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Research Article

Groundwater Potential Zone Mapping of Ondo State Using Multi-criteria Technique and Hydrogeophysics

Epuh EE[1]*, Joshua EO[2], Elesho AO[1], Orji MJ[1], Damilola OM[1] and Adetoro PT[1]

[1]Department of Surveying and Geoinformatics, University of Lagos, Nigeria; [2]Department of Surveying and Geoinformatics, University of Ibadan, Nigeria

ABSTRACT

The delineation of groundwater potential zones in Ondo State was carried out using Remote Sensing, Geographic Information Systems (GIS) and Hydrogeophysics. In this study, various thematic maps such as: soil map, slope, drainage map, land use/Land cover map, geological map, rainfall map, lineaments map were obtained from enhanced satellite imagery. These maps were overlaid in terms of weighed overlay method using Spatial Analysis tool in Arc GIS 10.5. During weighed overlay analysis, different ranks were given to each individual parameter of each thematic map and weights were assigned according to their influence. Results showed that spatial distribution of the most promising sites for groundwater exploration was dependent on the interrelated factors of lithology, topography and geologic structure. The groundwater potential map obtained from the study area showed that 17.5% of the total study area lie within the "very high" potential zone, 12.0% of the area falls within the "high", 39.5% lies within the "moderate" zone, 25.7% lies within the "low "potential zone while 5.3% lies within the very low potential zone. The very high potential areas lie within the sedimentary zone in the southern part of the study area with high alluvial deposits, while the "very low" prospect zone lies majorly within the basement complex zone in the northern part of the study area. The query results on Ijapo Vertical electric sounding (VES) data analysis shows the presence of four lithology: top soil, sand (which contains the fresh water), sand clay (which contains the brackish water) and the clay (which contains the saline water). The boreholes susceptible to salt water intrusion were identified and the best drilling point with respect to depth were also determined.

Keywords: Groundwater; Multi influencing factor; Remote sensing; GIS; Hydrogeophysics

INTRODUCTION

Groundwater is the largest available reservoir of freshwater. Most fresh water is locked away as ice in the polar ice caps, continental ice sheets and glaciers [1].

Most groundwater originates from rainfall that has entered the earth. In the overburden aquifer, water fills the void space between grains of the soil. Bedrock aquifers underlie the surface soils (overburden) and overburden aquifers. In the bedrock aquifers, water occurs in fractures and other voids in the bedrock. Some types of bedrock such as sandstone may also have additional voids (intergranular voids) that are filled with groundwater. As is the case for surface water, groundwater flows from higher elevations (or pressures) toward lower elevations (or lower pressures). Groundwater pressure, rather than elevation, controls the rate and direction of flow in confined (or artesian) aquifers. Those are aquifers that are isolated under impervious or poorly pervious strata (aquicludes and aquitards). Groundwater potential zonation means using the surface and sub-surface indicative parameters either by direct or indirect scientific methods for determining the potentiality of the groundwater zones in an area by quantitative and qualitative assessment. The surface features can be easily accessed through remote sensing and field verification, whereas the sub-surface information can be obtained through observatory wells and electrical resistivity methods

Several authors have enumerated the problems of inadequate supply of safe water in Ondo State [2-4]. In respect of the above problem, groundwater been suggested as the most reliable source of fresh water to the populace. Previous works on the development of ground water in Ondo state were faced with the problem of

***Correspondence to:** Epuh EE, Department of Surveying and Geoinformatics, University of Lagos, Nigeria, E-mail: eepuh@unilag.edu.ng

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failed (abortive) hand-dug wells and boreholes, which are as a result of the poor knowledge of the hydrogeological characteristics of the basement aquifers. However, [5] carried out a study on the evaluation of groundwater potential of Baikin, Ondo State Nigeria using Resistivity and Magnetic Techniques. He opined that the weathered and fractured aquifers constituted the main aquifer units within the study area. Most of the groundwater investigation in Ondo state has been centered on the use of Electrical resistivity method [6-9].

None of these studies incorporated the use of Multi-Influencing Factor (MIF) multi-criteria decision-making analysis for groundwater mapping in the study area. Besides, each of them was localized to their immediate study area.

In recent time, the use of remote sensing for groundwater investigation has been on the increase. Remote Sensing method with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources [10]. Several authors have demonstrated the technique of the integration of remote sensing data and GIS tool to be extremely useful for groundwater studies [10-15]. To gain deep insight of groundwater potential zones of the area before exploration, there is need for the incorporation of remote sensing, geologic and geophysical surveys. However, this study is aimed at delineating groundwater potential zones in Ondo State by integrating different contributing factors such as: soil, slope, drainage density, land use/Land cover distribution, geological setting, rainfall distribution and lineament density using the Multi-Influencing Factor technique and Hydrogeophysical information.

Geological and hydrogeological description of Ondo state

Ondo state is located in the South-Western part of Nigeria. The study area lies between Longitudes 40 30' and 60 0'E and Latitudes 50 30' and 80 15'N. It covers a geographic area of 14,500 km^2. It is bounded by Kwara, Kogi and Ekiti State in the North, Edo and Delta in the east, Ogun, Oyo and Osun States in the west and in the South by the Atlantic Ocean as shown in Figure 1. The terrain is undulating, surrounded by isolated hills and inselbergs. The topographical elevations vary from 320 m to 450 m above the sea level [16]. The area is drained by River Ala and its tributaries (Figure 2). The drain pattern is dendritic flowing in N-S direction. In areas with complex basement rocks, waters are contained in the weathered and fractured zones within the aquifers, since water cannot be found everywhere like in the sedimentary terrain. The Ondo state is underlain by rocks of the Precambrian basement complex of the southwestern Nigeria [17,18]. The major lithological units include the granite gneiss and migmatite gneiss [19,20]. These rocks form inselbergs, isolated or residual hills and continuous ridges. The area exhibit varieties of structural setting such as foliations, folds, faults, joints and fractures. The gneiss shows the evidences of ancient tectonic activity in the form of a major strike slip fault trending approximately N-S and oilier minor faults, joints and folds in NE-SW [6]. The general strike direction of faults, joints and fractures trend N-S. The river Ala and its tributaries constitute die surface water resources of the study area. The foliation trends of the area are NNW-SSE, the lineament of the rocks in the area is E-W [6]. However, in some parts the basement rocks are concealed. Ondo experience high annual rainfall with a mean of 1333.2 m [16].

The groundwater is contained in weathered and fractured basement columns, which primarily recharges by surface precipitation (rainfall) and secondarily by lateral flow from rivers and their tributaries. The basement aquifers are often limited in extent both laterally and vertically [21]. The previous geological, hydrogeological and geophysical investigation had revealed the existence of discontinuities, of basement aquifers which form the basis of detailed knowledge of the subsurface geology, its weathering depth and structural disposition. The geophysical method has also found useful applications in ground water investigation and

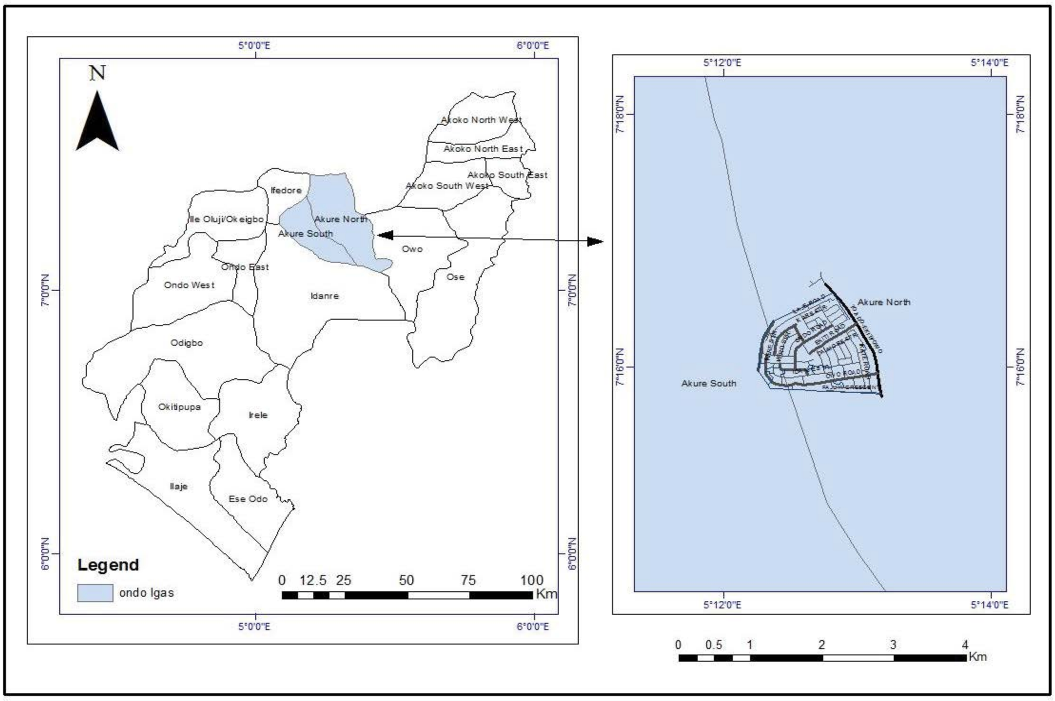

Figure 1: Map showing Ondo state and the VES observation location.

