance (Ehilenboadiaye *et al*., 2018). Environmental contamination is one of the main concerns of earth scientists and researchers worldwide. The accelerated pace of industrial development coupled with uncontrolled growth of the urban population has resulted in the increasing production of solid/liquid residues (George *et al*., 2014). The rate and extent of leachate infiltration is controlled primarily by the ease at which the subsurface layers beneath the cassava processing mills, dumpsite and its surroundings allow contaminant to migrate. Reports have shown that permeable sandy materials allow rapid infiltration of contaminants while less permeable clayey materials provide geological barrier that retards its movement (Olla, 2011;.

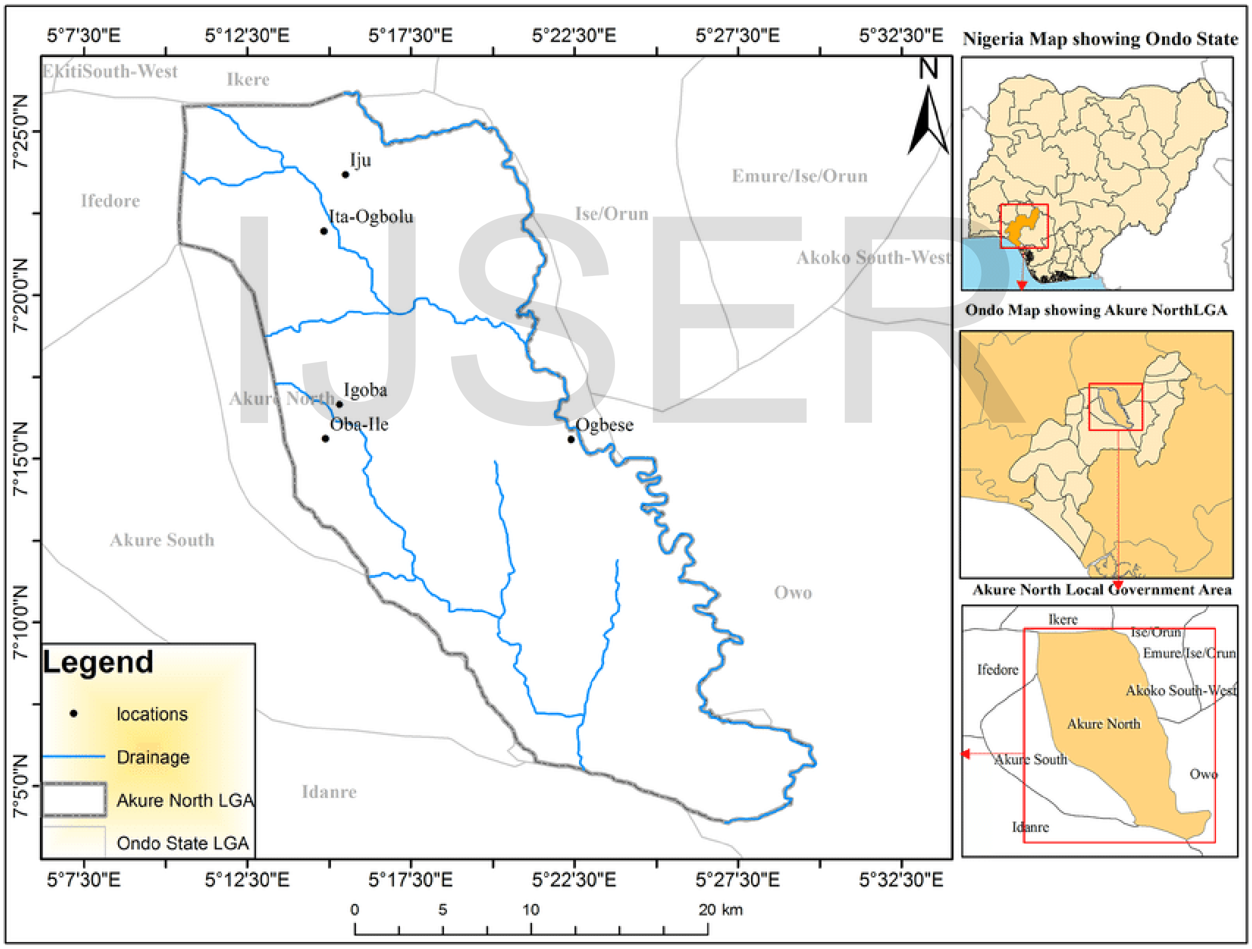

Figure 1.1: Location Map of Akure North, South western Nigeria Showing the Study Area (Modified after Ajakaye 2017).

Awoniyi, 2013). Therefore the need to understand the subsurface soil profile has become pertinent to assess the impact of any overlying processing mill on the underlying aquifer system. The quality of groundwater is a useful parameter to be investigated in areas where cassava processing mills and dumpsites are located in order to confirm any possible leachate contamination arising from such site that might cause serious health issues for inhabitants that drink such groundwater as hand dug wells or borehole. Leachate can constitute anomalous concentration of such parameters as total dissolve solids (TDS), total organic carbon concentration (TOC), electrical conductivity as well as heavy metals on the ambient of groundwater hence, there is need to analyse the physiochemical parameters of water samples from different wells in the area for possible leachate contamination (Adigun *et al*., 2017).

There are various local cassava processing mills and dumpsites situated within the study area, most of which are very close to hand dug wells and water ways. Effluent from the processed cassavas and refuses are been disposed indiscriminately within the study area. In addition, people residing in this community are not well educated so most of them excrete along water ways and streams. This singular act has an adverse effect on the inhabitants within the area. This research work, therefore intends to evaluate the groundwater vulnerability to contamination by applying ENTROPY model to geophysical and satellite data. An entropy-based weighting scheme determines the weights for a set of criteria by quantifying the amount of information within the decision matrix and based on evaluation values (Soheil Boroushaki, 2017). Information entropy is a measure of the degree of disorder within a system. It can quantify the amount of expected and useful information content within criterion values, and it measures the contrast intensity among a set of spatial criteria (Soheil Boroushaki, 2017).

2.0 Location and Geology of the Study Area

The Study Area (Fig 1.2) is located in Ogbese Community along Akure-Owo Road Ondo State. It lies between longitude 7^{0} 15' 30'' E and 7^{0} 16' 2'' E and latitude 11^{0} 21' 55'' N and 11^{0} 22' 15'' N expressed in Universal Traverse Mercator (UTM) as 761200 and 761800E and 803000 and 804000N (Fig 1.1). River Ogbese which is the major river in the area flows in an approximately North South direction (Oladapo *et al*., 2017). The study area is surrounded by villages and towns with an estimated population of about 20,000 inhabitants, including seasonal traders and labourers (Oladapo *et al*., 2017). The Study Area falls within the Precambrian Basement Complex of South-western part of Nigeria, which includes granite-gneiss and migmatite (Fig 2.1). The basement complex rocks in Ondo State is predominantly composed of Migmatite and granitic gneiss, Quartzites, slightly Migmatised to Unmigmatised meta-sedmentary schist and meta-igneous rocks, Charnockites, Gabbroic and Dioritic rocks believed to be members of the older granite suite, others include mainly granites, Granodiorites (Rahaman, 1976).

