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GROUNDWATER POTENTIAL EVALUATION IN A TYPICAL HARDROCK TERRAIN USING GRRAT INDEX MODEL

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ABSTRACT

Geological and geophysical surveys had been carried out in parts of Alagbaka area, Akure, southwestern Nigeria, with the aim of evaluating the groundwater potential using the **G**eology of the study area, Aquifer **R**esistivity, Bedrock **R**elief, **A**quifer type and **T**hickness (GRRAT) index model. Geological and hydro-geophysical data were used to generate five thematic maps for **G**eology, Aquifer **R**esistivity, Bedrock **R**elief, **A**quifer type and **T**hickness (GRAT) of the aquifer units in the study area. GRRAT ratings were obtained based upon a calculationof weight and range of each of the parameters. They were used to develop the GRRAT indexmap ofthe study area. The GRRAT index modelmap generated for the study area showed that the very low, low, moderate and high groundwater potential zones cover about 15%, $45^{0}/_{0,}$ 35% and 5% respectively of the investigated area. This study concludes that the GRRAT index model can greatly increase the success rate of drill borehole projects and can also be a useful tool in the decision making process for groundwater development in a typical hard rock terrain.

KEYWORDS: Geology, Geoelectric, GRRAT Index, Groundwater Potential, HardRock

INTRODUCTION

The search for groundwater has been advanced across the globe in view of the generally accepted opinion that it is the best natural source of quality water for both drinking and irrigation purposes (Hoque et al., 2009). Several tools ranging from geophysical, hydrogeological, remote sensing and geographic information system (GIS) have been harnessed for delineation of this precious resource within the subsurface. Some recent researches have been undertaken to regionally predict the groundwater potential index using artificial intelligence techniques by incorporating parameters that influence the occurrence of groundwater (Musa et al., 2000; Murthy et al., 2003; Shigdi and Gracia, 2003; Madan et al.,2010). The study area, parts ofthe Alagbaka Housing Estate, Akure Metropolis, Southwestern Nigeria, is known for several abortive/dry boreholes and hand dug wells. The increasingpopulation in Alagbaka area has imposed a great pressure on the available groundwater resources. It, therefore, becomes imperative to carryout detailed hydro-geophysical investigation of the study area with a view to meet the water need of the people in the area. Previous hydro-geophysical investigations carried out around the study area and in similar geologic terrainon groundwater potential evaluation(Olorunfemi et al., 1999, Omosuyi et al., 2013, Bayode, 2013)were based on few relevant hydro-geophysical indicators controlling groundwater occurrence.This includes thick overburden and moderate resistivity values of weathered material. These approaches are limited, since only a few factors/parameters out of many were considered. This perhapsaccounted for the high failure rate of a boreholedrilled in the study area. The aim of this studyisto adopt a different approachinvolvingdevelopment of an index modelfrom thematic maps that willintegrategeologic and hydrogeophysicalparametersfrom geoelectric method controlling groundwater occurrenceinthestudy area,and use this todevelop a groundwater prospect map for theinvestigated area.

Description of the Study Area

The study area,Alagbaka, is located in the Southeastern part of Akure Metropolis, Southwestern Nigeria. It lies between geographic co-ordinates of Northings 800400 and 800900 mN and Easthings 741550 and 745550 mE in the Universal Traverse Mercator (UTM), Minna Zone 31 (Figureure 1). The topographic elevation in the area ranges from 427 to 418 m above mean sea level. The study covers an areal extent of about 315 km^2. The study area is located within the tropical rain forest in Southwestern, Nigeria with dry and wet seasons. The wet season starts from around mid March and ends in October with an average annual rainfall of between 1500 mm and 2100 mm while the dry season starts around November and ends in March (Iloeje, 1980). The average maximum temperature is about 33 ˚C (Iloeje, 1980).