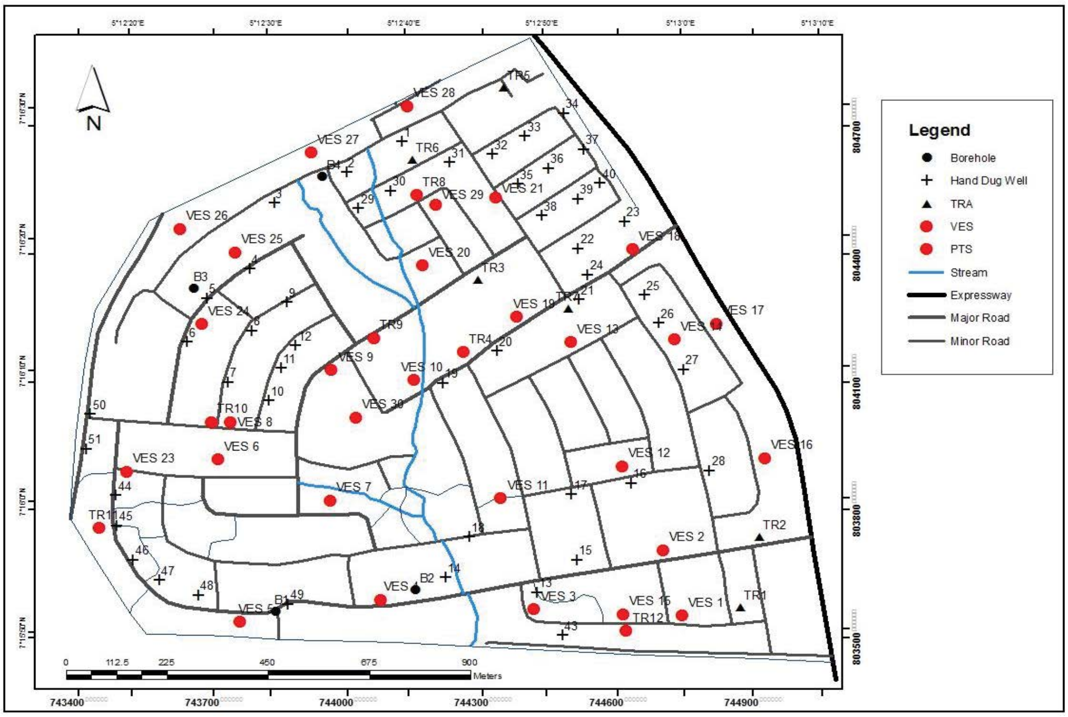

Figure 2: The Ijapo VES acquisition base map.

geologic mapping in areas of aquifers delineation, saline water mapping, lithological boundary differentiation, and determination of structural trends among others [22,23]. According to [24,25], the electrical resistivity has been used to determine the depth of bedrocks, structural Mapping, determination of the nature of the superficial 1 deposit.

MATERIALS AND METHODS

Data acquisition

Remote sensing and GIS datasets: The remote sensing data for the project were acquired from Landsat satellite observation as well as the Shuttle Radar Topographic Mission (SRTM) as shown in Table 1. Other data sources are also presented. The Image Processing Coordinate System parameters are shown in Table 2. In this study, research methodology is diagrammatically represented in Figure 1. The Land cover, Lineament density, Soil, Geological, Slope, Drainage density and Rainfall maps generated were weighted using the multi-influencing factor technique (MIF) and integrated using the weighted overlay analysis method.

Hydrogeological and geophysical investigation: Vertical electrical sounding (VES) survey method was employed in this study. The purpose of VES is to investigate the changes in subsurface formation resistivity with depth. It shows apparent resistivity (pa) variation with depth with sample use of electric sounding which provides an estimate of the resistivities of the first and last layers and indicates the relative resistivities of intermediate layers. Hence the method is useful in determining and delineation of bed depth. The potential electrode configuration used for the vertical electrical sounding (VES) was the Schlumberger array with a maximum current electrode spacing of 150m. Thirty (30) VES stations were occupied. Constant separation transverse is also known as lateral electrical profiling was used to determine lateral variations in conductivity or its inverse resistivity. The current and potential electrodes were maintained at a fixed separation and progressively moved to measure the apparent resistivity along a profile. Available borehole information (static water levels, lithological logs and groundwater yields) were used for subsurface geological sequence, delineation, aquifer type identification and groundwater potential evaluation. A total of thirty (30) vertical electrical soundings (VES) involving the Schlumberger electrode arrays were carried out at 11 localities scattered within the estate as shown in Figure 3. Electrical profiling, known as constant separation traversing (CST), uses collinear arrays to determine lateral resistivity variations in the shallow subsurface at a more or less fixed depth of investigation. The current and potential electrodes are moved along a profile with constant spacing between electrodes. The two most common array types used for CST are the dipole-dipole and pole-dipole arrays, where a dipole is a pair of current or potential electrodes. Since a clear delineation of subsurface anomalies often requires a technique for determining both lateral and vertical features. A combination VES and CST array, such as a multi-level dipole-dipole array, can overcome the limitations associated with purely profiling or sounding techniques.

Data processing

Geographic Information System (GIS): The GIS model used for the creation of the database is called the Extended Entity Relational Model (EERM). An Extended Entity Relational (EER) object is called an entity and EER object classes are called “entity-set”. The EER model supports simple, primitive or abstract attributes; class hierarchies and controlled classes of enumerated atomic values or ranges of values. In EER, abstract attributes are specified as relationship sets between (and external to) entity-sets, rather than local to entity-sets. The EER model does not support set-valued attributes, tuple attributes, union value classes and derived classes and attributes. However, set-valued attributes can be modelled using additional (auxiliary) entity-sets, tuple attribute which can be specified using auxiliary relationship-sets, and a union value class can be specified using an auxiliary entity-set specified as a generalization of the entity-sets that are involved in a union value class.

Table 1: Attributes of datasets.

S/N	Remote Sensing Data	Data Source	Year
1	Shuttle Radar Topographic Radar Mission Digital Elevation Model (SRTM DEM): 1 arc sec (30m)	United States Geological Survey (http://earthexplorer.usgs.gov)	2000
2	Landsat 8 Operational Land Imager Scenes (Path/Row): 190/55, 190/56, 189/55	United States Geological Survey (http://earthexplorer.usgs.gov)	2018
3	Soil Map of Nigeria	Soil Survey Division of the Federal Department of Agricultural Land Resources (FDALR) Kaduna in 1990.	1990
4	Geology map of Nigeria	Nigeria Geological Survey Agency (NGSA)	-
5	Rainfall data	Tropical Rainfall Measuring Mission (TRMM) (https://pmm.nasa.gov/data-access/downloads/trmm)	2017

Table 2: Image processing coordinate system.

Parameters	Quantity Value
Projection	UTM Zone 31N
False easting	500000
False northing	0
Central meridian	3
Scale factor	0.9996
Latitude of origin	0
Linear Unit	Meter
Datum	WGS 1984

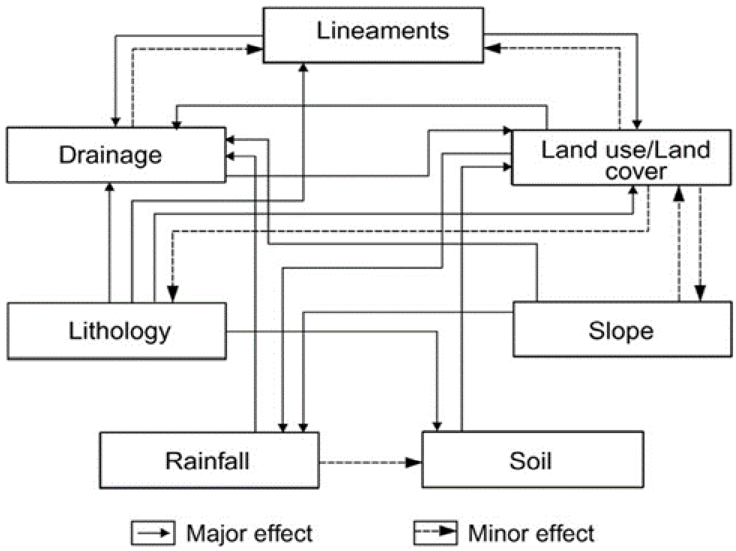

Figure 3: Interrelationship between factors which influence groundwater potential [40].

