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Original Research

Groundwater Potential Zonemapping using Analytical Hierarchy Process, Remote Sensing and GIS for Enugu Metropolis, Nigeria

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Abstract

Enugu state is highly dependent on surface water as a result of the scarcity of ground water resources. The number of boreholes being drilled in and around the city failed because of inadequate groundwater prospecting prior to drilling. This study aimed to assess the ground water potential of Enugu metropolis using geographic information system (GIS) and remote sensing. The factors considered were geology, slope gradient, hydraulic conductivity, lineament density, drainage density, rainfall distribution, land use and land cover, geomorphology, and soil type. The Analytical Hierarchical Process (AHP) was used to weigh the various parameters in accordance with their impact on the presence of groundwater in the research area. Thematic maps were developed for each of these factors. The weighted index overlay was carried out and the groundwater potential map produced was classified as very low, low, moderate,high and very high groundwater potential zones covering 16.8%, 26.62%, 22.39%, 19.53% and 14.61% of the study area respectively. It was seen that the metropolis had the worse groundwater potential. The high groundwater potential zone was spread all round the study area but occurred mostly in the north-western part of Enugu State and was the most suitable location for the exploitation of potable water for urban use.

KEY WORDS; Ground water, Analytical Hierarchy Process (AHP), Ground water potentials, Geographic information system (GIS), Mapping.

1.0INTRODUCTION

Ground water is one of the most important natural resources, which is essential for both ecodiversity and humanity. It is essential to conserve endemic natural resources and to successfully preserve them through resource management. The pore spaces of soil and the fault areas of geological formations, which are below the earth's surface, are where

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groundwater can be found. (Machireddy 2019).Groundwater resources are scarce in many areas of Nigeria, and when they are present, it is challenging to assess their potential because of the variation in their occurrences. Due to differences in the country's geology units, certain locations have an easier time developing groundwater than others. Because of increasing demand for groundwater for domestic, industrial, and agricultural purposes, this has led to overexploitation, which has decreased groundwater levels and, as a result, allowed seawater to seep into coastal aquifers.

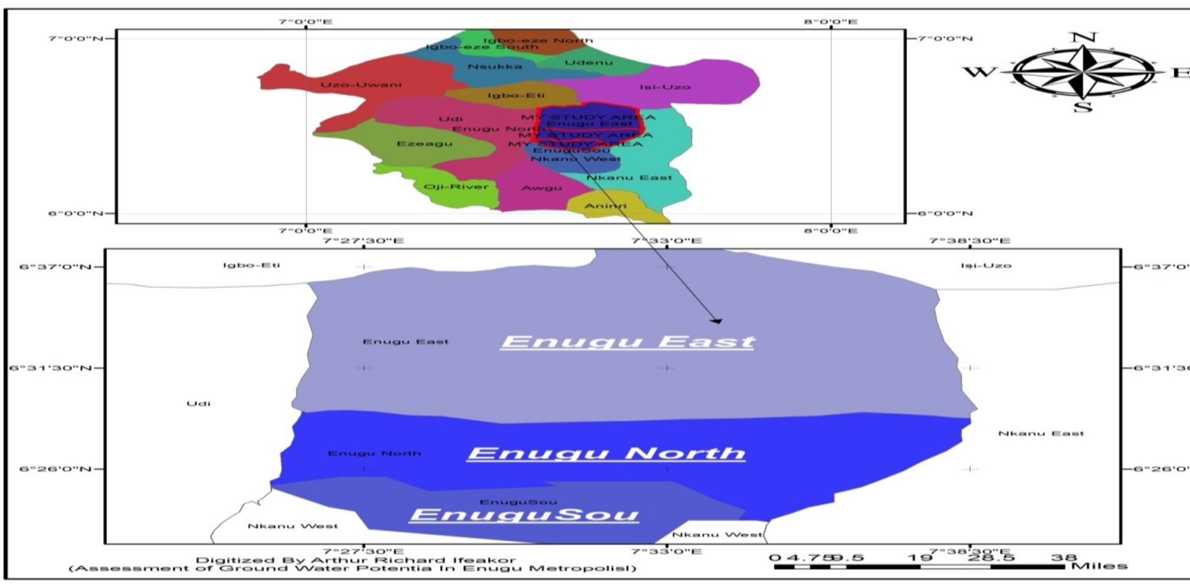
One of the major issues the people of Enugu Metropolis is the lack of access to safe drinking water. They were forced to rely on contaminated wells, rivers, and streams for their water supply.Inadequate water delivery in the study area has been largely attributed to a lack of adequate data information for planning and management because of the limited water supply in the research area, in addition to inefficient and disorganized capital investments in water supply infrastructure. Plans for water supply also frequently take into account political difficulties instead of regional demands and realistic technical considerations. In terms of quality monitoring, the population's use of groundwater is practically unreported.

To identify, categorize, map, and plan natural resources, remote sensing (RS) technology is used to create precise sources of data. (Ifatimehinet al., 2009). Remote sensing and geographic information systems (GIS) are now being used more to address water resource planning, development, and management challenges. Many organizational levels and consumers can benefit from a GIS system's installation in water utility (Roland and Zoran, 2011). In order to identify groundwater potential zones around the world, many academics have used the Remote sensing and GIS processes(Karimi and Zeinivand 2021; Allafta et al. 2021; Aju et al. 2021; Aykut 2021; Qadir et al. 2020; Gyeltshen et al. 2020; Gebru et al. 2020; Zghibi et al. 2020).Multiband, multidate, and multistage satellite imagery has been extensively employed in Asia and other developed countries for the management of land use and the study of water resources (Akingbogun and Oloyede, 2012). The distribution of rural water supply facilities, groundwater potential, pollution sensitivity zones, and other features can all be inferred from maps produced using GIS. Political decision-makers and operators in the study region must act quickly and decisively in order to meet the Sustainable Development Goals of water supply, sustainable water infrastructure, and protection of the groundwater aquifer from overuse.