Geology and Hydrogeology

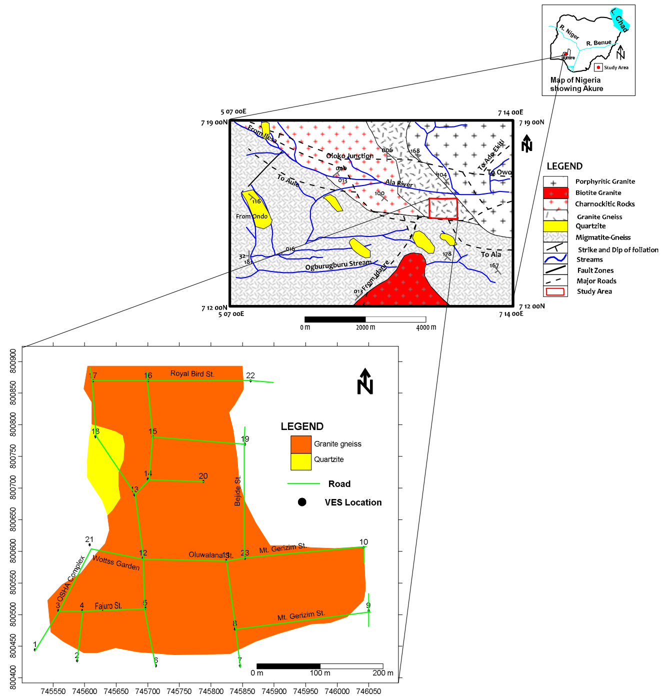
The study area is underlain by the Basement Complex rocks of Southwestern Nigeria (Rahaman, 1976). Field observation revealed that the study area is underlain by two lithologic units these include granite and quartzite (Figureure1). The basement rocks are found to outcrop in places within the investigated area. The concealed basement rock is suspected to contain secondary structures (faults, fractures, joints and shear zones) imposed on it by previous tectonic activities which are likely to contain water in addition to the regolith. The thickness of regolith is dependent on the rock type, location of faults and fractures, topography and rainfall (Richard and Paul, 2004). Previous boreholes drilled in the investigated area without a sound knowledge of both geological and geophysical investigations wereeither failed outright or of very low yielding capacity. Based on this, there is need to harness combined geological and geophysical informationfrom overburden material and the subsurface geologic structural discontinuities for the assessment of productive boreholes within the study area.

MATERIALS AND METHODS

Geological survey of the investigated site was carried out to map the lithological boundaries ofthe various rock units occurring in the study area.

The electrical resistivity method was employed in the geophysical survey.The electrical resistivity survey involved the Vertical Electrical Sounding (VES), using the Schlumberger array. The resistivity measurements were carried out with the Ohmega resistivity meter.Twenty six (26) sounding data were acquired in the study area and were distributed to cover the entire study area (Figureure.1) and their locations were georeferenced accordingly. The electrode spread of AB/2 (m) varied from 1 to a maximum of 100 m. The VES data interpretation involved the partial curve matching and 1-D computer assisted forward modeling with the Win RESIST 1.0 (VenderVelper, 2004) software. The information obtained from the geological mapping and the geophysical interpreted layer geoelectric parameters (resistivities and thicknesses) obtained from the investigated area were incorporated into the**G**eology of the study area, Aquifer **R**esistivity, Bedrock **R**elief, **A**quifer type and **T**hickness (GRRAT) index model which was used to generatethe groundwater potential map for the study area.

The GRRAT index modelis designed to evaluate groundwater potential based on five (5) geological and hydro-



Figureure 1:Location, Geology and Data Acquisition Map of the Study Area Inset Geological Map of Akure (After Owoyemi, 1996)

geophysical parameters. These include geology, aquifer resistivity, bedrock relief, aquifer type, and aquifer thickness. Each parameter is assigned a weight based on relative importance in influencing the groundwater prospect. Each of the five parameters is further assigned a rating for different ranges of values. Each of the parameter rating and weights ranges from 0.2 – 1and 2 – 5 respectively (Table 1).The GRRAT Index, a measure of the groundwater potential, is computed from the linear combination of the product of weights and rating for each of the parameters as follows:

GRRAT= $\sum_{i=2}^{5}\{(W_{i)} RI\}/\sum_{i=2}^{5} W_i$ Chachadi (2005)**(1)**

Where $W_i$is the i^{th} indicator weight and R_i is the rating of the i^{th} indicator. Thus the user can use geological and geophysical information from the area of interest and choose variables to reflect the specific conditions within the area chosen,the corresponding ratings and to estimate the indicator scores. The maximum GRRAT index is obtained by substituting the maximum rating in equation (2) below:

$GRRAT_{INDEX} = \{(W_1\times R_1) + (W_2\times R_2) + (W_3\times R_3) + (W_4\times R_4) + (W_5\times R_5)\}/\sum_{i=2}^{5} W$ **(2)**