3.0 Materials and Method of Study

3.1 Geophysical Data

The vertical electrical sounding (VES) field technique utilizing Schlumberger electrode configuration was adopted for this study. Twenty eight (28) VES points were occupied across the study area with a view to understanding the characteristic of lithological sequence overlying the aquifers. Analysis and interpretation of the data obtained were made both quantitatively in order to establish the geo-electric/geologic sequence beneath the study area. The quantitative analysis involving partial curve matching and computer iterations to determine geoelectric parameters of geoelectric sequence beneath the study area. Three factors considered to be of great influence on aquifer vulnerability were derived from the geoelectric parameter which are the topsoil resistivity (TSR), longitudinal conductance (LC) and the hydraulic conductivity (HC).

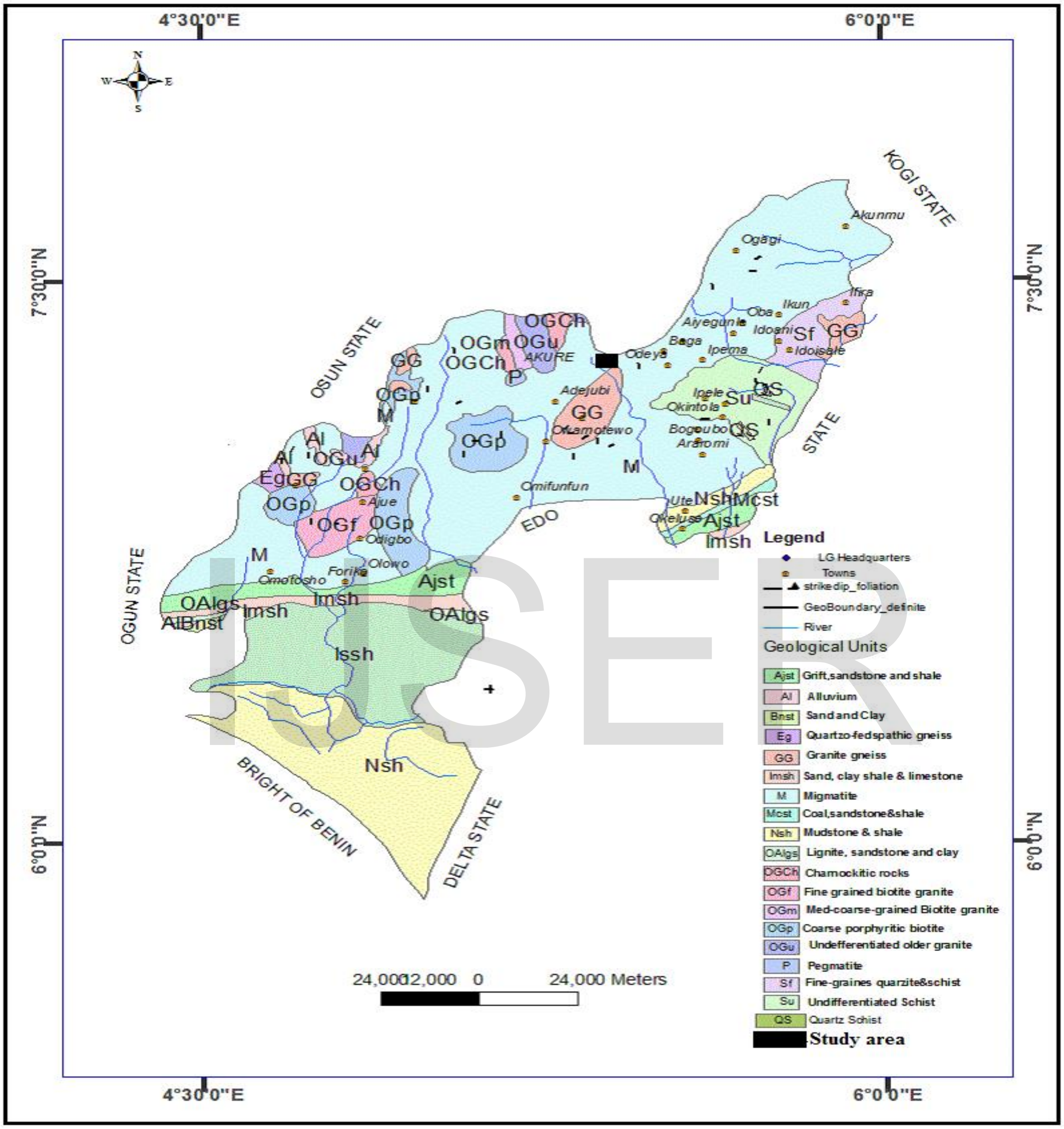

Figure 2.1: Geological Map of Ondo State showing the Study Area (modified after the Nigerian Geological Survey Agency, 2006).

The longitudinal conductance (Si) is computed by the relation;

$S_i = h_i/p_i$ (1)

Where S_i= Longitudinal Conductance, h_i= Layer Thickness, p_i= Layer Resistivity

The hydraulic conductivity is computed by the mathematical relation;

$K = 0.0538\ e^{-(0.0072e)}$ (2)

Where k = Hydraulic Conductivity, p= Layer Resistivity

3.2 Satellite Data

The slope map for the investigated area was extracted from the ALOS PALSAR DEM for the investigated area. The process was performed using spatial analysis tool under the surface tool box. ALOS PALSAR DEM was also used to generate the drainage map for the investigated area using the Flow Direction and Flow Accumulation tools in ArcGIS.

3.3 Well Data Acquisition

A total of Six (6) hand dug wells was selected for the hydrochemical analysis based on their proximity to cassava mills and dumpsites. The water analysis is targeted for the validation of the research work. Water samples from the six wells within the study area were collected and stored in 100Cl plastic container (sample bottle). Detailed chemical analysis targeted at determining cations and anions that are indicative of pollution, were conducted on the samples. The quality of the ambient groundwater was evaluated by comparing the concentration levels of measured parameters obtained with the recommended standards of the Nigeria Industrial Standard (NIS, 2017).

3.4 Principle of Entropy Method

STEP 1Normalize the Decision Matrix

$$rij = \frac{xij}{\sum_{i=1}^{m} xij} \quad (1)$$

STEP 2 Compute Entropy

$$ej = -h\sum_{n=1}^{m} rij\ \ln rij,\ j = 1,2 \dots, n\ and\ i = 1,2 \dots, m \quad (2)$$

$h = \frac{1}{\ln(m)}$ Where “m” is number of alternatives (3)

STEP 3 Compute the Weight Vector

$$Wj = \frac{1-ej}{\sum_{j=1}^{n}(1-ej)}\ , 1,2, \dots n \quad (4)$$

$$dj = 1 - ej, \quad (5)$$

$dj = degree\ of\ divergence,\ ej = Entropy\ value,\ Wj = Weight\ Vector$

4.0 RESULTS AND DISCUSSION

4.1 Field Sounding Curves

The curve types obtain in the study area are the A, H, and HA. Figure 4.1 shows the distribution of the curve types in the study area. The geoelectric layers depicted by these curves ranges from three to four layers. The study area is overlaid generally by a clayey layer, which serves as a protective medium for the aquiferous zone and therefore reduces the risk of pollutant penetrating into the groundwater. This singular act makes the aquifer in the region confined in nature.