The aim of this research is the assessment of ground water potential in Enugu metropolis using geographic information system (GIS) and remote sensing, with the objectives of deriving thematic maps of factor influencing groundwater potential zones of the area, determine the Groundwater potential zone (GWPZ) and validating the results using borehole data.

2.0Description of study area

At its creation in 1991, Enugu functioned as the administrative seat for the former Eastern Region, the former Anambra State, and later the newly constituted Enugu State. Enugu is situated between latitudes 07º 26'E and 07º 37'E of the Greenwich meridian, which is between latitudes 06º 21'N and 06º 30' N of the equator. Nkanu East Local Government Area forms its eastern border, Udi Local Government Area forms its western border, Igbo-Etiti and Isiuzo Local Government Areas constitute its northern and southern boundaries, and Nkanu West Local Government Area forms its southern border (Chukwu, 2015).The city of Enugu is made up of the three local governments of Enugu North, Enugu East, and Enugu South asshown in Figure 1. The population of Enugu metropolitan was close to two million, according to estimates from 2015. Its population density is around 427.6 persons per square kilometer (National Population Commission, 2006). The climate in Enugu is categorized as hot and humid. This humidity is at its peak between March and November. The relative humidity varies between 40% and 80%, while the average yearly temperature ranges from 22^0 C to 30^0 C.



3.0 Materials and Methods

3.1 Materials

The data used for the analysis includes rainfall, geologic formations, land cover, slope, soil type, geomorphology, lineament density, hydraulic conductivity, and drainage density. In order to extract these parameters, remote sensing and GIS (Geographic Information System) analysis were employed to delineate the study region. For validation, a field investigation that included ground trothing and borehole point data collection. In addition, water level indicator and a hand-held GPS receiver were the main pieces of apparatus employed, together with Arc GIS and Remote Sensing (ENVI) Software for classifying land use.

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3.2 Method of data collection

Rainfall (RF): In order to map and rasterize the pattern of rainfall that occurs in Enugu Town, rainfall data were generated from the synoptic meteorology station in Enugu State and neighboring stations by Nigeria Meteorological Agency (NIMET). Using the projected coordinate system, point data of the Enugu and its environs were interpolated with the Inverse Distance Weighted (IDW) method on the Arc GIS software to construct the thematic map of rainfall.

Geology (GL): The Nigerian Geological Survey Agency Sheet 60 geologic map of Enugu, which was produced at a scale of 1:250,000 and covers the entire study area, was scanned and imported into the ArcGIS environment where it was geo-referenced using the map projection of the Geographic Coordinate System and digitized to extract the rock type (aquifer media and impact of vadose zone).

Land Cover (LUC): Envi 4.5's unsupervised classification method was used to extract the land use of Enugu Town using Landsat 8 images, which provided a general understanding of the land use and cover classes in the region. To create a color composite that was used for the unsupervised categorization, bands 543 were merged. Prior to applying supervised classification to the imagery, ground truthing data was employed to confirm the land use/cover class. Based on fieldwork, the land use/cover of the research region was categorized.

Slope (SL): Slope is a crucial factor for zonation of groundwater potential since it is one of the most significant essential characteristics. The Shuttle Radar Topography Mission (SRTM) digital elevation model from the United States Geological Survey(USGS) which has a 30m resolution in a GIS setting was used to extract and demarcate the slope categories.

Soil texture/media (SO): The soil map of Enugu Town, which was created at a scale of 1:300,000 by the State Ministry of Agriculture in Enugu State, was scanned and imported into the ArcGIS 10.5 environment where it was georeferenced using the Geographic Coordinate System map projection.

Geomorphology (GM): The Geomorphology map of Enugu was produced by the department of Geography,Enugu State university of technology. It was scanned and imported into ArcGIS 10.5 environment where it were geo-referenced and digitized based on the map projection of Geographic Coordinate System (WGS 1984, 32^0 North).

Lineament Density (LD): Joints, faults, and fractures on the topological map were digitally captured from the Nigerian lineament map, which was obtained from the Nigeria Geological Survey Agency(NGSA) at a scale of 1:2,000,000. Next, a density map was promptly created using edge detection filters and a map of the faults' kilometers per square kilometer.

Drainage Density (DD): The United States Geologic Survey's DEM (Digital Elevation Model) was used to extract the drainage density. The DEM data displays information from more representative photos, therefore 3D Analyst capabilities on ArcGIS software were required to do the hillshade process. On the first phase, the hill shade process on DEM data with four value variations had to be completed. The DEM imagery was then obtained by superimposing all of the images produced by the hillshade procedure over one another to provide views of the research region from all directions. After overlaying the DEM data, ArcGis software was used to obtain the drainage pattern using the LINE Algorithm.

-Hydraulic conductivity (HC): Soil samples were collected at 9th Mile Ngwo-Enugu road ($6^0$25'33.75"N $7^0$24'46.41"E), Umuagu ($6^0$15'46.40"N $7^0$21'16.03"E) and Presidential road Enugu ($6^0$26'00.85"N 7^0'31'22.27"E) in order to determine the hydraulic conductivity of the area. The method used to test permeability was the Falling Head Method, and the coefficient of permeability (K) was calculated and entered into the ArcGis Spatial analysis tool using the Inverse Distance Weight (IDW) tool to generate its raster mapping.

3.3 Delineation of the Groundwater Potential Zones (GWPZ)

The two most popular and well-known GIS-based methods for defining groundwater potential zones are multi-criteria decision analysis utilizing Analytical Hierarchical Process (AHP) and the modified DRASTIC MODEL. These techniques aid in the integration of all theme layers. Nine(9) different theme levels in all were taken into account for this investigation. These nine theme levels are meant to regulate the flow and storage of water in the research area. According to how they affected groundwater occurrence, these influencing factors were weighted in their association. Parameters with a high weight indicate a layer that will have a significant impact, and a parameter with a low weight indicates a layer that will have a minor impact on groundwater potential.