Generation of thematic layers from the influencing factors: In this study, seven influencing factors were considered in the delineation of ground water potential for the study area. The factors include geology, slope, land cover, lineament, drainage, soil, and rainfall. The geological map of Nigeria was obtained from the Nigeria Geological Survey Agency (NGSA) in a vector form. The section of the geological map that intersects Ondo State was extracted and converted to Raster format in preparation for the weighting process. Three geological classes are present in the study area. The slope was generated from the SRTM DEM using the Slope tool in the Raster Surface tools under the 3D Analyst toolbox in ArcGIS 10.5. The slope raster pixels are depicted in inclination angle to the horizontal. The Land cover was extracted from the Landsat scenes using the Maximum likelihood algorithm on ENVI 5.3 classic software environment. The portion of the soil distribution data that intersect Ondo State was extracted in ArcMap and converted to raster file as the soil layer. The Rainfall data for Ondo State was downloaded from the TRMM portal as raster points and a raster interpolation process was executed for the creation of the rainfall distribution map for the study area. Drainage lines were extracted from the SRTM DEM which served as input to the line density tool in ArcMap for the generation of drainage density map. Several significant approaches for the delineation of lineaments from satellite images have been proposed by [26-33]. The amalgamation of expertise and computer algorithm in lineament detection and interpretation by [34,18] produced excellent results. Landslide scale presented by the satellite images, also enables regional and local lineament analysis [35-38]. However, semi-automatic extraction combining the expert, the lineament density in this research was generated from the lines of fault extracted from the filtered Landsat 8 composite bands (7,4 and 1). The filtering process of convolution and morphology in ENVI 5.3 software was used. The extraction of the lines was done in the PCI Geomatica software environment. After the production of the maps, interrelationship between all these factors were determined based on previous studies and reviewed literatures. Figure 3 shows the interrelationships between the factors.

Procedure of assigning weightages in using multi-influencing factor technique: The multi influencing factor technique basically involves determining interrelationships between factors that influence ground water potential and assigning weights to them as a result of their interrelationship and strength of influence [39]. Based on the inter-dependence and inter-relationship of factors, the effects of each major and minor factor are assigned a value of 2.0 and 1.0 respectively (Figure 4).

The cumulative values of both major and minor effects are considered for calculating the relative rates as shown in Tables 3 and 4. This rate is further used to calculate the score of each influencing factor. The proposed score for each influencing factor is calculated by using the formula shown in Equation 1 [39,40];

$$\left[\frac{M_j+M_i}{\Sigma(M_j+M_i)}\right] \times 100 \qquad (1)$$

Where Mj represents major relationships between two factors and Mi represents minor relationships between two factors.

The internal features of the thematic layers were ranked by dividing the previous scores (Pi) by the number of internal features in each factor. But the feature that is perceived to have the highest influence in that thematic layer will be assigned the proposed score/weight (Pi) previously assigned to the thematic layer. The method of calculating the ranks of the internal features of the layers is explained and expressed further in Equation 2:

$$W_i \text{ of the next important class of the thematic layer} = W_i \text{ of the first class} - \frac{P_i}{n} \qquad (2)$$

Where Pi is the weight of thematic layer, Wi is the rank value of the individual class/feature and n is the total number of features in each factor [39].

Hydrogeophysics (VES interpretation, scaling and gridding of geoelectric sections): This instrument gives the apparent resistivity directly along with its corresponding depth values. Thirty VES are carried out at selected points in the study area using Schlumberger array with current electrode spacing $\left(\frac{AB}{2}\right)$ up to 100 m. The for each current electrode separation is calculated by multiplying the resistance value by Schlumberger configuration factor [41,42]. The formula for calculating of Schlumberger array is given in Equation 3.

$$\rho_a=\left(\frac{\pi\left(\frac{AB}{2}\right)-\left(\frac{MN}{2}\right)^2}{2\left(\frac{MN}{2}\right)^2}\right)\times R \qquad (3)$$

where R" is the resistance of the material"

In this method, plottings were made by electrode space ‘a’ in X-axis and electrode separation divided by apparent resistivity values in Y-axis. The point of intercept gives depth of various interfaces. The VES curves were quantitatively interpolated by partial curve matching using two-layer model curve sand the corresponding auxiliary curves. Multi-layered field curves were matched segment

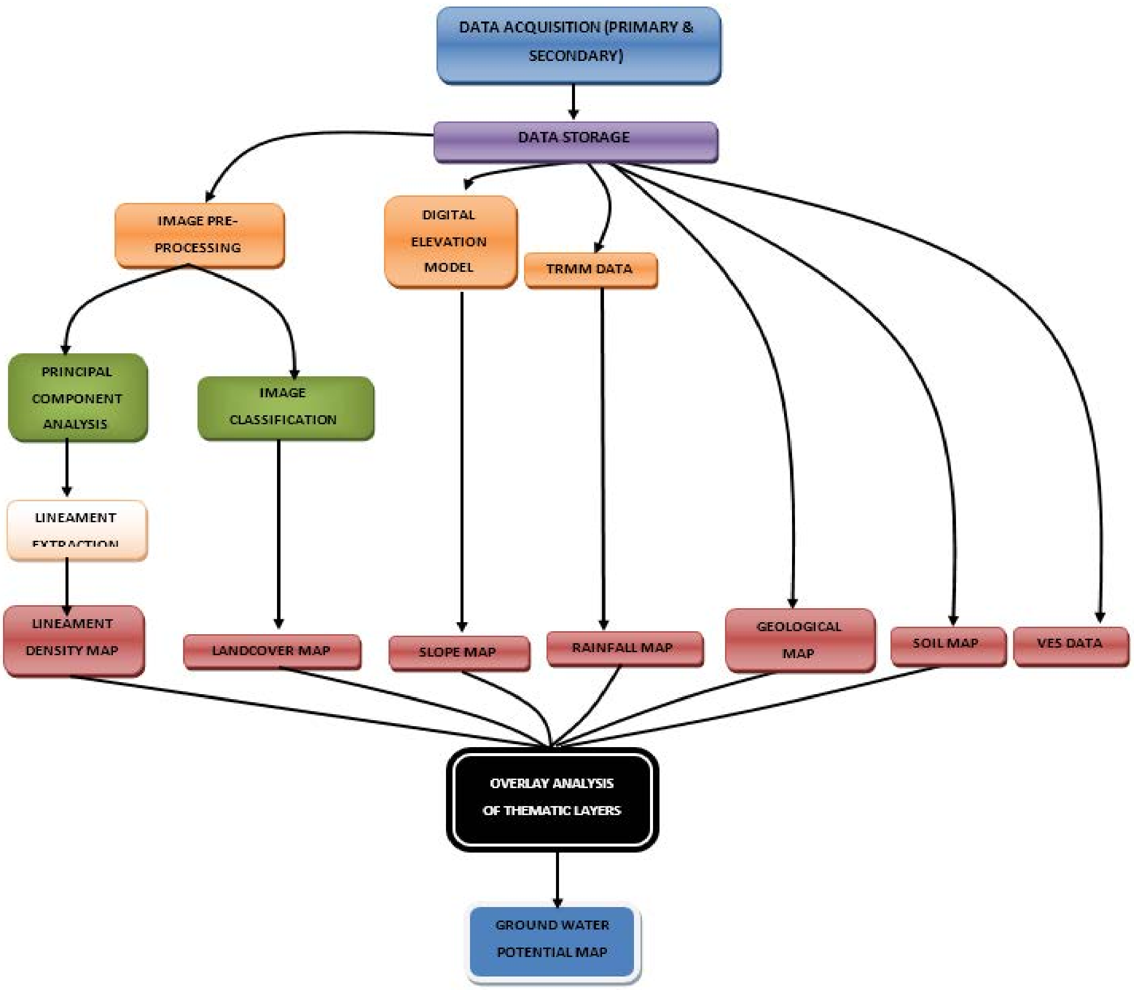

Figure 4: Flow chart for the integration of the methods adopted.

Table 3: Weighted and % influence of different thematic layer.

1	Geology	25	Sandstone	7
			Undifferentiated Basement complex	5
			Alluvium	3
2	Drainage Density	9	1-3	1
			3-5	4
			5-7	6
			7-9	9
3	Slope	16	0-1	9
			1-3	7
			3-7	5
			7-14	3
			14-41	1
4	Rainfall	9	119-136	1
			136-156	3
			156-177	5
			177-199	7
			199-223	9
5	Soil	6	Sandy loam	5
			Sandy Clay	2
6	Landcover	22	Waterbody	9
			Rock outcrops	7
			Wetland	6
			Vegetation	5
			Bareland	3
			Built-up	1
7	Lineament	13		

Table 4: Groundwater potential zoning.

Zone	Groundwater Category
10-13	Very High Potential
9-10	High Potential
7-9	Moderate Potential
6-7	Low Potential
4-6	Very Low Potential

by segment starting from the small electrode spacing. VES data using the various auxiliary curves (H,K,A, and Q). This is done by plotting the VES data on a transparent paper and then curve matched using the two (2) standard layer master curve and four (4) auxiliary type curves (H,K,A, and Q). This procedure required segment-by-segment curve matching starting from the position with shorter electrode spacing and moving towards those with longer spacing. The theoretical VES curves were generated from partial curve matching interpretations results (layer thickness and resistivities) using a computer program (WINRESIST) based on the input data. The field curves were then compared where with the computer-generated curves where a good fit (i.e. >90% correlation) was obtained between a field and a computer-generated curve, the interpretation result was considered satisfactory. The interpreted VES data generated the geoelectric section for each VES stations showing the interpreted layers and their lithology. The scaling and gridding of the geoelectric section involves the construction the construction of a digital file suitable for aquifer reservoir mapping and gridding. The geoelectric sections were digitized with respect to their differential lithostratigraphic thickness. The modules in the reservoir scaling were designed to produce chains of cells for visual representation of beds, bed sets, lamina, and lamina sets in a two-dimensional outlook. Each lithologic unit was assigned its own interpreted geologic parameters and this process was carried out in all the thirty geoelectric sections used in the research. The extended entity relational model was utilized in the creation of the Hydrogeophysics database.