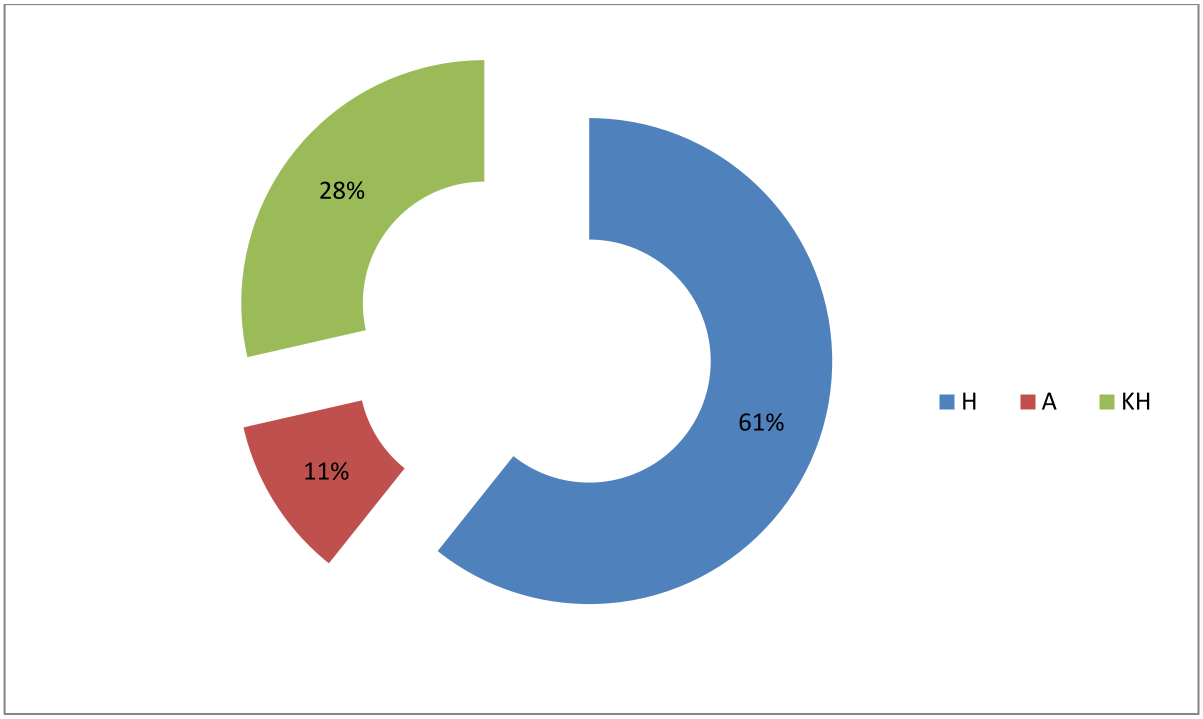

Figure 4.1: Curve Types in the Study area

4.2 Aquifer Vulnerability Assessment in the Study Area

The assessments of aquifer vulnerability to contaminants have been undertaken by investigating the capacity of the layer overlying the aquifer units in the study area (vadose zone) to offer protection to the underlying aquifer units. Hence, the topsoil resistivity, longitudinal conductance, hydraulic conductivity, drainage density and topography slope of the vadose zone are taken into consideration.

4.2.1 Topsoil Resistivity

The resistivity of the topsoil ranges from (7.345-407.7) Ωm. The topsoil resistivity map (Fig. 4.2) shows that the topsoil in the study area is generally characterized by very low to low resistivity values at the central, southern and northwestern part of the study area. This is an indication that these portions of the study area will have a good protective capacity and aquifer in the sections will be less vulnerable to contaminants due to its impervious nature. Except for the east and north-eastern part of the study area which has medium to high resistivity values. These portion will show a moderate protective capacity and aquifer in this sections will be more vulnerable.

4.2.2 Longitudinal Conductance

The longitudinal conductance of the vadose zone which also provides a measure of the aquifer protected capacity is presented in (Fig 4.3). The longitudinal conductance of the vadose zone ranges between (0.0015-0.0507) mhos. The vadose zone in major parts of the study area offers poor to weak protection for the underlying aquifers based on their characterized low longitudinal conductance. However, moderate protection can be envisaged in few areas in the central, north-western and southern parts where relatively moderate longitudinal conductance was observed. The longitudinal conductance map shows a very low to low longitudinal conductance at the north-eastern and eastern part of the study area.

4.2.3 Hydraulic Conductivity

The hydraulic conductivity ranges from (0.00372-0.0482)m/day. The hydraulic conductivity map (Fig. 4.4) shows that the study area is dominated by low to very low hydraulic conductivity values. A moderate hydraulic conductivity in the eastern and north-western part of the study area. In addition, a high hydraulic conductivity was observed in the closure of the eastern part of the study area, with pockets of high zones also observed in some parts of the northern and western region.