The following equation was used to integrate all nine thematic layers with the weighted overlay analysis function of the spatial tool in the ArcGIS platform to create a groundwater potential zone map for the research area.

$$GWPI = [(RFr * RFw) + (GLr * GLw) + (LUCr * LUCw) + (SLr * SLw) + (SOr * SOw) + (GMr * GMw) + (LDr * LDw) + (HCr * HCw) + (DDr * DDw) \quad (1)$$

where, GWPI refers to groundwater potential index, RF stands for rainfall, GL stands for Geology, GM for Geomorphology, LUC for land use land cover, DD for drainage density, LD stands for lineament density, HC for Hydraulic conductivity, SL for slope, SO for Soil type , the subscripts r and w refers to the normalized weight of a theme and normalized weight of individual features of a theme, respectively.

3.4 Weighing of derived maps using the Analytical Hierarchical Process

The Analytical Hierarchical Process (AHP), based on Saaty and Vargas (1991)'s Analytic Hierarchy Process (AHP), was used to weight the individual thematic layer class weights and scores. Using this method, the relative importance of each individual class within the same thematic map was compared to one another by pair-wise comparison matrix, and nine significant matrices was prepared for assigning weight to each class. The AHP was used to categorize the zones into very poor, poor, moderate, high, and very zones. Each of these zones was described based on the characteristics of its specific thematic layer. Groundwater potential zones were defined for the research region by grouping the interpreted layers through weighing many contributing factors and, in the end, assigning various potential zones as designated below. Shown in Figure 2 is the flow structure for delineating Ground water Potential Zone and the procedures for assigning weight using AHP are depicted in table 1.

Table 1: Measurement scale of AHP (Saaty 1980)

Scale	Degree of Preference	Explanation
1	Equal importance	Two elements contributes equally to the objective
3	Moderate importance	Experience and judge slightly favor one element over another
5	Strong or essential importance	Experience and judgment strongly favor one element another
7	Very strong importance	One element is favored very strongly over. It dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Values for inverse comparison	Can be used to express intermediate values

The Saaty's 1–9 scale (table 1) was used to calculate the relative importance values, where a score of 1 denotes equality between the two themes and a score of 9 denotes the extreme importance of one theme relative to the other (Saaty 1980).Using Saaty's nine-point relevance scale in conjunction with the thematic layers used to define groundwater potential, a pairwise comparison matrix is created. The major eigenvalue and the consistency index in the AHP represent the idea of judgmental uncertainty (Saaty 2004). Through the use of the following equation, Saaty provided a consistency index (CI) that represents deviation or degree of consistency:

$$CI = \frac{\lambda max - n}{n - 1}, \qquad CR = \frac{CI}{RI}$$

Where n is the number of classes and max is the greatest eigenvalue of the pairwise comparison matrix. A measurement of the delineation of the groundwater potential zone is the consistency ratio (CR). The equation describes the consistency of the pairwise comparison matrix, where RI stands for Ratio Index. Table 2 provides the value of RI for various n values. The consistency is acceptable if the CR value is less than or equal to 0.1. The subjective assessment needs to be revised if the CR is higher than 10%.

Table 2:Saaty's ratio index for different values of n.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

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3.5 Validation of Groundwater Potential Map.

By comparing the groundwater potential map results with the research area's borehole yield point map, the groundwater potential map/results models were validated. Using a dataset of borehole points obtained through field work, the borehole point yield map was created. Using the spatial analyst tool of ArcGIS 10.5, the point yield of density function was used to create the yield map. Later, the well yield map was rescaled to match the output of the groundwater potential map and model. A suitability difference map was produced by comparing the two maps using the minus tool in ArcGIS 10.5's spatial analyst tool. The attribute table was queried for the difference between the observed and the modeled outputs from the suitability difference map, and both the area (in ha) and the level of agreement (%) were computed.