RESULTS

A total of seven (7) necessary thematic layers which includes: Land Cover, Soil type, Geology, Drainage density, Slope, Rainfall distribution, Lineament density were used in the integration for the determination of the Groundwater Potential Zones (GWPZ). This integration of thematic layers gives us certain acceptable interpretations for the possibility of the occurrence of groundwater. The depth to bedrock for aquifer determination were obtained using the VES results and a query on the database using GIS showed locations and depth for drilling both on the base map and on the digitized geoelectric section.

Land cover

The land use land cover (Figure 5) of a region is the result of the interaction of various factors such as physical, economic and social which shows extent to which man has been able to utilize the land resources gainfully. Land Cover refers to anything on the surface which is not subjected to anthropogenic action like forest, rivers, different types of rock exposures and others. The state land use land cover (Figure 5) is comprised of five identifiable features which are built up, vegetation, water bodies, bare land and farm land.

Soil map

There are four soil types within Ondo state. The soils are: sandy loamy, clay loamy, sandy clay and silty loamy. The movement and infiltration of water in these types of soils is not the same. The soil's moderate acidity makes it also suitable for garden plants. The soil is fairly highly suitable with few physical limitations and is very well drained. With only a slope of 0–2%, runoff is much reduced. The soil in the state is generally fertile, permeable and flat as shown in Figure 6.

Geological map

The characteristics of rocks in terms of compactness, density, weathering status, composition, joints and fractures plays vital role in weightage assignment for Lithology. Ranking of 4 is given to Alluvium or beach sand whereas the ranking of 1 is given to hard and indurated gneissic rock. The Ondo state is underlain by rocks of the Precambrian basement complex. The major lithological units are the undifferentiated basement complex which includes the granite gnesis and migmatite gneiss with little deposits of porphyritic granite and Charnockite well-shaped into the blocks. The geology also contains coastal sand and Alluvium (Figure 7).

Drainage zonation map of Ondo state

Drainage density (D_d) is calculated as the 'ratio of the total length of streams of all orders aL within the basin to the basin area (A)' and expressed as km/km^2. The stream in the state covers about 49 km which were analyzed in three orders. The streams extend across the state from different locations. The first order stream covers 28 km while the second order streams cover 13.61 km and the third order cover 7.37 km.

Slope variation in Ondo state

Slope is a slanting surface, which is at an angle of less than 900 to a flat surface. Slope is having an inverse relation with groundwater potential. Increase in slope increases runoff and thus decrease the infiltration and affects groundwater potential. Therefore, ranking of 0 is given to lowest slope categories and 39 for highest slope. Idanre has a slope range of between 15 and 20 which is quite

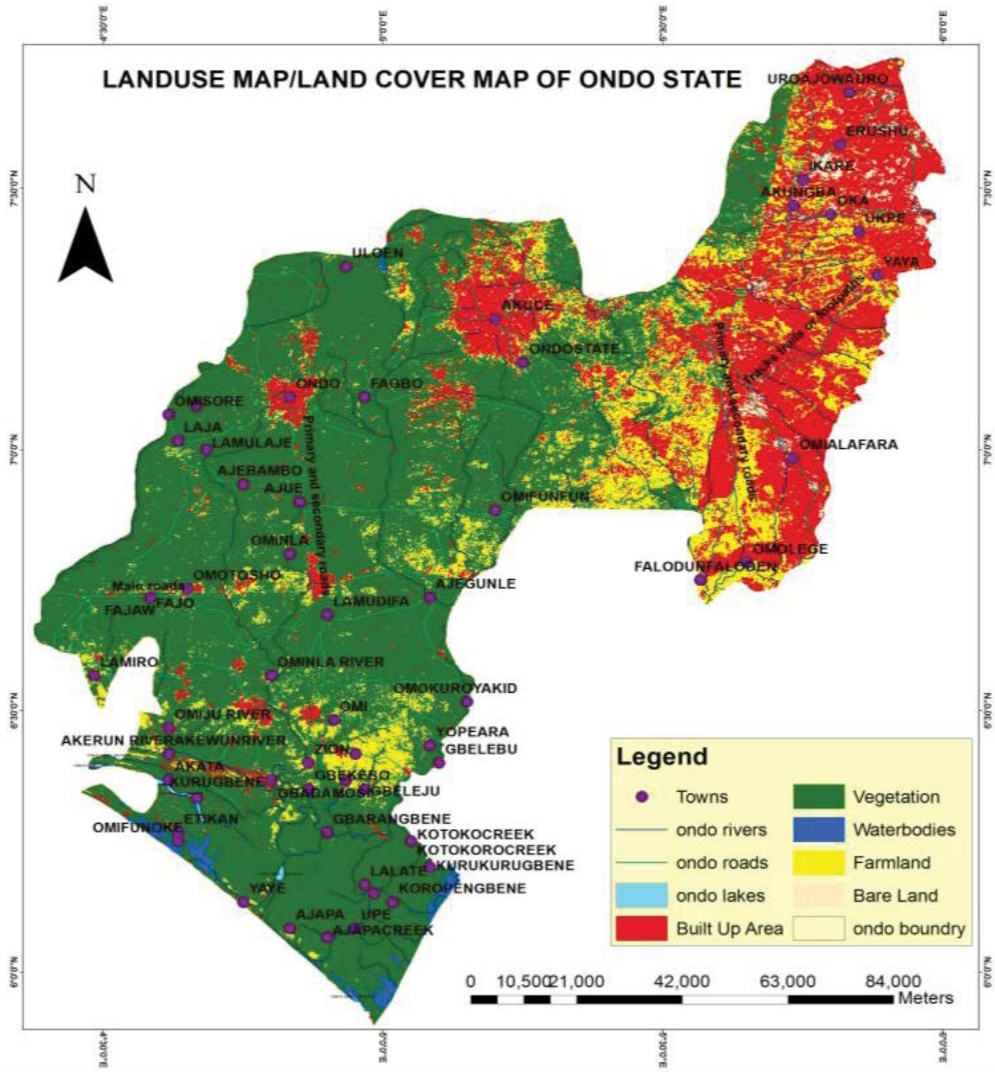

Figure 5: Land use Land cover map.

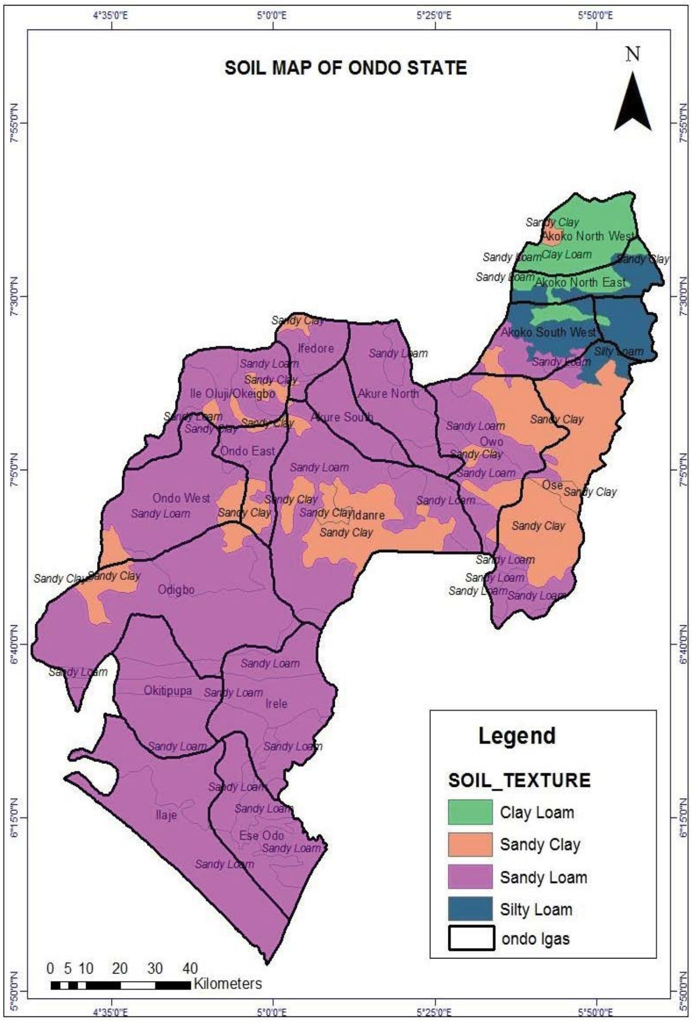

Figure 6: Soil map.