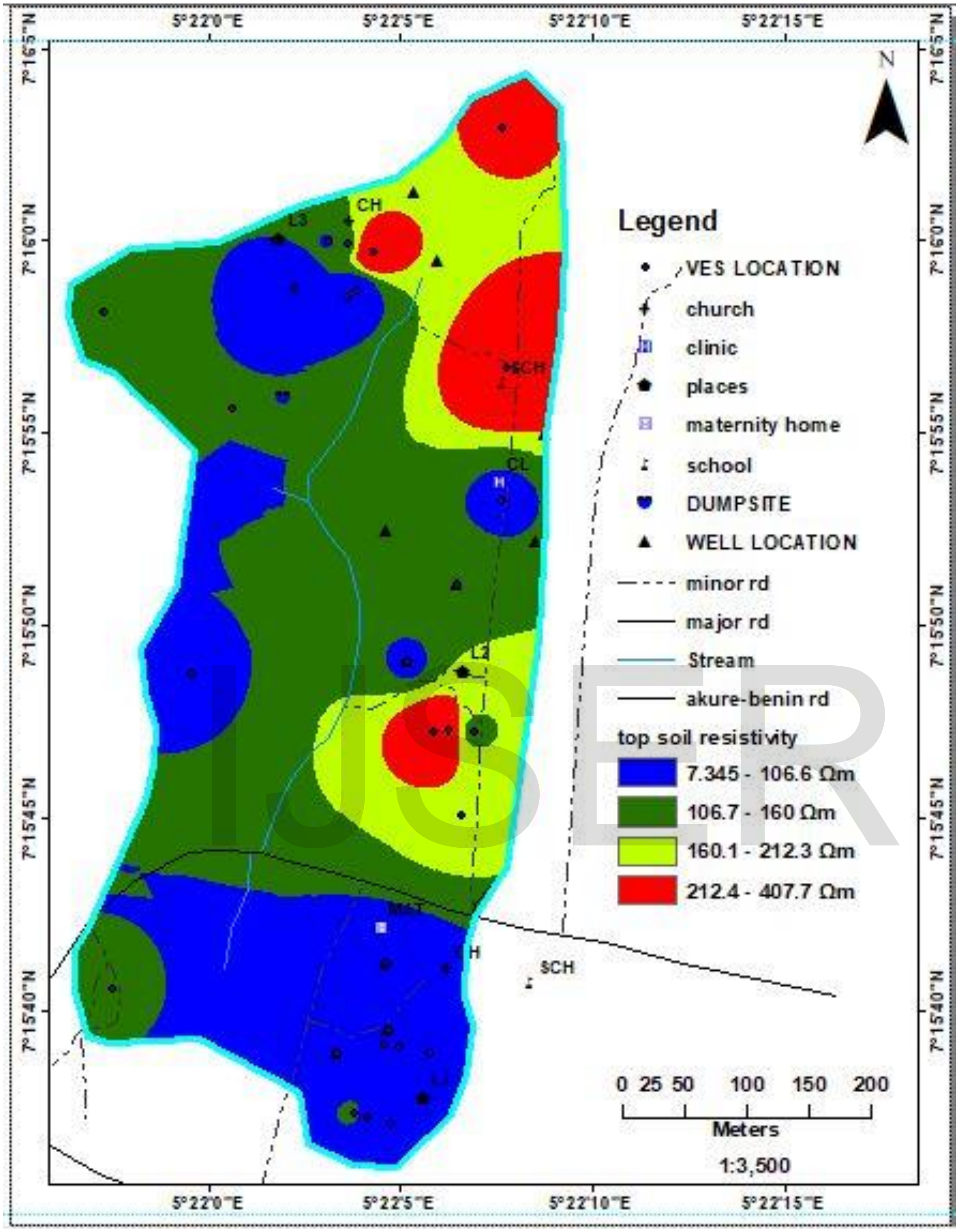

Figure 4.2: Topsoil Resistivity Map of the study area

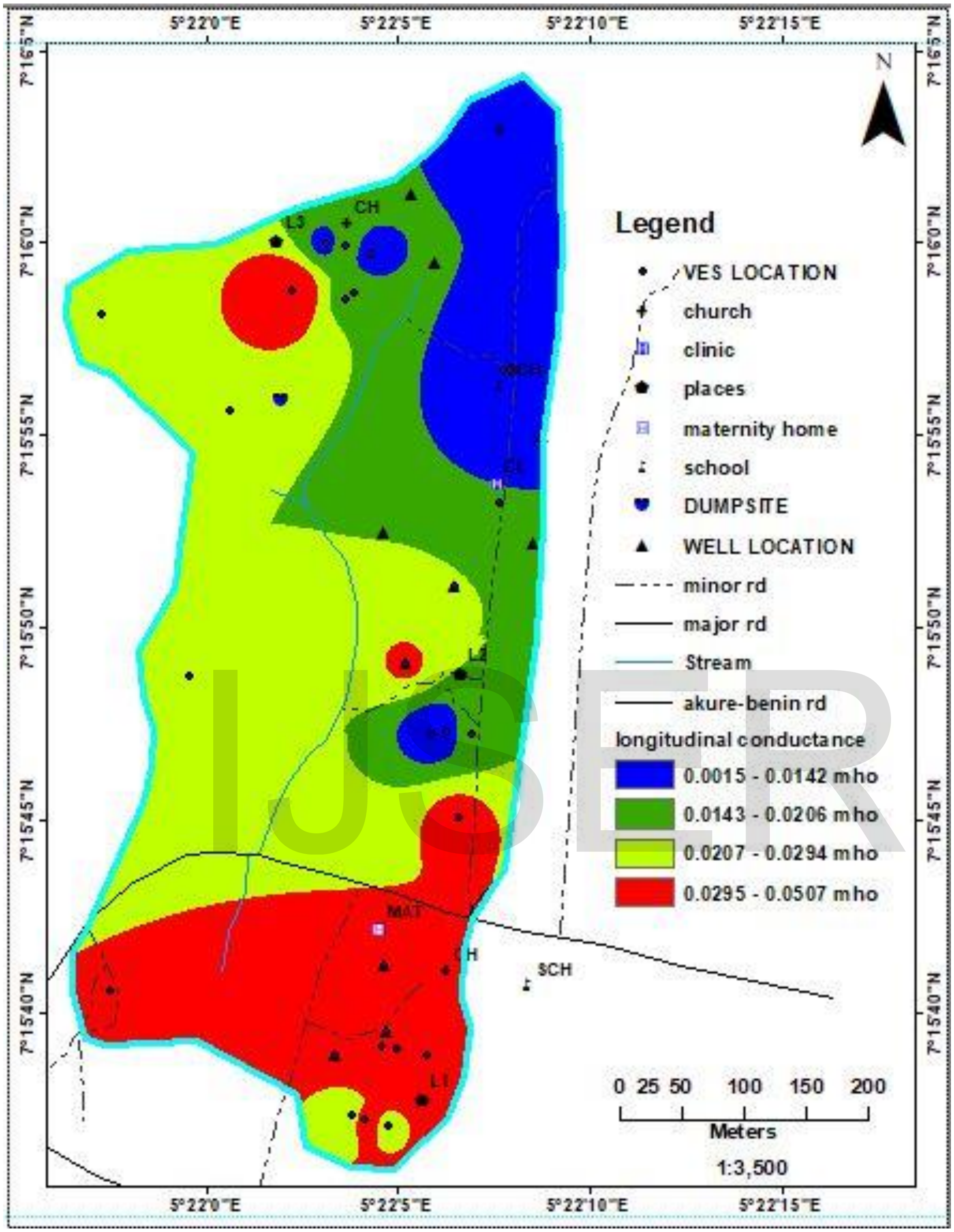

Figure 4.3: Longitudinal Conductance Map of the study area

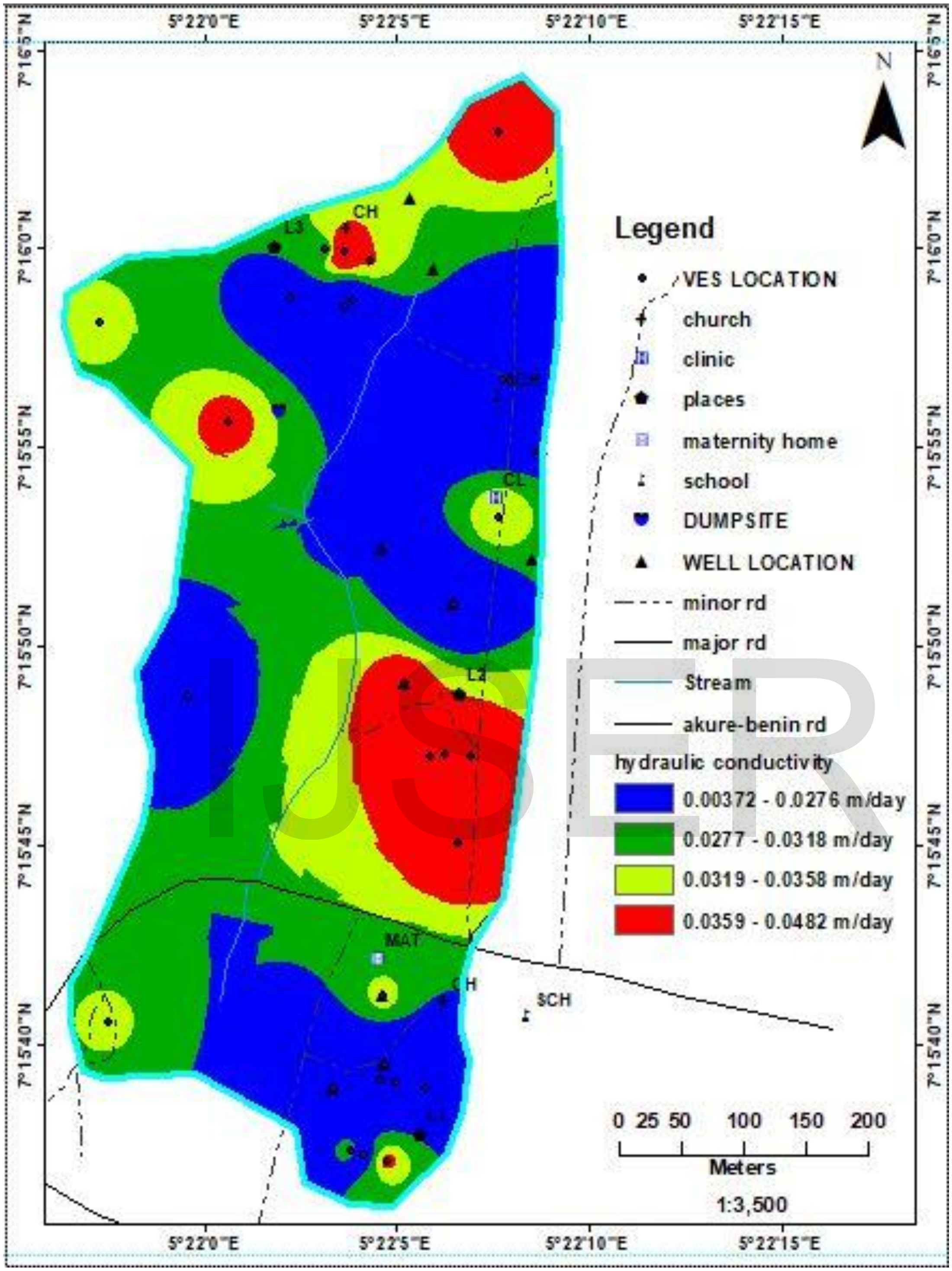

Figure 4.4: Hydraulic Conductivity Map of the study area

4.2.4 Drainage Density

How drained the environment is determines the degree of infiltration of that particular area. (Fig. 4.5) shows the drainage density map of the study area which is characterized into low, moderate, high and very high. Some parts of the north, central, and southern part of the study area have very high density. When the drainage density is very high, the runoff will be very high and consequently the rate of infiltration will be very low. This can be observed from the map where by the highly drained region is in same direction with the river flow in the study area. Conversely the lower the drainage density the lower the runoff and the higher the degree of infiltration. Furthermore, some areas in the northern, southern, western, eastern and central part of the study area is characterized by low drainage density, which means the area is not well drained and therefore it is expected to have high level of infiltration.

4.2.5 Topography Slope

The topographic slope is characterized into low, moderate, high and very high (Fig. 4.6). The north-western and some areas in the south-western part has high to very high slope, which is indicative of little potential for recharge, thus allowing pollutants little opportunity to reach the groundwater table. However, the larger part of the study area is characterised by moderate to low slope, this can be found in the north-eastern, central, eastern, southern and some regions in the western part of the study area. This area has a low degree (flat) which tends to retain water for longer time, hence providing greater chance for the infiltration of recharge water, which may contain a considerable amount of pollutants.