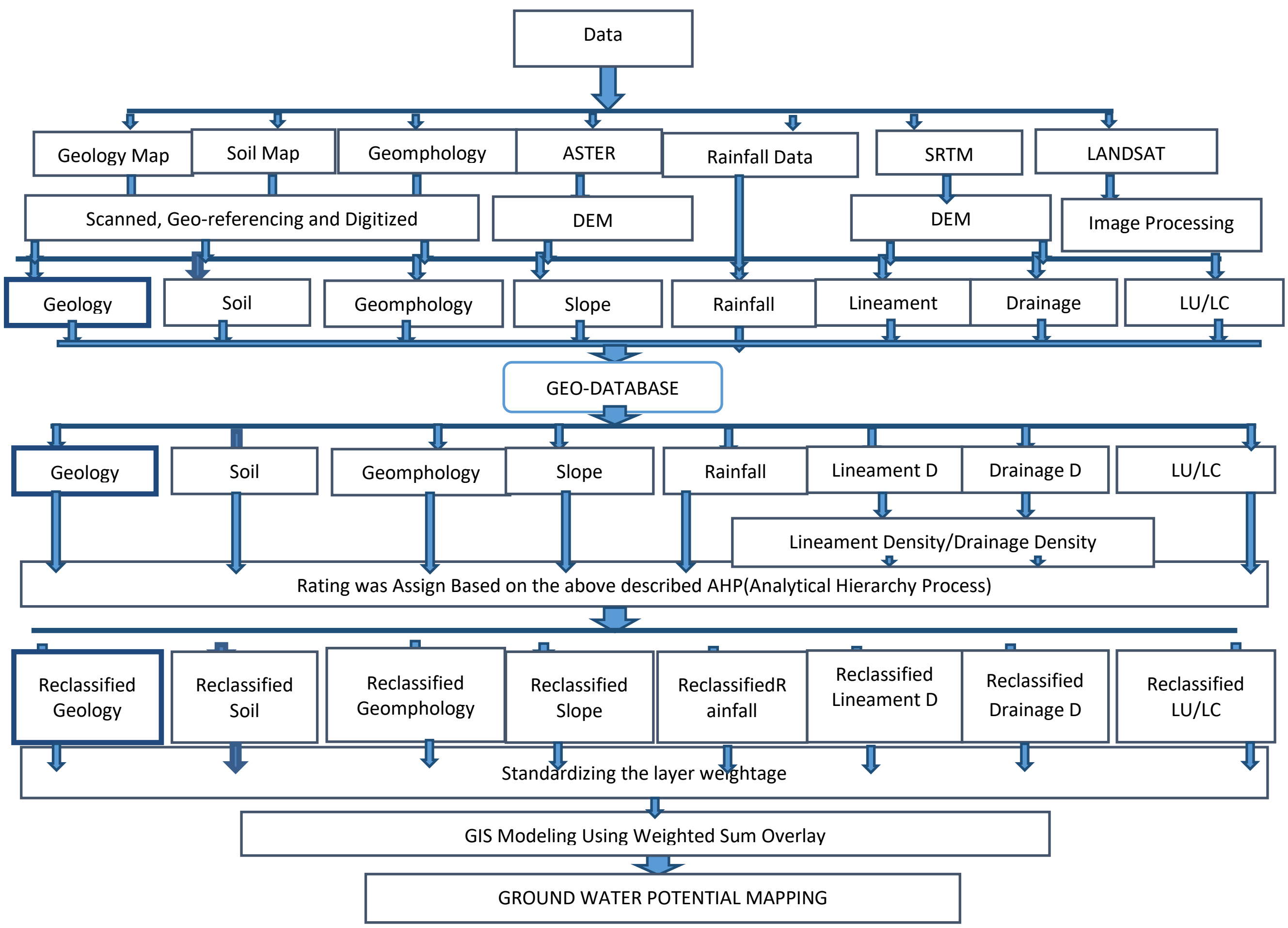

Figure 2: Flow structure for delineating Ground water Potential Zone

4.0 RESULT AND DISCUSSION

Factors impacting groundwater potential were mapped and categorized in order to evaluate possible groundwater zones within the study region. Analytical Hierarchical Process (AHP) pairwise comparison was used to determine the weight of the groundwater potential affecting factor. Groundwater potential influence thematic maps have been divided into Very poor, poor, moderate, good, and very good zones.

-Rainfall: Rainfall is the source of groundwater. It was anticipated that there would be more water available for infiltration and percolation in the event of more rainfall. In the research area, annual rainfall ranges from 1900mm to 1400mm and falls from south to north of the Enugu state. Thematic map of rainfall is shown in Figure 3. Similar to Aggarwal et al. (2013), the location with the most rainfall was scored highly and given a rating of 0.36 based on how important rainfall is to groundwater generation. Given the close proximity of the amounts of rainfall, a value of 0.04 was given to the location with the least quantity of rainfall. The effect of rainfall on ground water potential was rated (18.8%) using the AHP as shown in table 3.

-Geology (GL): The area under study is covered by rocks from the Cretaceous to the Quaternary, including the Asu River Group, Ezeaku Shale Group, AwguNdeaboh Shale Group, AsataNkporo Shale Group, Mamu Formation, Ajali Formation, Nsukka Formation, Imo Shale Group, BendeAmeki Group, Coastal Plain Sands, and Alluvium. Numerous authors, including Ramam and Murty (2012),McLean et, al(2022), have written on the field description, paleontological, sedimentological, and petrographic/mineralogical properties of the various rock types.

Deep interactions exist between the rock and the groundwater aquifer, particularly in fractured rock. As a result, due to its relevance to groundwater occurrence, geology was given the weight of 16.7% based on the Analytical Hierarchy Process (AHP) ranking. Each geological characteristic was carefully categorized and scored according to how well it suited groundwater transmission and storage. The majority of rock types in the research region do not have good water bearing capacity, and their ability to retain water depends only on the presence of faults, fractures, joints, and ageing when compared to the sandstones (upper Coal measure). The Upper Coal Measure is more likely to include water than the Nkporo Shale Group due to its higher weight of 0.184 (18.4%). As a result, the potential for groundwater bearing by the various rock types available was determined. Figure 4 shows the Geology thematic map.