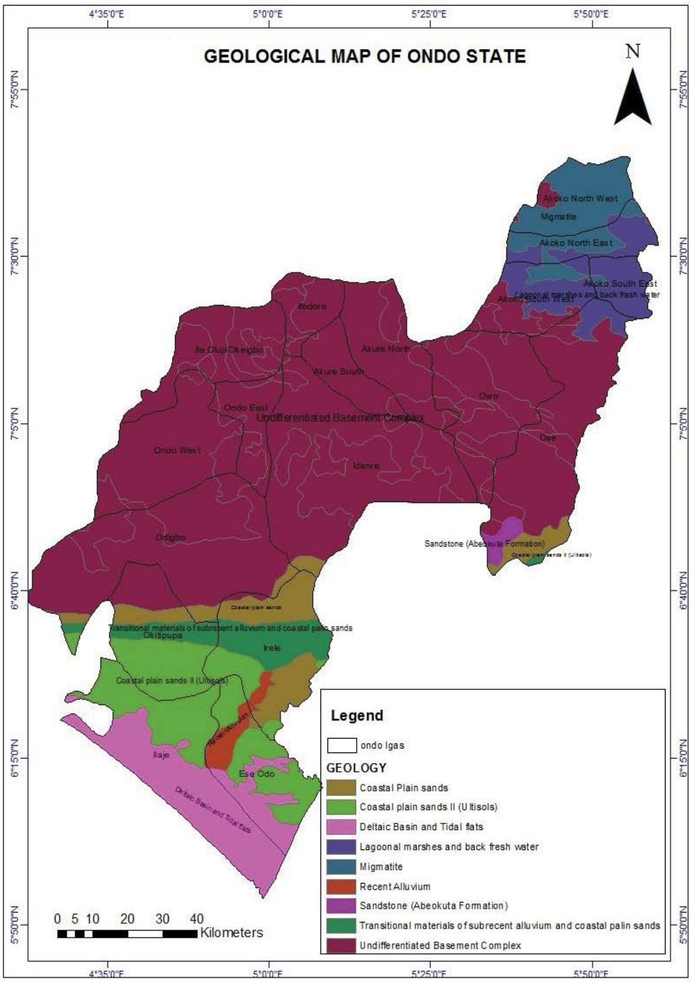

Figure 7: Geological map.

visible in the map. The slope map of the state (Figures 8 and 9) shows the flow anticipated from the northern part to the southern part. There tends to be a slower run-off in the northern part of the map than the southern part. The direction of flow is basically high towards the north east of the state.

Rainfall map of Ondo state

The study area has been classified into six zones based on the equal interval and suitable weightage has been assigned for each class. Figure 10 shows Ondo state rainfall map. The rainfall intensity decreases as we move from South to Northern part of the state.

Lineament density map of Ondo state

Generally, lineaments are associated with weathering and therefore increase porosity and permeability; hence, lineament density and groundwater potential have a direct relationship. Figure 11 shows the lineament map of the state. It depicts a characteristic feature of the occurrence of underlying structures in the both the sedimentary part and the basement complex region of the State. It also shows the fracture distribution and pattern in the study area. The very high lineament density showing the fracture distribution and complex structural pattern are found in the northern part of the state in Akoko (SW,SE,NE and NW respectively). Other areas of high density include Akure (NE and SW). These structural features corroborate with the findings of [18]. The high and moderate lineament density lies in the regions of Idanre, Ose and Odigbo. While the very low lineament density lies in the southern part region of Eso Odo, Irele and Ondo West which is the southern (sedimentary) region of the study area.

Groundwater map potential zones of Ondo

The suitability analysis like Weighted Overlay Index (WOI) is used for vector integration of all the thematic layers into a single Groundwater Potential Zone (GWPZ) map. The weights for different themes are assigned based on their influence over the ground water potential. Based on the evaluation of Ranking or the Weightage, the GWPZ are categorized. The summation of the products of the weights and themes as shown in Equation (4) gives the final Groundwater Potential Zone map. Based on the evaluation of Ranking or the Weightage, the GWPZ are categorized. The merit and demerit of the features and its influence over groundwater occurrence are exactly the point of consideration for assigning suitable weights. The final map is obtained by multiplying individual ranks of the thematic layers with the weightage assigned. The resultant map for the GWPZ is shown in Figure 12. Five categories ranging from very high (17.5%), High (12.0%), medium (39.5%), low (25.7%) to very low (5.3%). It was observed that the percentage distribution from very high to moderate GWPZ together covers about 69% of the total area.

$$GWPI = [(G_w)\times(G_T)]+[(LULC_w)\times LULC_T]+[(ST_w)\times(ST_T]+[(DD_w)\times(DD_T)]+[(RD_w)\times(RD_T)]+[(SL_w)\times(SL_T)]+[LD_w)\times(LW_T)] \quad (4)$$

Where GWPI = Groundwater Potential Index, G = Geology, LULC = Land Use Land Cover,

ST = Soil, SL= Slope, DD = Drainage Density, RD = Rainfall

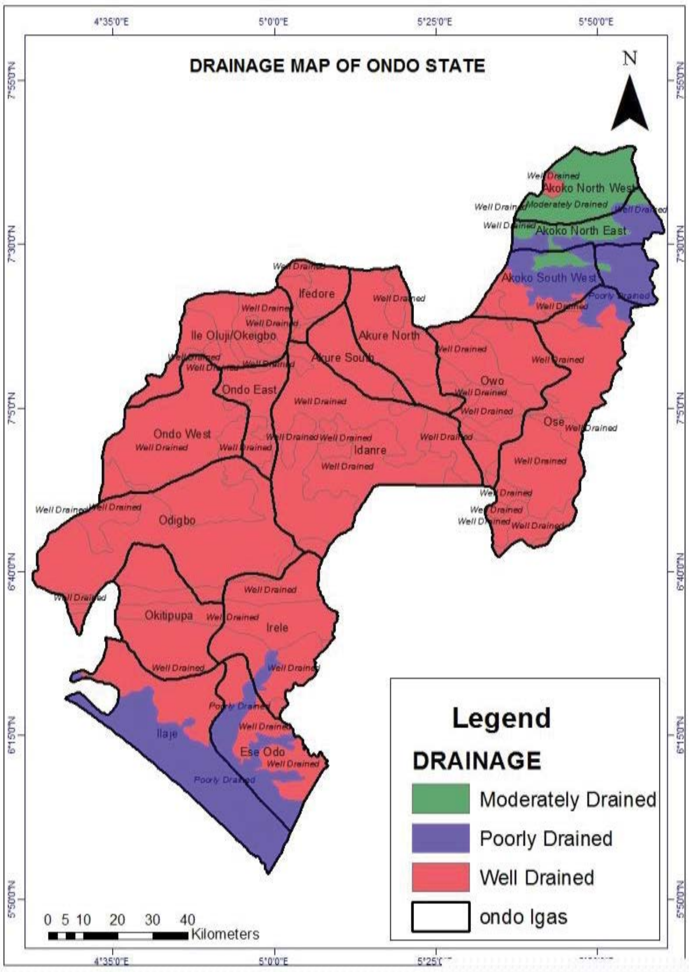

Figure 8: Drainage map.

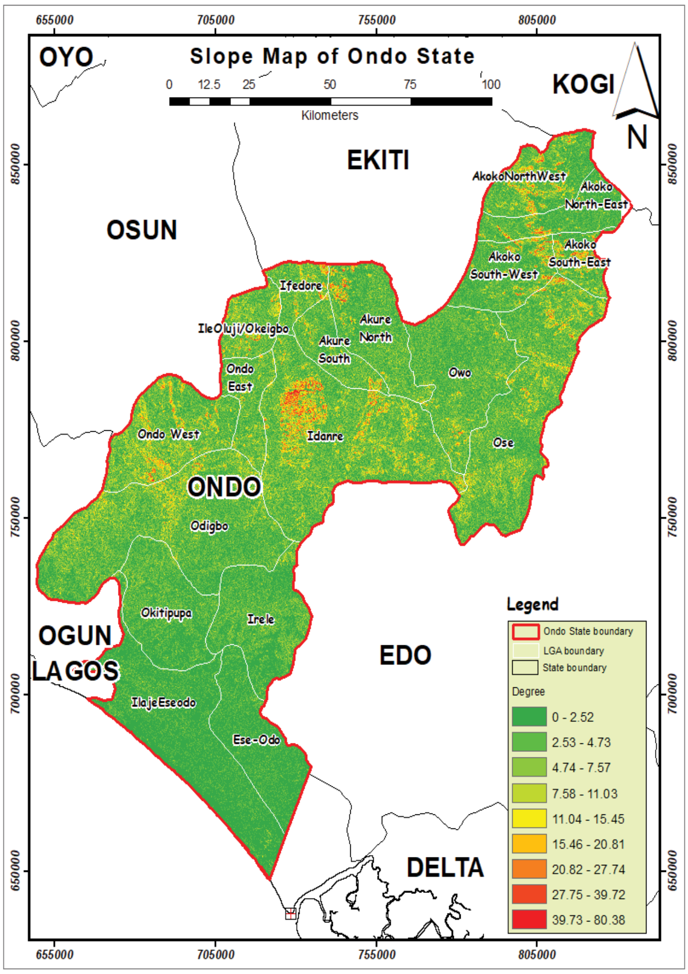

Figure 9: Slope Thematic layer.