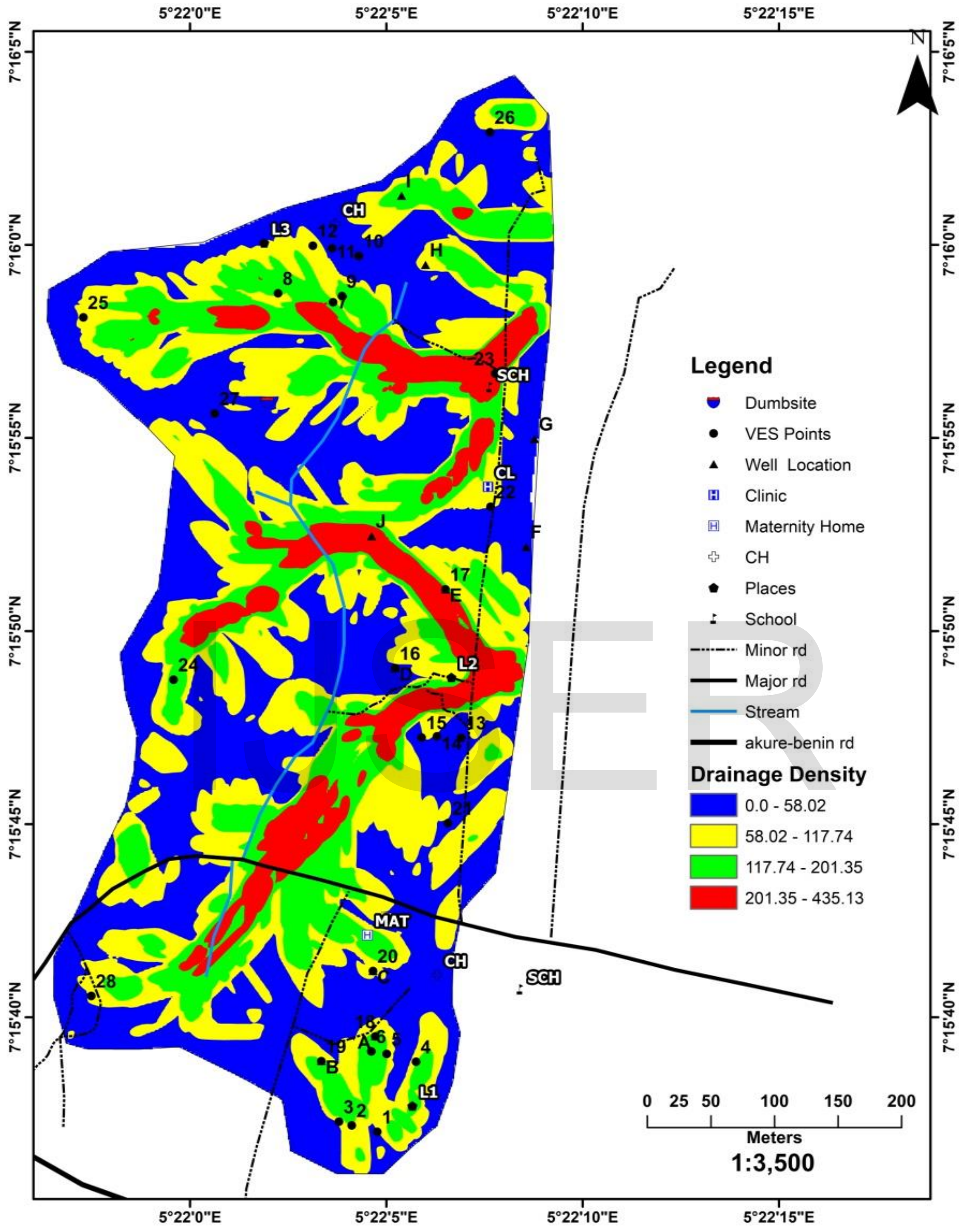

Figure 4.5: Drainage Density Map of the study area

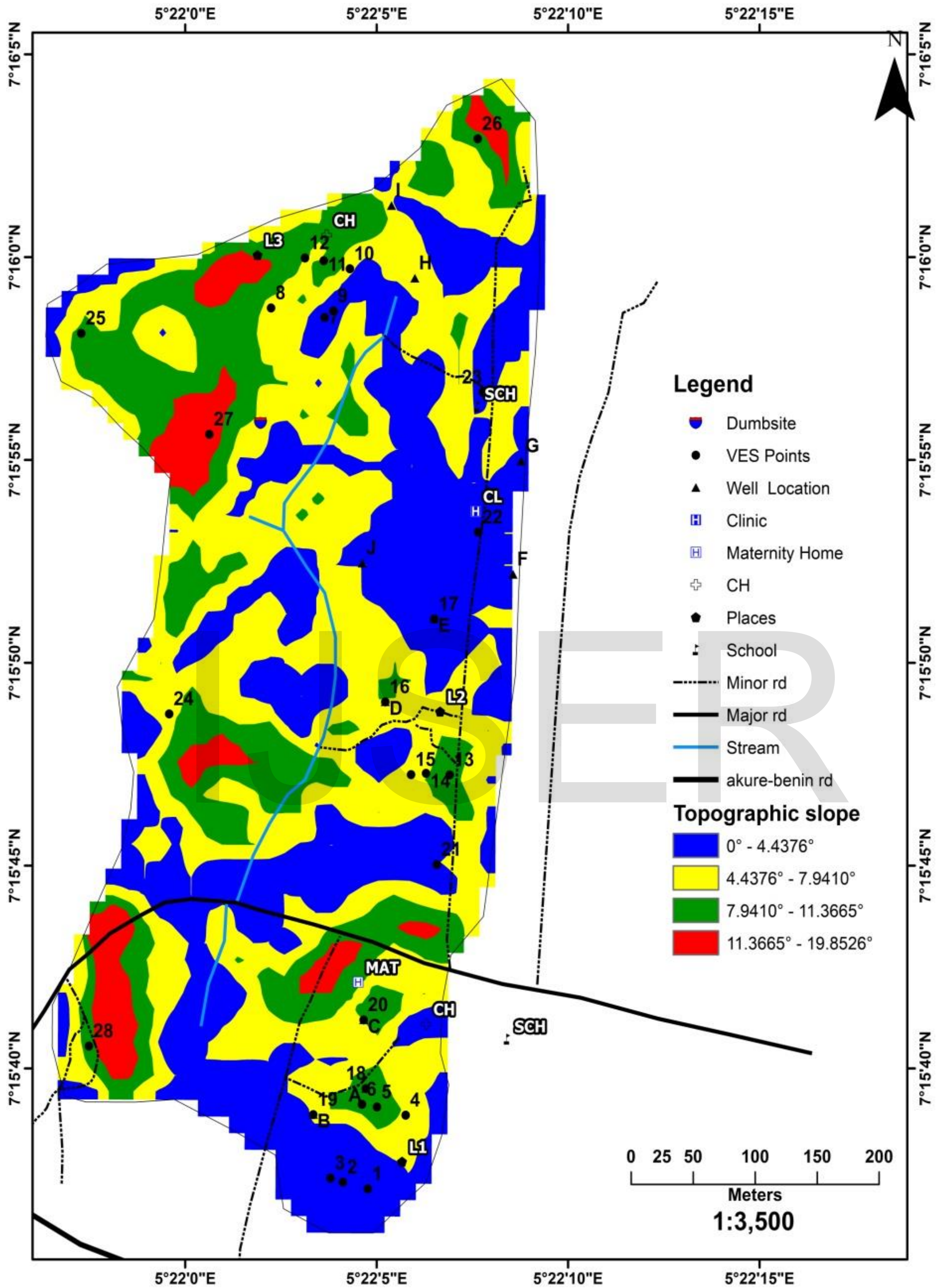

Figure 4.6: Topographic Map of the study area

4.3 Assignment of weights to factors

Table 4.1 show the weight assigned to each of the parameters considered in this study, which was produced using entropy method. Entropy weight is a parameter that describes how much different alternatives approaches one another in respect to a certain criteria, it is necessary that the weights sum to 1; the concept is taking from transportation models, the weight calculated by this method is also known as objective weight. The entropy value for each of the parameters was subtracted from one (1), so as to get the degree of diversification. The degree of diversification of each parameter divided by the sum of all the degree of diversification was used to compute the final weight.

4.3.1 Rating

Rates (R) were given to each of the parameters within the factors influencing the groundwater vulnerability of Ogbese (Table 4.1). The rating will assist in the estimation of the groundwater vulnerability index (GWVI) of Ogbese, South-western, Nigeria.

4.4 Groundwater Vulnerability Index (GWVI) Estimation

GWVI is obtained from the summation of the products of the assigned weights often denoted as “w” and the ratings denoted as “R”. Weighted linear average technique was used to estimate Vulnerability Index (VI). This technique is usually specified in terms of weightings (w) for each factor as well as rating score (R) for all option relative to each of the factor.

$$\mathbf{VI = \sum w_i R_i} \qquad 4.1$$

Where w is the weight (w) of parameter “i” and R is the rating score of parameter “i”

$$\mathbf{GWVI} = W_{TSR}\,\mathbf{R_{TSR} + W_{LC}\,R_{LC} + W_{HC}\,R_{HC} + W_{TS}\,R_{TS} + W_{DD}\,R_{DD}} \qquad 4.2$$

$$\mathbf{GWVI = 0.25\ R_{TSR} + 0.38\ R_{LC} + 0.0082\ R_{HC} + 0.15\ R_{TS} + 0.20\ R_{DD}} \quad 4.3$$

Table 4.1: Ratings for classes of factors

Influencing Factors	**Classes**	**Potential for vulnerability**	**Rating (R)**	**Normalised Weight (w)**
Topsoil Resistivity (TSR)	7.345-106.6	Moderate	3	0.25
	106.7-160	High	5	
	160.1-212.3	Low	2	
	212.4-407.7	Very Low	1	
Longitudinal Conductance (LC)	0.0015-0.0142	High	5	0.38
	0.0143-0.0206	Moderate	3	
	0.0207-0.0294	Low	2	
	0.0295-0.0507	Very Low	1	
Hydraulic Conductivity	0.00372-0.0276	High	5	0.0082
	0.0277-0.0318	Moderate	3	
	0.0319-0.0358	Low	2	
	0.0359-0.0482	Very Low	1	
Topographic Slope (TS)	0-4.44	High	5	0.15
	4.44-7.94	Moderate	3	
	7.94-11.37	Low	2	
	11.37-19.92	Very Low	1	
Drainage Density (DD)	0-58.02	High	5	0.20
	58.02-117.74	Moderate	3	