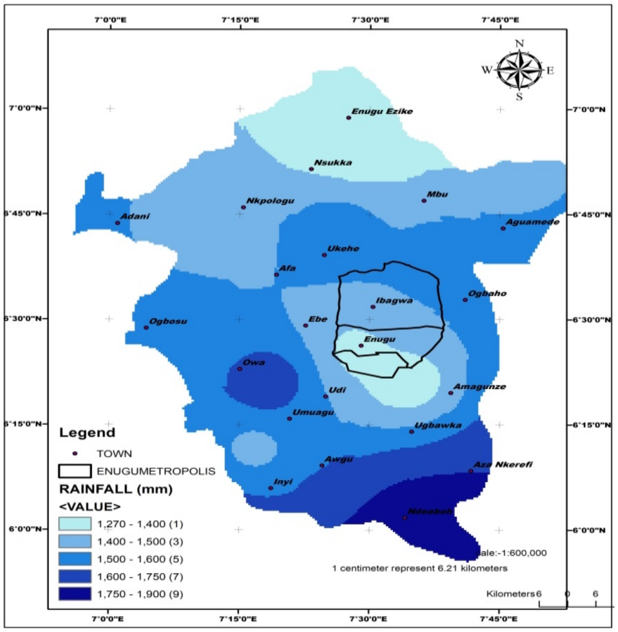

Figure 3: Rainfall Parameter /thematic Map

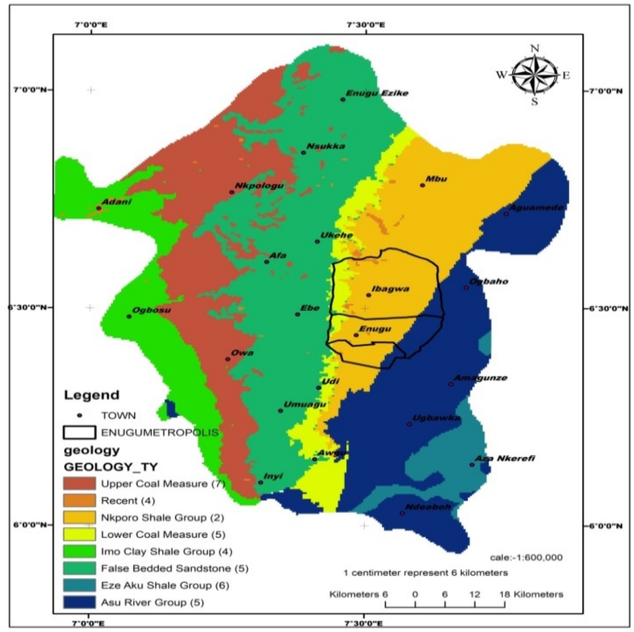

Figure 4: Geology Parameter thematic Map

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Land use/land cover (LUC): Data from land use and land cover maps provided crucial indicators of the extent of groundwater and four main forms of land cover emerged from the analysis of the following data: vegetation, settlement, rocks, bare land, and water bodies. The research region is mostly Vegetation area, accounting for 56.76% of the land use, whereas water body was the least prevalent element at 0.24% and rocks at 4.72%. (seeFigure 5).Figure 6 showed the research area's land cover, 4290km^2 was covered by vegetation, with about 1890km^2 covered by settlement. The vegetation promotes water infiltration, which aids in groundwater production. Based on these criteria, vegetation came in second place after the water body followed by the bare land area. Land cover was given the weight of 14.6% in accordance with the AHP theme since it is not in geological connection to the vados thickness for the passage of the water.

Slope (SP): The slope has an impact on how quickly water infiltrates an area and runs off the surface. The study area's slope was divided into the following categories: Nearly Flat (1.2–1.4), Gentle Slope (1.4–1.5), Moderate Slope (1.5–1.6), Strong Slope (1.6–1.75), and Very Strong Slope (1.75-1.9), with each covering 2999.4 Km^2 (39.67%), 2596 Km^2 (34.25%), 1456 Km^2 (19.27%), 461.45 Km^2 (6.1%), and 53.66 Km^2 (0.71%), respectively (see Figure 7). Theanalysis's findings indicated that locations with low slopes (0-0.60) have the most weight. Rainwater infiltration is directly impacted by the slope gradient (Yeh, et al, 2016). Because water runs rapidly down a steep slope during rainfall, it does not have enough time to permeate the surface and recharge the saturated zone, which results in a lesser recharge with higher slope rise. As a result, groundwater will occur more frequently in locations with low slope gradients than those with high slope gradients. For this reason, the slope classes were ranked from very good to very poor based on how likely they were to cause groundwater to occur.

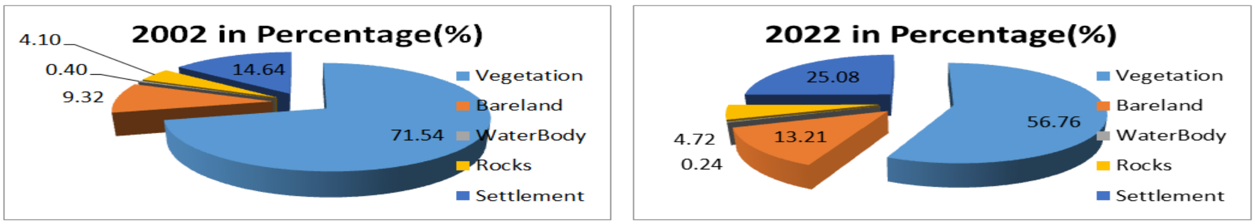

Figure 5: Showing Percentage Land Use Land Cover in 2022 and 2002

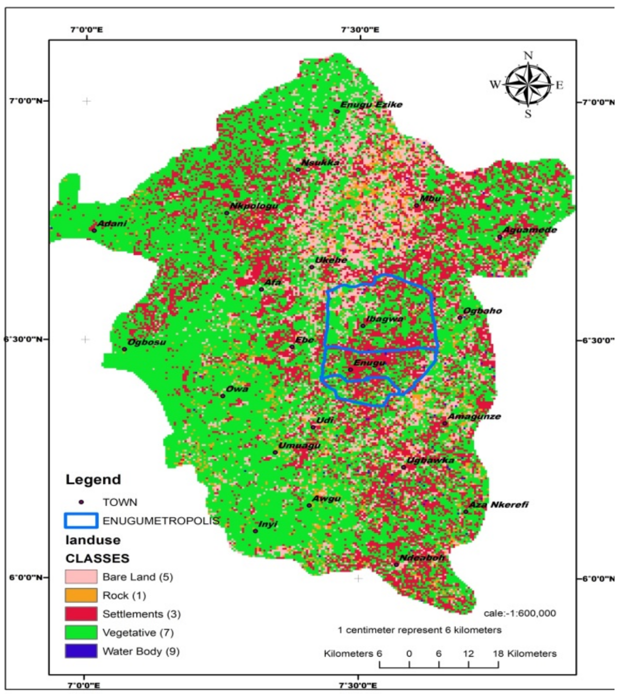

Figure 6: Land Used Parameter /thematic Map

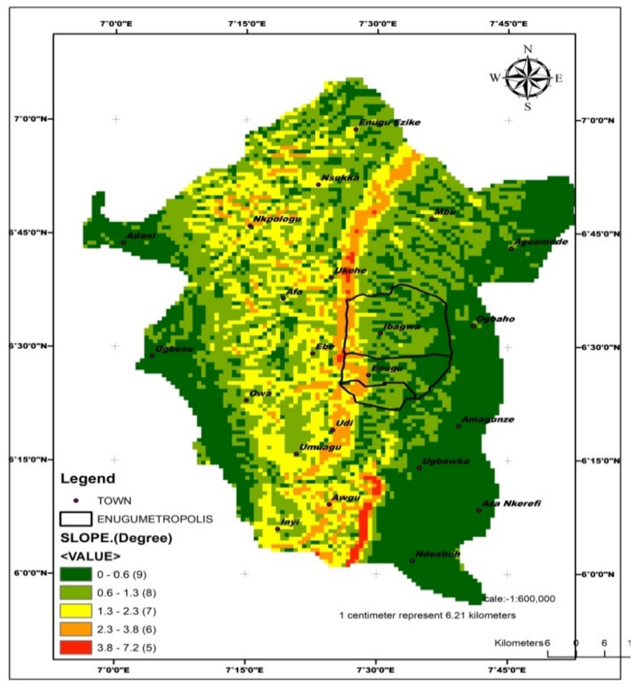

Figure 7 Thematic map of slope gradient of Enugu

- Soil media(SO): The size and nature of the soil media have a direct impact on the infiltration rate. The findings revealed four main types of soil, as shown in Figure 8. These are lithosols, hydromorphic soil, ferritic soil, and young soil. More than 48% of the overall area was taken up by the hydromorphic soils. Because lithosols contains a sizable amount of clay, which retains water and obstructs its passage, it was given a poor value rating. The fact that hydromorphic is synonymous with alluvium or river levees contributed to its high ranking. The southern portion of the study region is where hydromorphic is present. Based on this characteristic, lithosols were rated next to young soil because they are more likely to grow in areas with poor drainage due to a high water table (phreatic surface).