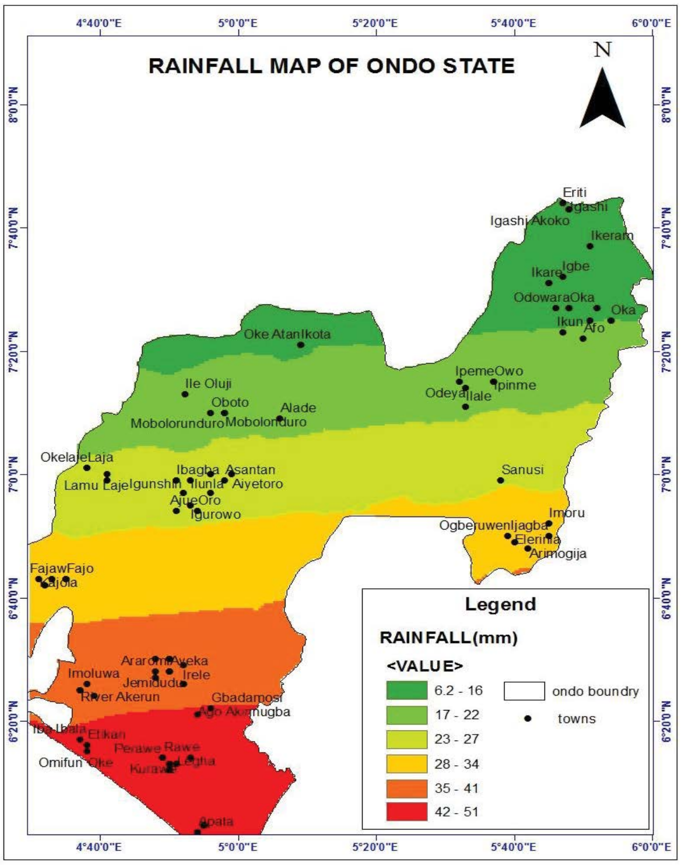

Figure 10: Rainfall map.

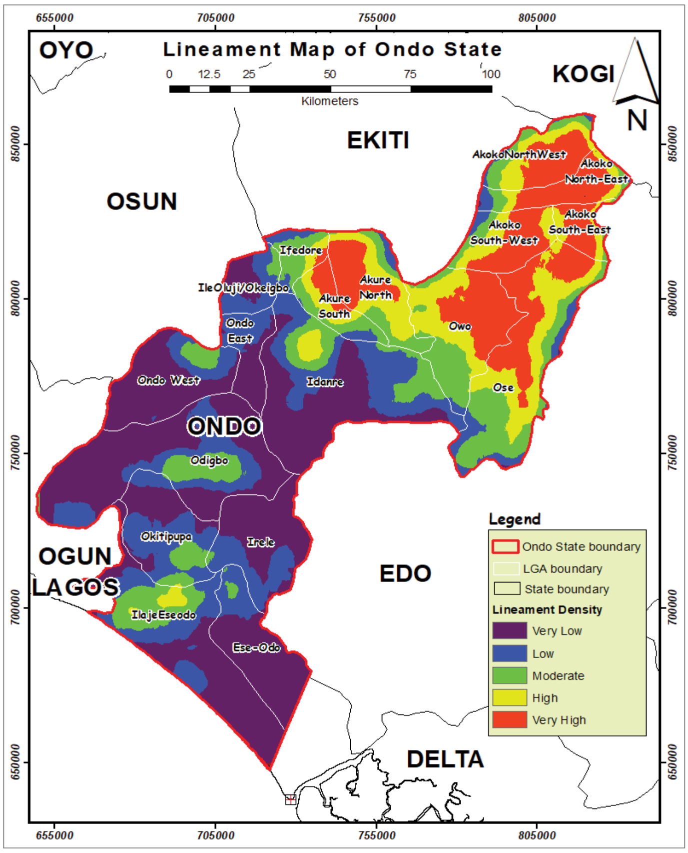

Figure 11: Lineament map.

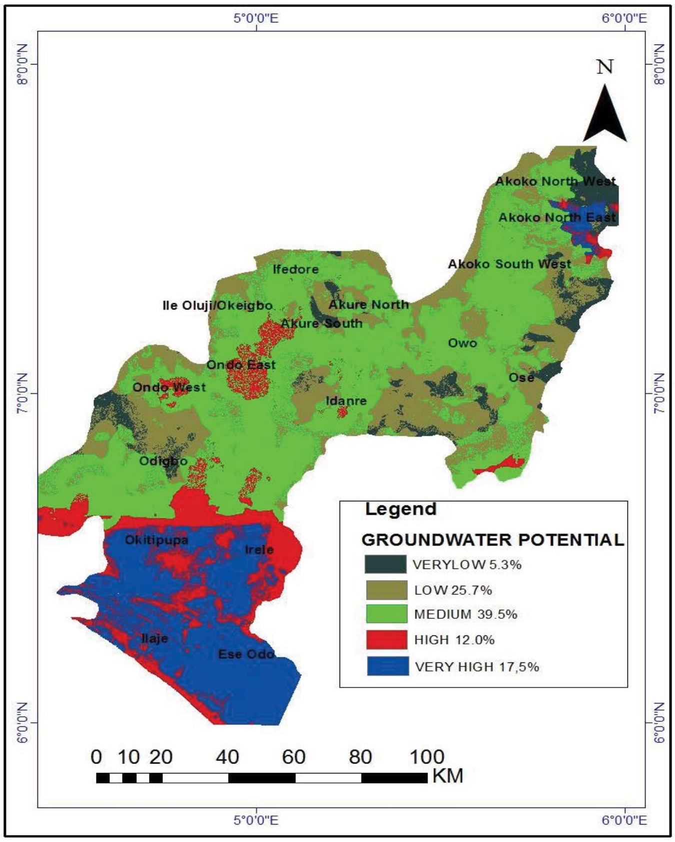

Figure 12: Groundwater potential zones map of Ondo state.

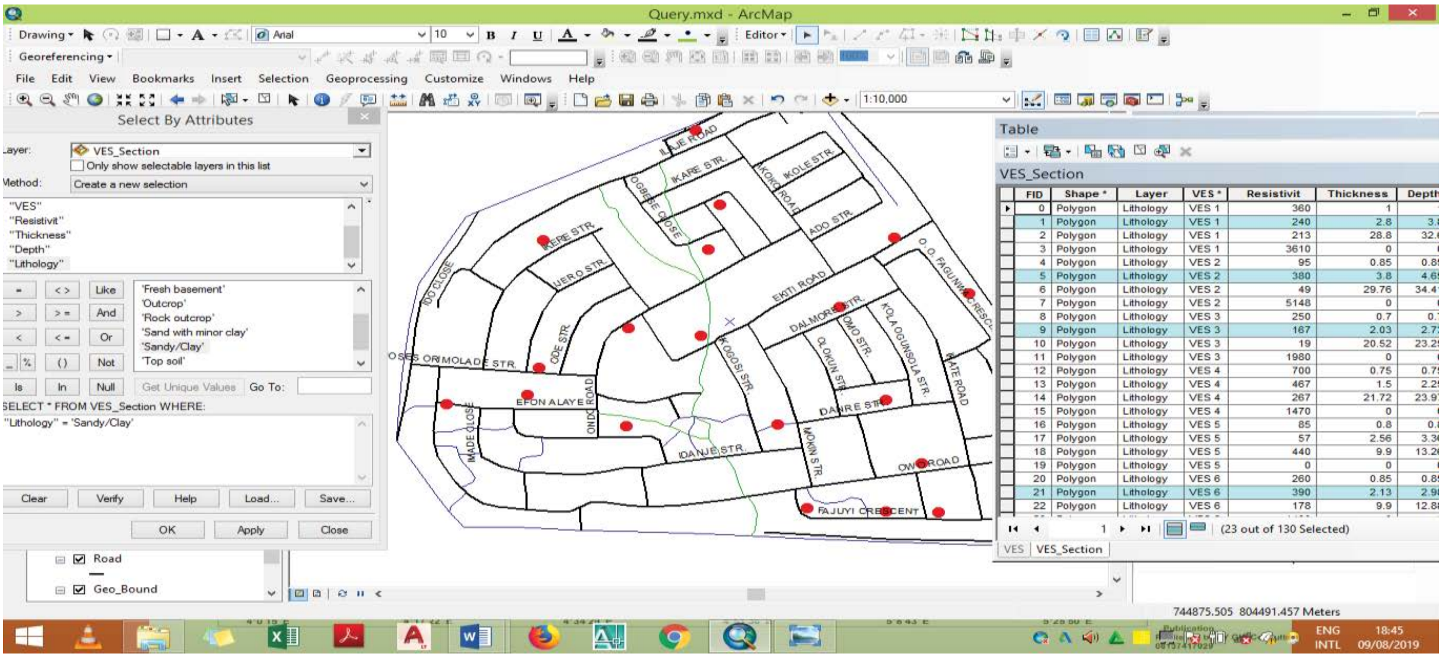

Figure 13: Query to find VES points of sandy/clay (brackish water) from base map.

Distribution,"

LD = Lineament Distribution, w = weighting Coefficient, T = Thematic Layers"

Integration of the VES data in the GIS environment

The groundwater potential evaluation of the area was further derived from the syntheses of the curve type analyses, as well as the composite maps of the resistivity and thickness maps of the sand layer and the overburden thicknesses shows that the study area has a good groundwater potential. Attribute queries were carried out on the base map to determine the spatial location for the following: Sandy/clay (brackish water), VES points of fractured (clean water) layer and fresh basement are shown in Figures 13-18.