$GRRAT_{MAX} = \{(5\times 1) + (3\times 1) + (2\times 1) + (2\times 1) + (3\times 1)\}/15$ **(3)**

$GRRAT_{MAX} = 1.0$ **(4)**

Likewise, the minimum GRRAT index is obtained by substituting the minimum importance rating in equation (5) as shown below:

$GRRAT_{MIN} = \{(5\times0) + (3\times0) + (2\times0) + (2\times0) + (3\times0)\}/15$**(5)**

$GRRAT_{MIN} = 0$**(6)**

Where the acronym in capital letter of the corresponding parameter in 'GRRAT' is formed from the highlighted and underlined letters of theparameters guiding groundwater occurrence (**G**eology of the study area, Aquifer **R**esistivity, Bedrock **R**elief, **A**quifer type and **T**hickness of the aquifer) while W = weight, and R = rating. The subscript numbers refer to the variable weights and rating respectively (Chachadi, 2005). The GRRAT Index was further divided into five categories: Very high, high, moderate, low and very low groundwater importance rating. Each category is a reflection of an aquifer inherent capacity to groundwater occurrence. The GRRAT possibility of the area to groundwater evaluation is discussed based on the value of the GRRAT index. The higher the GRRAT Index the higher the groundwater potential. GRRAT Index is relative and dimensions thatdepend on the geological and hydro-geophysical characteristics of an aquifer medium. A summary of these parameters and the weights, range assigned to them and ratings are presented in Table 1.

Preparation of the Parameter Maps

Each of the GRRAT parameters was expressed as thematic layer using SUFER 12 software. The maps generated were used to assess the intrinsic groundwater prospect within the investigated area. The data layers are described as follows:

Geology (G)

Geology is one of the main parameters affecting groundwater occurrence in any particular area. In the Basement Complex area of southwestern Nigeria, some of the rock units includemagnetite, quartzite, gneiss and granite.Field observation shows that some geologic units, due to their age, mineral composition, imposed structural characteristics from tectonic history, support groundwater occurrence more than others,such rocks include quartzite. of all the Basement Complex rocks, quartzite being more brittle than other basement rocks when subjected to stresscondition is highly susceptible to weathering,and consequently with higher fracture index,is the most favorable to the groundwater accumulation in a typical crystalline rock era when fractured/weathered.Also in the crystalline rocks of southwestern Nigeria, quartzite being more brittle and much older than gneiss, is likely to have suffered more tectonic deformation than gneiss. Therefore, it is considered to be a better rock for groundwater accumulation than gneiss. Table1 presents an indicator with sets of rock types and their rating with respect to groundwater potential. Based on this, quartzite was assigned higher rating value of 0.7 while granite-gneiss was rated 0.3. These values were used to develop a map for thisrating using SURFER software (Figureure 2). It is noted that VES 21 and 22 falls within the quartzite rock unit which supports all geologic criteria (age, tectonics activities and higher fracture index) with expected higher groundwater potential.

Aquifer Resistivity (R)

The resistivity or conductivity of the subsurface geologic material is mainly controlled by the water content. Water is conductive due to the dissolved ions present in it.

This factor makes the resistivity survey method an important tool in mapping porous medium in the delineation of groundwater potential zones. The VES interpretation results carried

Table 1:Summary of GRRAT Parameter, Weight, Ranges and Ratings for the Study Area

Parameter	Weight	Range			Rating
Geology	5	Lithology	Age	Fracture Index	
		Quartzite	2800 +/-200 M years	Very high	0.7
		Granite-gneiss	2100 +/-200 M years	Medium	0.3
Aquifer **R**esistivity	3	> 750 ohm-m		Very low	0.2
		550 – 750 ohm-m		Low	0.4
		350 – 550 ohm-m		Medium	0.6
		150 – 350 ohm-m		High	0.8
		< 150 ohm-m		Very high	1.0
Bedrock **R**elie	2	Ridge		Low	0.25
		Slope		Medium	0.5
		Zone of depression		High	0.75
Aquifer Type	2	Confined > 1500 ohm-m		Low	0.25
		Semi- confined 0-60/600-1500 ohm-m		Medium	0.5
		Unconfined 60-600 ohm-m		High	0.75
Aquifer **T**hickness	3	0-5 m		Very low	0.2
		5-10 m		Low	0.4
		10-15 m		Medium	0.6
		15-20 m		High	0.8
		> 20		Very high	1.0