According to the AHP result, soil media were given a weight of 12.5% impact on the potential for ground water in the research area, based on how important soil is to the occurrence of groundwater (see table 3). – **Geomorphology(GM):** The geomorphology of a region provides insight into the diverse landforms and earth structures associated to groundwater potential zones. The structural development of a geological formation . influences geomorphology, Gupta (2003). In other words, the movement and percolation of groundwater in a region are greatly influenced by geomorphology.

Four geomorphological units were established in this study based on their unique elevations as shown in Figure 9. The entire regions were made up of lowlands, plains, ridges, and cuesta. The lowlands were defined as regions having low height above mean sea level and geomorphological features that are gently rolling in plains

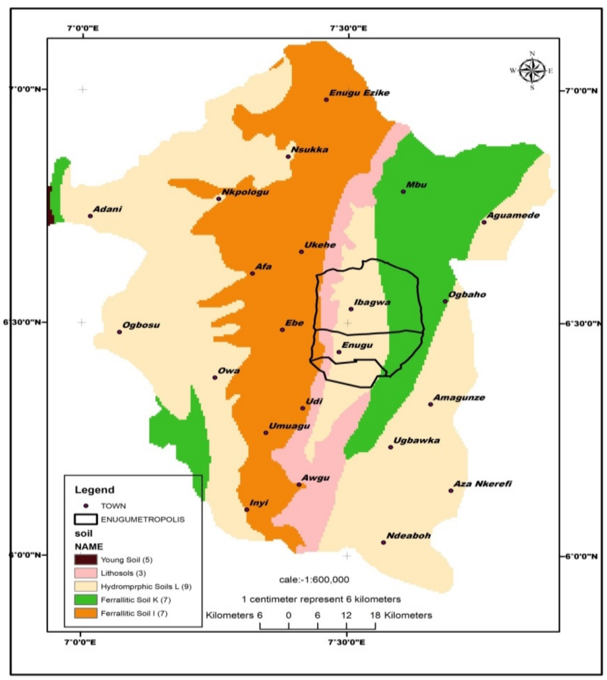

Figure 8: Soil Parameter /thematic Map

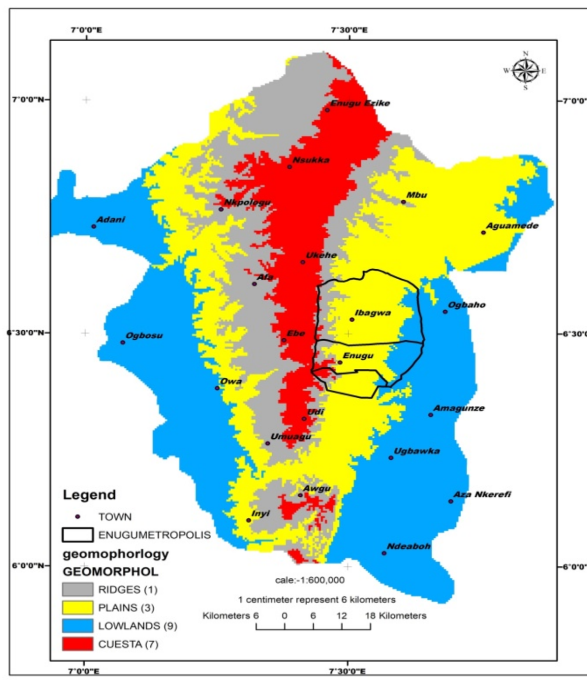

Figure 9: Geomorphology Parameter /thematic Map

-Lineament density (LD): Groundwater resources are significantly shaped and influenced by lineament characteristics like joints, faults, and fractures. Therefore, their delineation is crucial to the investigation of groundwater resources. Based on the frequency of occurrence, the lineament density was determined from the retrieved lineaments and divided into five groups. Agwu, Ebe, and AzuNkerefi were among the research region's locations where there were few or no lineaments (0.04-0.12 km/km^2), accounting for more than 60.2% of the study area. The lineaments density is divided into the following groups: 0.30-0.55 km/km^2, 0.20-0.30 km/km^2, 0.12-1.20 km/km^2, and 0.04-0.12 km/km^2. (See Figure 10).

One of the main sources of secondary porosity is lineament. High lineament density locations were shown to have the highest weights (0.36), while low density areas had the lowest (0.04). These places will be favorable for the occurrence of groundwater because of the ease with which the underlying aquifers may be easily recharged in these high lineament density areas.

-Hydraulic Conductivity (HC): The ability of the fluid to permeate pores and cracked rocks is known as hydraulic conductivity of the material. The sort of soils present in the area determine the conductivity. As a result of the soils in the area's being very permeable, the 9th Mile Ngwo-Enugu Road (6^{0}25'33.75"N 7^{0}24'46.41"E) has a high hydraulic conductivity at 4.333x 10^{-3} cm/sec. After extended durations of infiltration, the infiltration rate tends to asymptotically approach the saturated hydraulic conductivity (the maximum water transmission rate of the soil), even when air trapped in the soil prevents perfectly saturated flow in the vadose zone. The resultant hydraulic conductivity map from test conducted is shown in Figure 11.