DISCUSSION

The groundwater potential of a basement complex area is determined by a complex inter relationship between geology, post emplacement tectonic history, weathering process and depth,

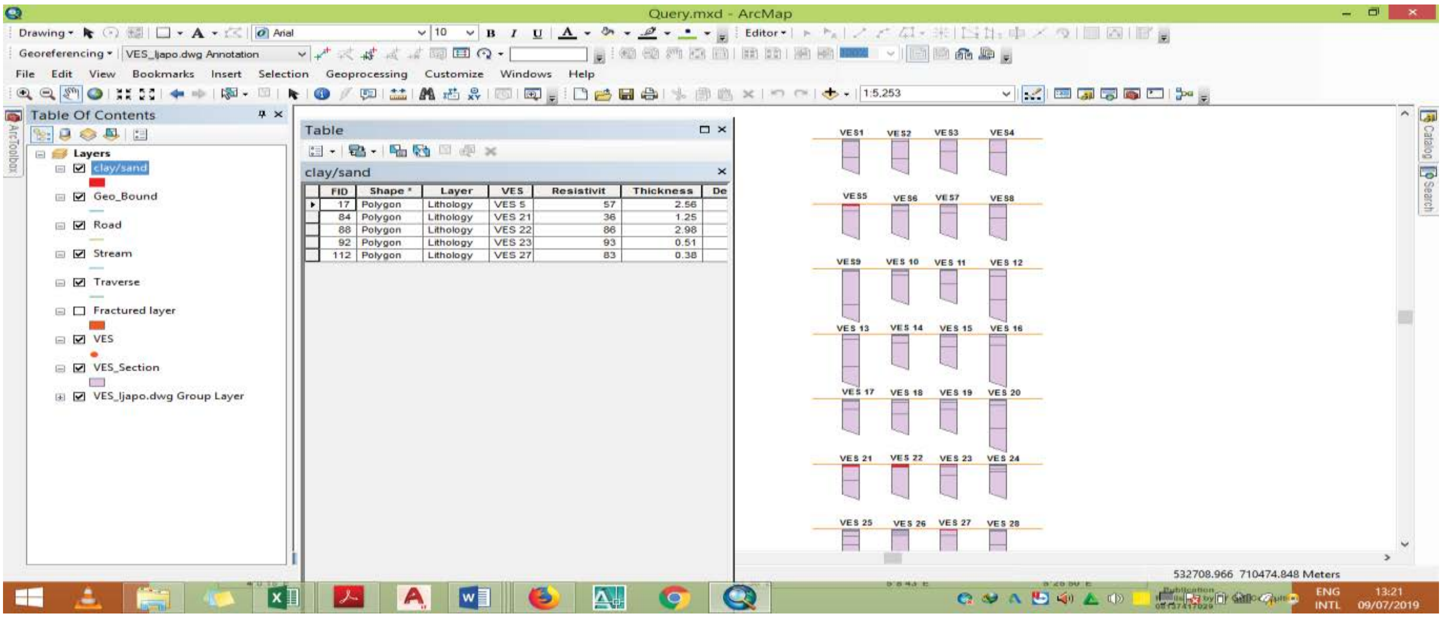

Figure 14: Query to find VES points of brackish water.

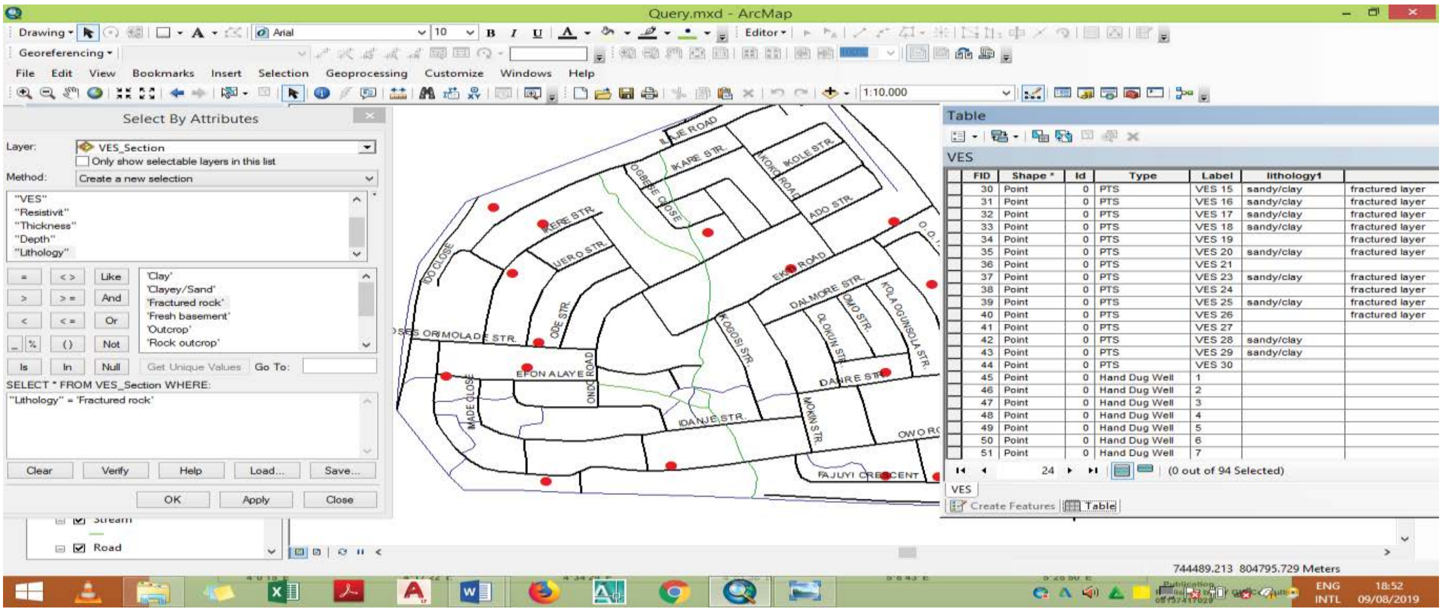

Figure 15: Query to find VES points of fractured (clean water) layer from base map.

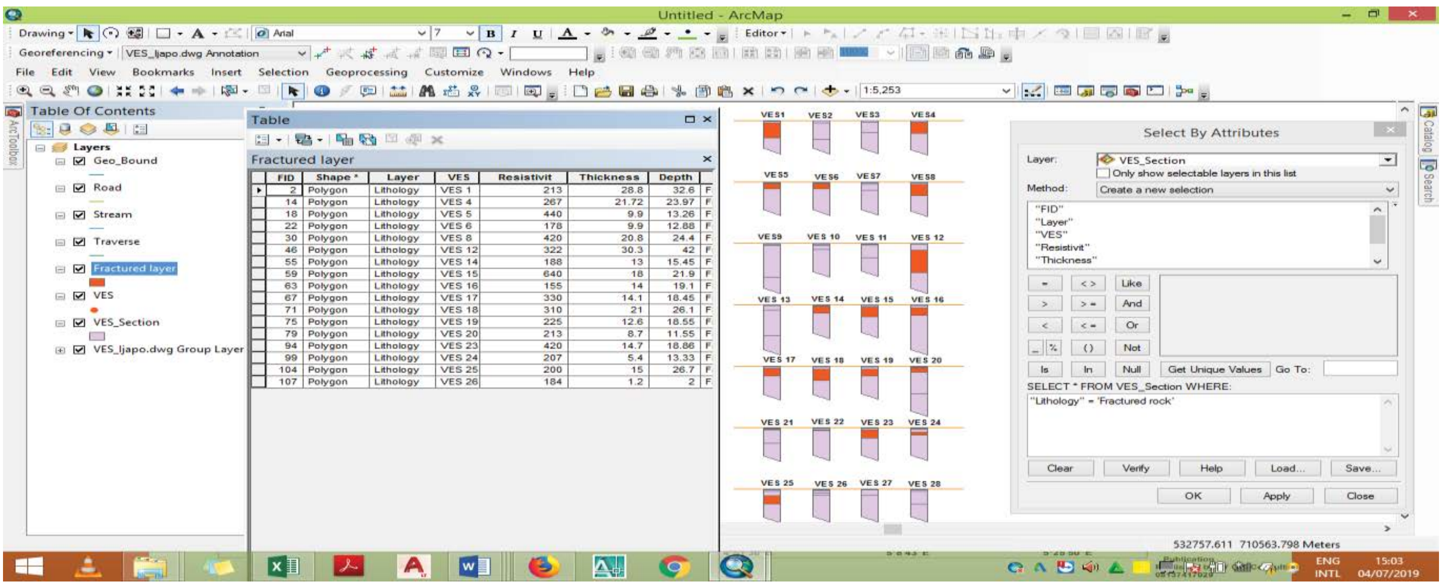

Figure 16: Query to find VES points of fractured layer.