Out within the study area delineated three subsurface geoelectric layers. These are the topsoil, weathered layer and fracture/fresh basement rock. The summary of the geoelectric parameters obtained in the study area is presented in Table 2. In this work, resistivity values were assigned a weight of 3 on a 15 point scale. Table 1 shows the resistivity weight, resistivity range and the rating. Areas of very high ratings of 1.0 depict areas of moderately low resistivity values of < 150 ohm-m while the area with ratings of 0.8, 0.6, 0.4, and 0.2 has resistivity values which range from 150 – 350 ohm-m, 350 – 550 ohm-m, 550 – 750 ohm-m and > 750 ohm-m respectively. This rating range of values which vary from 0.2 – 1.0 was used to develop the aquifer resistivity rating map for the investigated area (Figureure. 3). Since high groundwater potential zones have been found in areas that are characterized by bedrock depressions. Hence, bedrock relief helps in groundwater evaluation because it controls the subsurface flow and storage of groundwater in a typical Basement Complex area. Water flows from a region of high hydraulic head to the region of low head. The bedrock relief was obtained by subtracting the surface elevation from the overburden thickness at all the VES locations within the investigated area. The values obtained were used to develop the bedrock relief map in the investigated area (Figureure. 4a and b). The arrows in (Figureure. 4a) showthe groundwater flow direction, from the ridge to the slope and, subsequently, to the depression zones. Table 1 showsthe weight, range and rating for the bedrock relief. The depression zone was assigned an importance rating of 0.75 (groundwater collecting zone), slope 0.5 (low groundwater radiating zone) and ridge 0.25(high groundwater radiating zone). The range of values of 0.25 – 0.75 were used to generate the bedrock relief rating map for the study area (Figureure

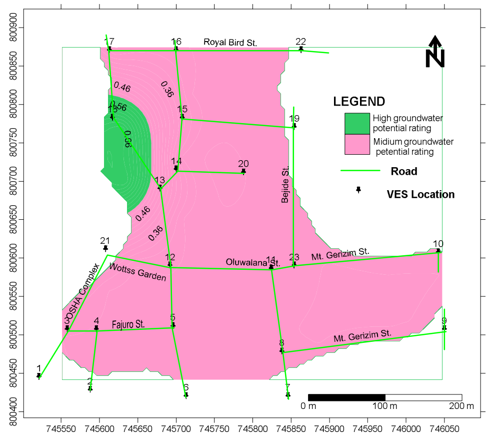


Figure. 2: Map Showing the Rock Types Rating in the Study Area

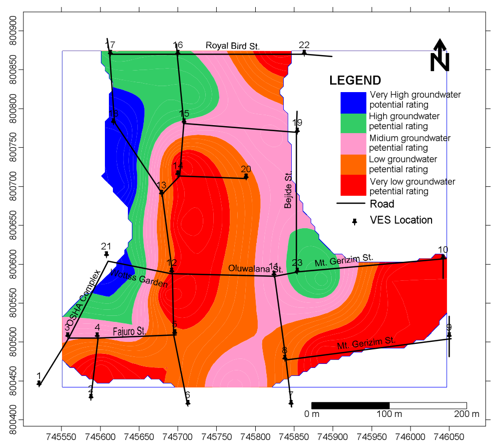


Figure. 3: Map Showing Aquifer Resistivity Rating in the Study Area Bedrock Relief (R)

4b). The map shows that the depression zone in the central to the north eastern part of the study area is characterized with a higher rangeof values of 0.62 – 0.78; this is an indication of higher groundwater prospect.

Aquifer Type (A)

The geoelectric layer resistivities and thicknesses obtained from the interpretation ofthe VES data was used to classify the aquifers in the study area into unconfined, semi-confined and confined.The aquifer material, include weathered layer (unconfined), clay/sandy clay (semi-confined) and partly weathered/fractured basement (confined).In a typical Basement Complex, unconfined aquifer has the highest yield of groundwater, followed by the semi-confined and the confined aquifer type respectively (Olorunfemi et al., 1999) (Table 1). This was used to rate the aquifer types, from which the aquifer type rating map was developed as shown in (Figureure. 5). The map shows that the central and the southeastern parts of the study area are characterized by unconfined aquifer, the southern, eastern and northwestern part by confined aquifer while the