	117.74-201.35	Low	2	
	201.35-435.13	Very Low	1	

Table 4.2: Vulnerability Index Estimation for all VES stations

VES	**LOCATION (UTM)**		**TSR (0.25)**		**LC (0.38)**		**HC (0.0082)**		**TS (0.15)**		**DD (0.20)**		**VI**
NO	EASTING	NORTHING	R	W*R	R	W*R	R	W*R	R	W*R	R	W*R	**∑(W*R)**
1	761472	803206	3	0.75	1	0.38	3	0.246	5	0.75	5	1	3.13
2	761452	803211	3	0.75	1	0.38	2	0.164	5	0.75	3	0.6	2.64
3	761442	803214	5	1.25	1	0.38	3	0.246	5	0.75	3	0.6	3.23
4	761502	803262	3	0.75	2	0.76	2	0.164	3	0.45	3	0.6	2.72
5	761479	803268	3	0.75	2	0.76	2	0.164	2	0.9	3	0.6	3.17
6	761467	803270	3	0.75	2	0.76	3	0.246	2	0.9	2	0.4	3.06
7	761434	803866	3	0.75	2	0.76	5	0.041	5	0.75	2	0.4	2.70
8	761391	803873	3	0.75	1	0.38	3	0.246	3	0.45	2	0.4	2.23
9	761441	803871	3	0.75	1	0.38	3	0.246	5	0.75	2	0.2	2.33
10	761454	803903	1	0.25	5	1.9	5	0.041	3	0.45	5	1	3.64

11	761433	803909	5 1.25	1 0.38	1 0.0082	2 0.9	5 1	3.54
12	761418	803911	3 0.75	1 0.38	2 0.164	2 0.9	3 0.6	2.80
13	761536	803520	5 0.75	2 0.76	3 0.246	2 0.9	5 1	3.66
14	761517	803521	2 0.5	5 1.9	5 0.041	3 0.45	5 1	3.90
15	761505	803520	2 0.5	2 0.76	1 0.0082	3 0.45	5 1	2.72
16	761484	803575	3 0.75	3 1.14	3 0.246	3 0.45	5 1	3.56
17	761523	803638	5 1.25	5 1.9	3 0.246	5 0.75	1 0.2	4.35
18	761470	803282	3 0.75	2 0.76	3 0.246	2 0.9	2 0.4	3.06
19	761428	803262	3 0.75	2 0.76	3 0.246	3 0.45	3 0.6	2.80
20	761468	803334	3 0.75	3 1.14	3 0.246	2 0.9	3 0.6	3.64
21	761526	803452	5 1.25	5 1.9	3 0.246	5 0.75	5 1	5.15
22	761558	803704	3 0.75	2 0.76	2 0.164	5 0.75	3 0.6	3.02
23	761561	803810	1 0.25	5 1.9	5 0.041	5 0.75	1 0.2	3.14
24	761311	803565	3 0.75	3 1.14	3 0.246	3 0.45	2 0.4	3.00
25	761239	803853	5 1.25	2 0.76	3 0.246	3 0.45	3 0.6	3.31
26	761556	804002	5 1.25	2 0.76	3 0.246	2 0.9	5 1	4.16

27	761342	803777	5 1.25	5 1.9	5 0.041	1 0.15	5 1	4.34
28	761248	803313	5 1.25	3 1.14	3 0.246	2 0.9	3 0.6	4.14

4.5 Groundwater Vulnerability Map

The groundwater vulnerability index map (Fig 4.7) was produced by overlaying the GWVI obtained for each of the contributing factors to groundwater vulnerability in the area using the ArcGIS 10.3 software. From the study, it was revealed that Ogbese can be zoned into Low, Moderate, High and Very High groundwater vulnerability zones. Ogbese is predominantly moderate- low in groundwater vulnerability. Pockets of very high groundwater vulnerability zones were also observed at the north-western and south-eastern part of the study area. However, at the extreme northern and southern part of the area, a low groundwater vulnerability zone was observed.

4.6 Validation

The well samples coordinates were posted on the final groundwater vulnerability map and it was validated merely by visual inspection, so as to indicate areas that correlate with the analyzed well water samples. In addition, the success rates (accuracy) approach according to Adiat (2013) where the numbers of analyzed well samples that coincide with the vulnerability and vice versa were used for the success rate accuracy of the prediction.

The success rate (accuracy) of the estimated groundwater vulnerability index (GWVI) can be obtained as follows:

Total number of analyzed wells = 6

Number of wells where the vulnerability coincides = 4

Number of wells where the vulnerability didn't coincide = 2

The success rate accuracy of the prediction = $\frac{4}{6} \times 100 = 66.7\%$

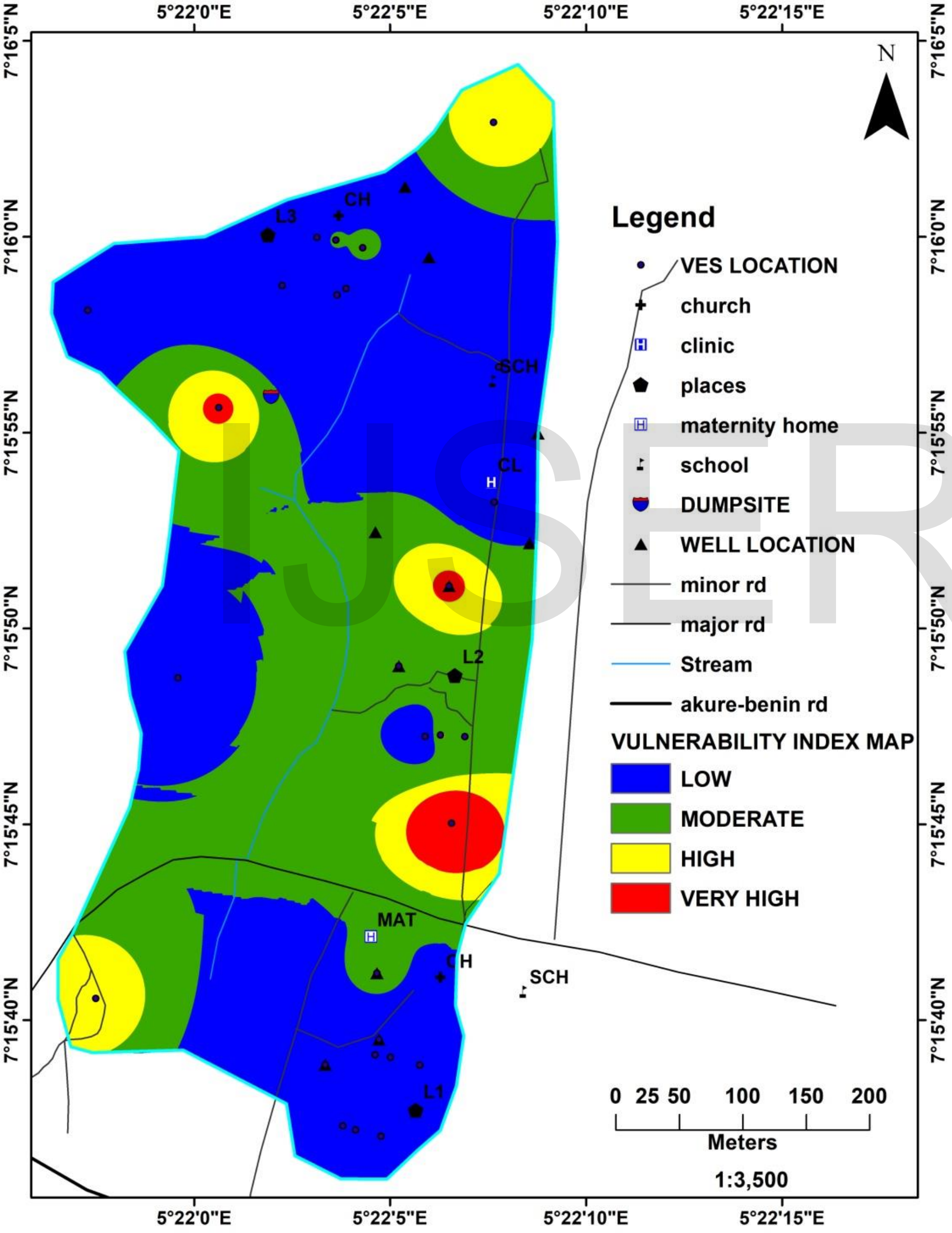

Figure 4.6: Groundwater Vulnerability Map of the study area

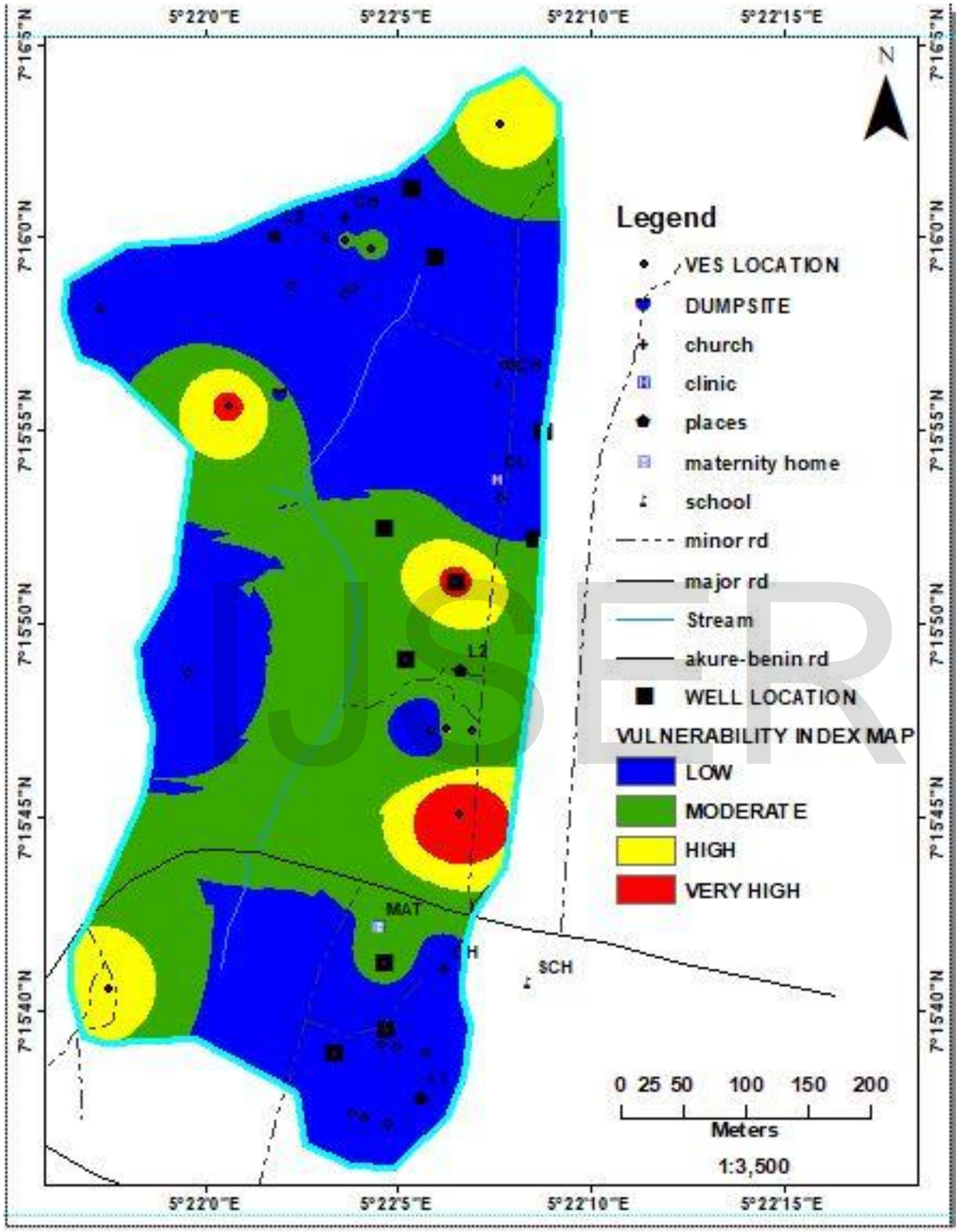

Figure 4.6: Validation of Groundwater Vulnerability Map

5.0 Conclusion

In an attempt to give information about the groundwater vulnerability in a basement complex terrain, integration of remote sensing and GIS (satellite data) and geophysical methods involving electrical resistivity methods was adopted to understand the groundwater regime of Ogbese, Ondo State South-western Nigeria. Five hydro geological parameters that can assist in delineating zones of groundwater contamination were considered. Geo-electrical parameters (topsoil resistivity, longitudinal conductance and hydraulic conductivity) were determined from Vertical Electrical Sounding (VES) while drainage density and topographic slope were generated from satellite data. These parameters were all combined using Multi Criteria Decision Analysis (MCDA) in the context of Entropy method. Appropriate weights and ratings were assigned to each contributing factors, the data's were managed in a GIS environment in other to produce the groundwater vulnerability map of Ogbese.

The resulted groundwater vulnerability map was validated using well information obtained in the study area. All the physicochemical parameters of the analyzed well water samples are below the NIS maximum permissible standards for drinking water, indicating that the groundwater within the study area has not been polluted by cassava effluent or leachate from dumpsite. However the groundwater vulnerability map of the study area indicates that the northern part, central and southern parts of the study are comprises of moderate to low vulnerability, which is as a result of the clayey layer overlying the aquiferous unit. The depth extent may have been limited by relatively thick column of clay which may have acted as a barrier to further contamination. Also the high success rate (66.7%) of estimated GWVI obtained from geophysical data and satellite data set indicate that the proposed methodology is capable of producing reliable results.

The study also established the efficacy of MCDA and ENTROPY model Vis a Vis the relevance of integrated approach between remote sensing and GIS (satellite data) and geophysical method in effectively evaluating groundwater vulnerability of an area. The Entropy model can be observed in different discipline since it is data driven which provides rapid and precise results. It will also help in resolving subjectivity typical of knowledge driven technique.

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