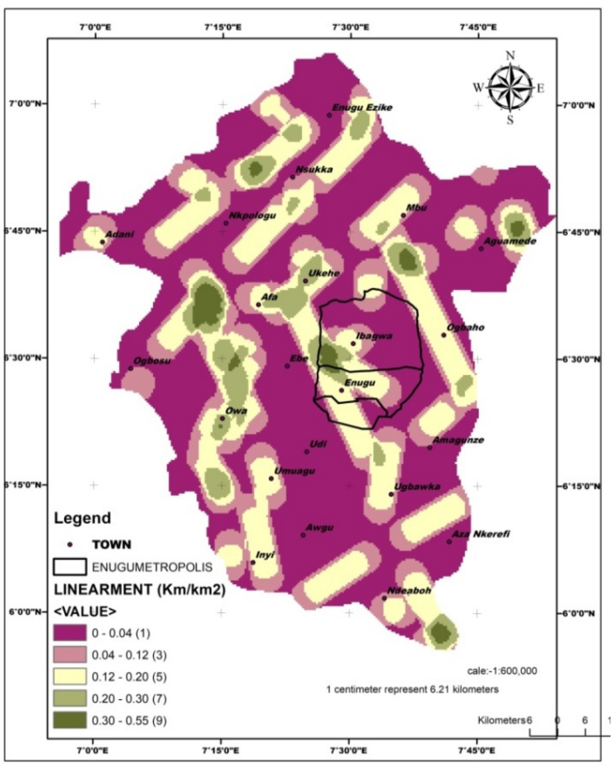

Figure 10: linearment density thematic Map

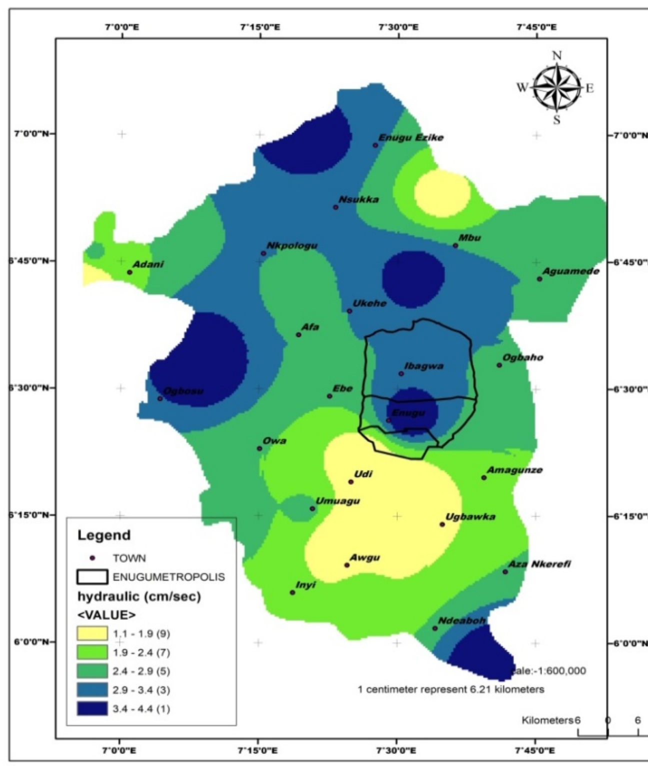

Figure 11:Hydraulic conductivitythematic Map

-Drainage Density: Regarding the structural discharge of water and the conservation of soil resources, the drainage system may also give light on the state of watersheds. It is the total length of the stream segment for all orders divided by the area of the unit. An inverse relationship exists between permeability and drainage density. The less permeable a rock is, the less rainfall infiltration occurs, and this rainfall infiltration is typically concentrated in surface runoff. Five classes have been established for the study area. These classes have been independently assigned to the following ranges: (0 to 0.1 km/km^2), (0.1 to 0.18 km/km^2), (0.18 to 0.25 km/km^2), (0.25 to 0.34 km/km^2), and (> 0.34 km/km^2). In the north-southwest corner of the research area, the drainage density is the highest (> 0.34 km/km^2) as indicated in Figure 4.9. Due to its interconnection with surface runoff and permeability, drainage density is evasively related to the eligibility of groundwater potential zones. Based on its relative significance to groundwater formation and in accordance with the AHP, drainage density was given weights of4.2%, similar to Machireddy S. R.(2019). High drainage density areas have less penetration since a large portion of the rainfall over the area is wasted, making the area's groundwater prospects poor and vis-vasa.

Table 3: Index table for Ground Water Potential (Enugu State and its Metropolis)

RASTER	ATTRIBUTES/RANGES	Weight	Sub-theme weight	Normalized Weightage	Theme Weight (%)	GWPZ INDEX(%)
Rainfall	1750-1900	9	9	0.360	18.8	6.768
	1600-1750		7	0.280		5.264
	1500-1600		5	0.200		3.760
	1400-1500		3	0.120		2.256
	1270-1400		1	0.040		0.752
Geology	Upper coal measure	8	7	0.1840	16.7	3.073
	Eze aku shale group		6	0.1580		2.639
	Asu river group		5	0.1320		2.204
	False bedded sandstone		5	0.1320		2.204
	Lower coal measure		5	0.1320		2.204
	Recent		4	0.1050		1.754
	Imoclay shale group		4	0.1050		1.754
	Nkporo shale group		2	0.0530		0.885
Land use	Water body	7	9	0.360	14.6	5.256
	Vegetation		7	0.280		4.088
	Bareland		5	0.200		2.920
	Settlement		3	0.120		1.752
	Rock		1	0.040		0.584
Slope (degree)	0.00-0.600	6	9	0.257	12.5	3.213
	0.600-0.130		8	0.229		2.863
	0.130-2.300		7	0.200		2.500
	2.300-3.600		6	0.171		2.138
	3.800-7.200		5	0.143		1.788
Soil type	Hydromorphic	5	9	0.375	10.4	3.900
	Ferralithic		7	0.292		3.037