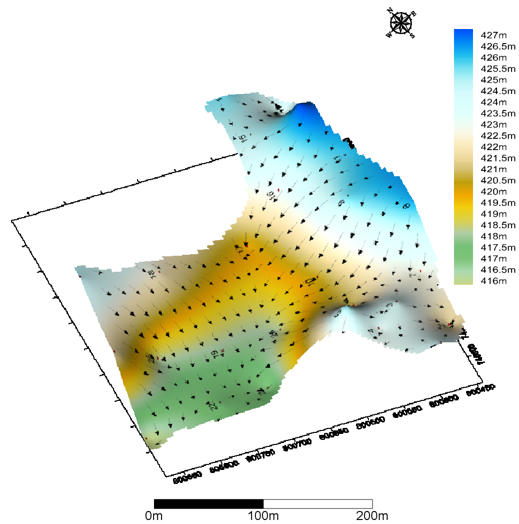


Figure. 4 (a): 3-D Bedrock Relief Map of the Study Area with Arrow Showing the Groundwater Flow Direction.

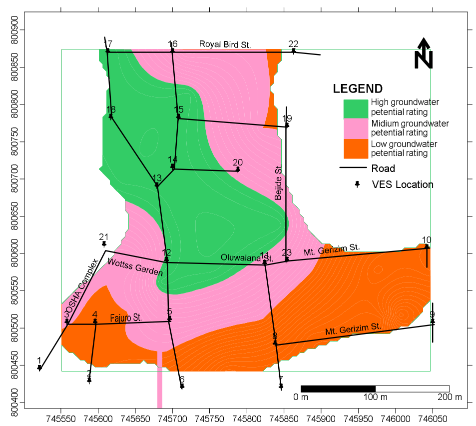


Figure. 4 (b): Map Showing Bedrock Relief Rating in the Study Area

Aquifer Thickness (T)

When all geologic parameters for groundwater potential have been met, parameters such asthickness of aquifer must also be put into consideration, because the higher the aquifer thickness (overburden thickness) the higher the chance of groundwater occurrence in a typical Basement Complex area. In the study area the values of the aquifer thickness were obtained from the Vertical Electrical Sounding (VES) interpretation results. The thickness of the aquifer obtained in the area ranges from 0.5 - > 20 m while the model rating value rangesfrom 0.2 – 1.0 (Table 1). The rating range of values was used to develop the aquifer thickness rating distribution map for the study area (Figureure. 6).

RESULT AND DISCUSSIONS

Vertical Electrical Sounding (VES) Interpretation Results

A summary of the geoelectric characteristics obtained from the study area are presented in Table 2. The VES interpretation results delineated three subsurface geoelectric layers. These are the topsoil, weathered layer, fractured

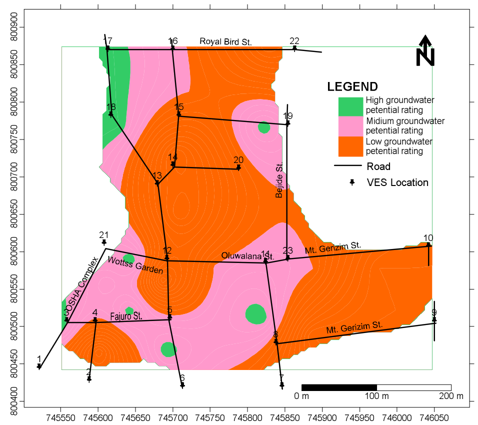


Figure. 5: Map Showing Aquifer Type Rating in the Study Area.

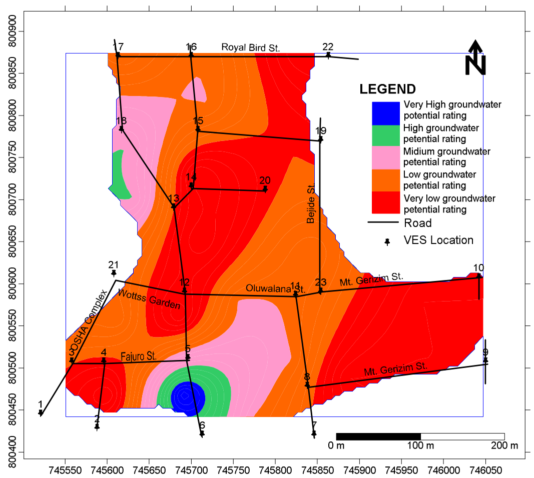


Figure. 6: Map Showing Aquifer Thickness Rating in the Study Area.

basement and fresh basement Table 2. Unconfined aquifer is surrounded by the semi-confined aquifer in the central and southeastern part of the study area.