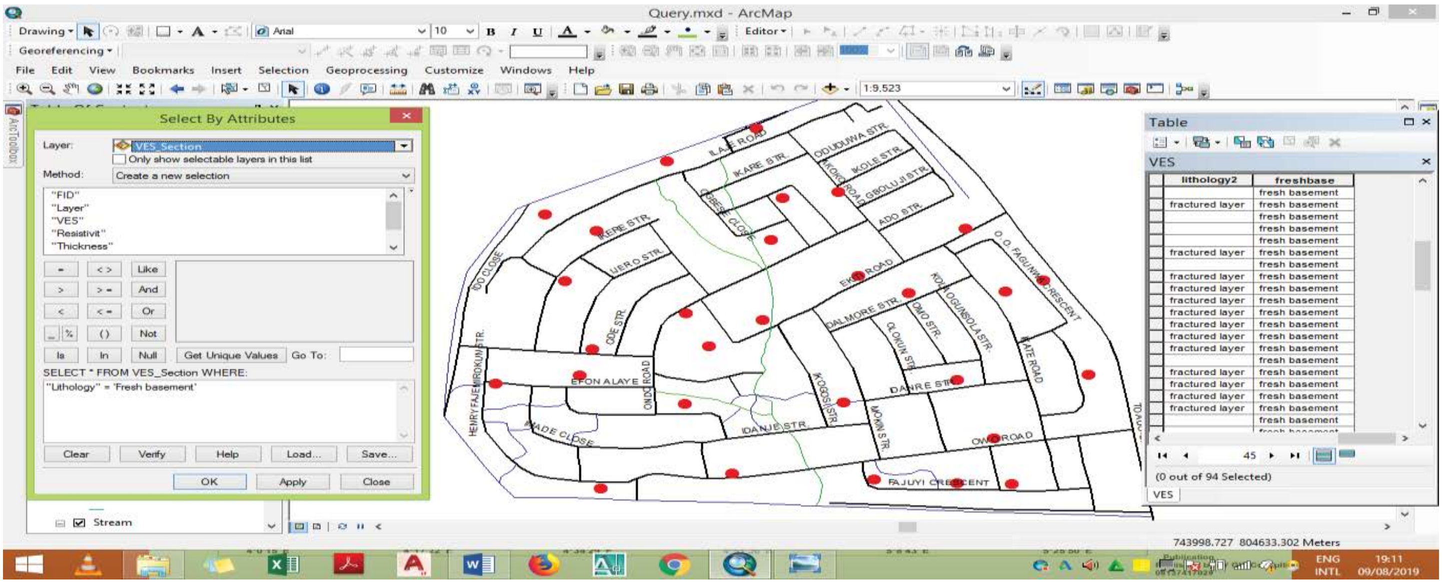

Figure 17: Query to find VES points of fresh basement from base map.

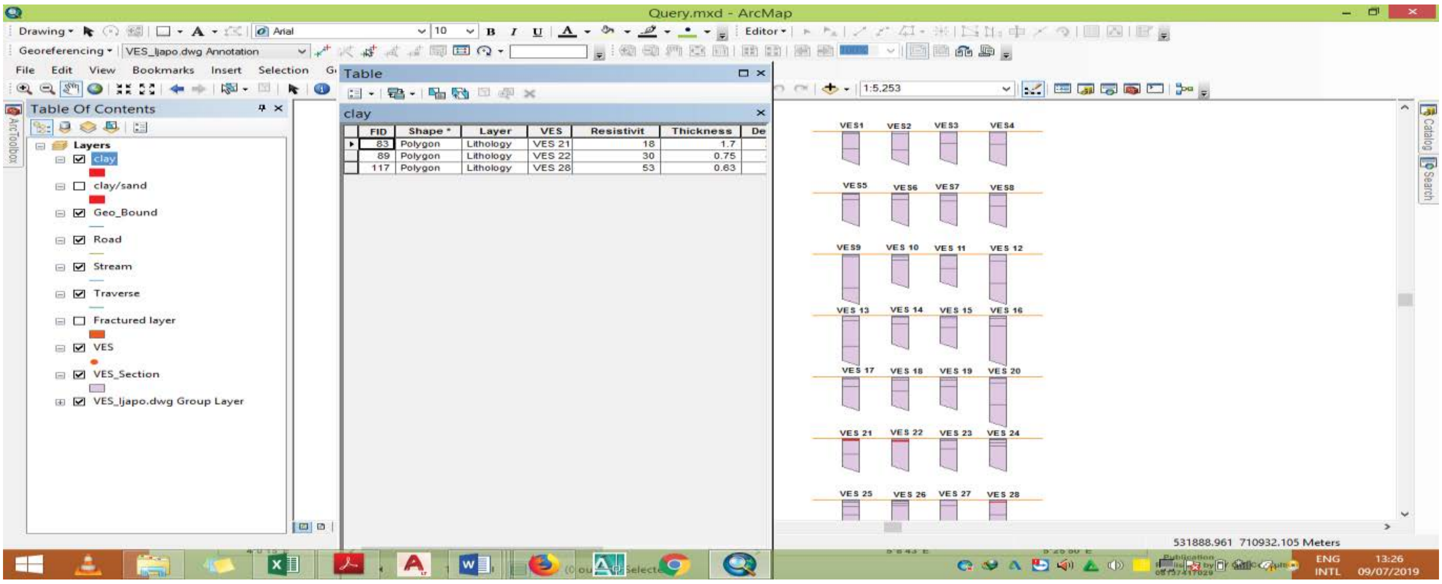

Figure 18: Query to find VES points of saline water.

nature of weathered layer, groundwater flow patter, recharge and discharge [43]. The area underlain by gneissic rocks shown more responsiveness to stress by fracturing the charnokites. They show more fractured aquifers. Some of them fall within the bedrock depressions where the bedrock is concealed and not close to the surface. The have high overburden thickness. These planes will possibly have high secondary porosities with consequently high storage capacity and high groundwater potentials.

The geoelectric sections identified a maximum of four subsurface layers -the sandy clay/clayey sand/gravel topsoil; the clay/clayey sand/sand layer; the weathered basement [7,8]. The layer thickness for the upper three layers are respectively 0.7-1.2 m, 0.6-4.25 m, and 6.50 m-58.0 m with resistivities 22-1050 Ωm, 18-700 Ωm and 19-1530 Ωm respectively, with the exception of some locations that entered into the fifth layers. The bedrocks in most places are infinitely resistive with an overburden thickness of between 5.0m and 57.0m. The weathered layers show resistivity ranging from 14-62 Ωm. The bedrock relief/structural maps delineate a series of bedrock ridges and depressions within the survey area. Results from the VES data show that BH1 and BH2 found around VES 4 and 5 with overburden thickness between 13.0 m and 24.0 m along Owo road show high yield while BH3 located in Ikere Street shows also a high yield very close to BH1 yield in value. BH1 is found around VES 6 with overburden thickness of about 13.5 m. The BH4 is a medium yield borehole found in Ilaje Street, very close to VES 27 and having overburden thickness of about 14 m. This occurred around bedrock ridges. It may not be a good site to drill further wells since water move away from bedrock ridges to the depressions. The capacity for storage will be very low, so it will not be able to serve more than one compound. The weathering process is favored by the climatic conditions of the study area with annual rainfall of between 120 mm and 1500 mm and relative humidity of 80% the annual rainfall favours significant recharge of the basement aquifers through surface precipitation. The discontinuous nature of basement aquifers reduces the influence of recharges through groundwater flow.

The bedrock depressions being groundwater collecting centers are priority areas for groundwater development which are found in certain locations of the study area. The lithological differentiation between the different rock types from the lineament density map (Figure 11) revealed that most fractures occur in the region of gneissic rocks. It shows therefore that groundwater potential in basement complex terrains depends, therefore, on post-emplacement processes such as tectonism and weathering which could lead to the development of secondary porosity and permeability [18,44,45]. The layer resistivity value of the weathered layer for granite and porphyritic granite gneiss are generally <450 Ωm. However. Charnockite show more susceptibility to weathering since they easily weathered into clay having resistivity of about 19 Ωm with few areas showing little or no fracturing. With this delineation all the areas underlain with gneissic rocks are probable sites for groundwater exploration clue to the responsiveness to stress by fracturing. The majority of the areas have the capacity to protect the groundwater from being polluted. The groundwater flow pattern which is towards the centers of the bedrock depressions (see slope thematic map Figure 9) implies that the Ala River and its tributaries are probably being significantly recharged by the groundwater.

CONCLUSION

Integration of remote sensing, GIS and vertical electrical resistivity data has been used to integrate 7 thematic layers. The GWPZ are classified into five classes based on the integration of rank and weights assigned for different thematic layers. The zones associated with low slope, lateritic soil, high lineament density, forest or agricultural land and coastal plain yields good groundwater potential. Whereas, the areas associated with high slope, clayey soil, low lineament density, high drainage density, built-up land and structural hills yield low groundwater potential. It is observed that the groundwater potential category with high and very high zones together covers about 29% of the total area. These results provide a better hydrogeological understanding of the study area. Pollution of groundwater in Ijapo estate could be both point source and non-point source though it is expected that some parts of Ijapo Estate will most likely be polluted mostly through human induced means and not through environmental changes.

The groundwater potential map has shown that 69% of the state lies between the moderate to very high groundwater potential zones. Therefore, groundwater could be used as a good source of water supply to the citizens of the state. The majority of the location is underlain by gneiss rocks which are more responsive to fracturing; therefore, the area is a good site for drinking water explorations with the few exceptions of some areas which are underlain by Charnockite. The queries on the basemap and geoelectric sections give the clarity of such locations. This is because Charnockite is not a good aquifer for groundwater. The results show that the application of remote sensing and GIS in the determination of groundwater potentials zones has become a precursor for groundwater mapping as it provides the various ranges of the potential of the zone before the geophysical method to determine the aquifer characteristics.

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