GRRAT Groundwater Potential Map

After all the parameters have been multiplied by its designated weighting factor, then the final GRRAT index was determined by summing each GRRAT thematic parameter. Once the GRRAT index has been estimated (Table 3), this was used to generate the final intrinsic groundwater potential map for the investigated area (Figureure. 7). The GRRAT indices range from 0.2 – 1.0. The GRRAT index was then divided into five categories: Very low, low, moderate, high and very high groundwater potential zones. The region with very high to high GRRAT index are characterized with high groundwater potential zones while the region with very low, low and medium GRRAT index are characterized with very low to medium groundwater potential zones (Figureure. 7). A small portion in the western part of the investigated area is

Table 2: Summary of Geoelectric Characterization of the VES Interpretation Results

Layering	Resistivity Range (Ohm-M)	Thickness (M)	Lithologic Description	Aquifer Type
Topsoil	18 – 443	0.6 – 2.6	Clay, Sandy clay, Clayey sand and Lateritic.	Unconfined
Weathered layer	45 – 247	1.1 – >12.9	Clay/Sandy clay and Clayey sand.	Semi-confined
Fractured basement	139 – 817	4.6 – 46.6	Partly weathered and Fractured basement rock.	Unconfined/confined
Fresh basement	541 – ∞		Fresh basement	

*Depth to Bedrock varies from 1.1 to >12.9 m

Table 3: GRRAT Index Rating and their Groundwater Potential Class

S/N	GRRAT Index Rating	Groundwater Potential Class
1	0 – 0.2	Very Low Potential
2	0.2 – 0.4	Low Potential
3	0.4 – 0.6	Moderate Potential
4	0.6 – 0.8	High Potential
5	0.8 – 1.0	Very High Potential

characterized by high GRRAT index rating value of 0.6 – 0.8 and hence high groundwater potential zone. The eastern and a larger part of the western, southern and southeastern part of the study area are characterized by medium GRRAT index rating value of 0.4 – 0.6 and hence moderate groundwater potential zone. Part of the eastern, central and southwest part of the investigated area is dominated by low to very low GRRAT index rating values of 0.2 – 0.4 and 0 – 0.2 which implies low to very low groundwater potential zones. The GRRAT index map showed areas where groundwater potential is very high to very low. About 5% of the study area is characterized by high, 35% moderate, 45% lower and 15% have very low groundwater potential zones.

CONCLUSIONS

Geological mapping and surface electrical resistivity survey was conducted in parts ofAlagbaka area, Akure, with the aim of evaluating groundwater potential of the area using integration of five geologic and hydro-geophysical significance failure, namely: geology of the area, aquifer layer resistivity, bedrock relief, aquifer types and aquifer thickness. The GRRAT index rating generated map showing that the very low, low, moderate and high groundwater potential zones cover about 15%, $45^{0}/_{0,}$ 35% and 5% respectively of the investigated area. The very low to low groundwater potential zones are found in the central, northeast, southwest and south eastern part of the study area while the medium to high groundwater potential zones are located in the eastern and southeastern part of the study area. In conclusion GRRAT index model can greatly increase the success rate of drill borehole projects and can also be a useful tool in the decision making process for groundwater development and location of social amenities in the investigated area.

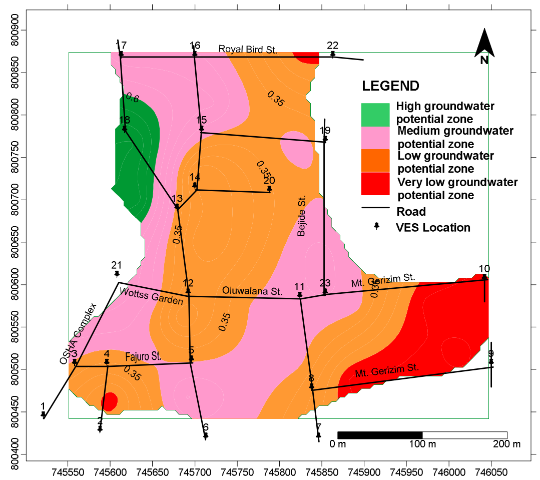


Figure. 7: GRRAT Index Rating Map Showing the Groundwater Potential Zones in the Study Area.

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