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	Young soil		5	0.208		2.163
	Lithosols		3	0.125		1.300
Geomorphology	Lowlands	4	9	0.45	8.3	3.735
	Plains		7	0.35		2.905
	Ridges		3	0.15		1.245
	Cuesta		1	0.05		0.415
Linearment Density	0.300-0.550	4	9	0.360	8.3	2.988
	0.200-0.300		7	0.280		2.324
	0.120-0.200		5	0.200		1.660
	0.040-0.120		3	0.120		0.990
	0.000-0.040		1	0.040		0.332
Hydraulic Conductivity (cm/sec)	3.400-4.440	3	9	0.360	6.3	2.268
	2.900-3.400		7	0.280		1.764
	2.400-2.900		5	0.200		1.260
	1.900-2.400		3	0.120		0.756
	1.100-1.900		1	0.040		0.252
Drainage density	0.000-0.010	2	9	0.257	4.2	1.079
	0.010-0.180		8	0.229		0.962
	0.180-0.250		7	0.200		0.840
	0.250-0.340		6	0.171		0.718
	0.340-0.521		5	0.143		0.601
SUM				9	100	100

4.1 Delineation of Groundwater Potential Zones (GWPZ)

The groundwater weightage of the significant surface and subsurface structures for ground water recharging is presented in table 4 shows that rainfall is thought to be the most significant element affecting groundwater potential with sub-theme weight of (18.8%), followed by geology (16.7%). The map of potential ground water areas of the study area and the state at large are shown in Figure 15 and Figure 14 respectively. The demarcated map demonstrates the critical relationships between the potential groundwater zones in the study area and the factors affecting ground water potential. The resultshows categorically that areas with a groundwater potential are in the western areas and are quite high, whereas places with a groundwater potential in the eastern area are low.

Very low drainage and very high lineament density zones were present in the area predominantly underlain by Upper Coal Measure and False Bedded Sandstone in the very High potential zones 1104.92 km^2 (14.61%) and High potential zones 1476.7 km^2 (19.53%) respectively (See Figure 12). The Ezeaku Formations, Lower Coal Measure, Nkporo Shale Groups, ridges, and cuesta are largely underlain by the moderately potential 1692.8km^2 (22.39%), low 2012.46km^2 (26.62%), and very low 1274.19km^2 (16.85%) potential zones. Low potential zones, which comprise 2012.46 km^2 (or 26.62% of Enugu State's total area), make up the majority of the state. The groundwater potential map shows that low and very low groundwater potentials which make up about 90% of the Metropolis, are dominant in the research area (Enugu Metropolis), whereas moderate groundwater potential zones dominate the remaining 10%.

Low to moderate groundwater potential areas are dispersed throughout the research area, but they are primarily found in its northern and western regions. This is consistent with the research done by Olaniyan and Eduvie (2013) that used the resistivity method to explore the groundwater resources of RafinGuzan in Nsuka, Enugu State and discovered that the area had significant potential for groundwater. It is similar to the high groundwater potential zones identified by Ali and Lal(2015) when they identified groundwater potential zones in Allahabad district using remote sensing and GIS techniques that the high groundwater potential zones are found in areas with low drainage density, high lineament density, low slope gradients, and low elevations.

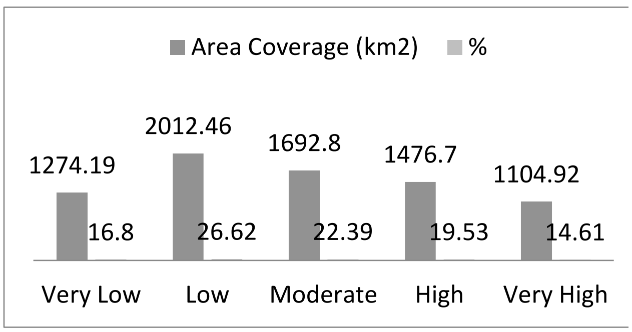

Figure 12: Area of Ground Water Potential Zones of Enugu State

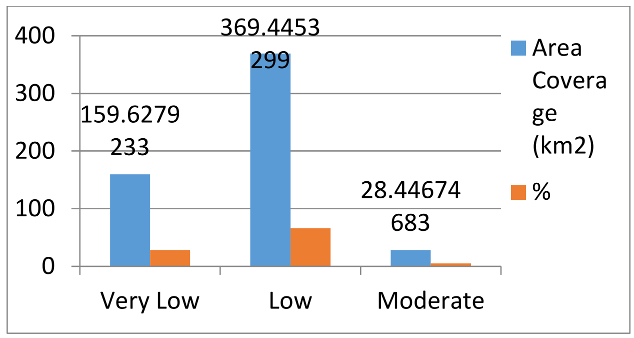

Figure 13: Area of Ground Water Potential Zones of Enugu Metropolis

Table 4: Pairwise Comparism of Factors Affecting GWP in Enugu State and its Metropolis

	RF	GL	LUC	SL	SO	GM	LD	HC	DD	Weightage	%
RF	**1.000**	1.125	1.286	1.500	1.800	2.250	2.250	3.000	4.500	**0.188**	18.8
GL	0.889	**1.000**	1.143	1.300	1.600	2.000	2.000	2.667	4.000	**0.167**	16.7
LUC	0.778	0.875	**1.000**	1.200	1.400	1.750	1.750	2.333	3.500	**0.146**	14.6
SL	0.667	0.750	0.857	**1.000**	1.200	1.500	1.500	2.000	3.000	**0.125**	12.5
SO	0.556	0.650	0.714	0.800	**1.000**	1.250	1.250	1.667	2.500	**0.104**	10.4
GM	0.444	0.500	0.571	0.700	0.800	**1.000**	1.000	1.333	2.000	**0.083**	8.3
LD	0.444	0.500	0.571	0.700	0.800	1.000	**1.000**	1.333	2.000	**0.083**	8.3
HC	0.333	0.375	0.429	0.500	0.600	0.750	0.750	**1.000**	1.500	**0.063**	6.3
DD	0.222	0.250	0.286	0.300	0.400	0.500	0.500	0.667	**1.000**	**0.042**	4.2
SUM	**5.333**	**6.000**	**6.858**	**8.000**	**9.600**	**12.00**	**12.00**	**16.000**	**24.000**	**1.000**	100

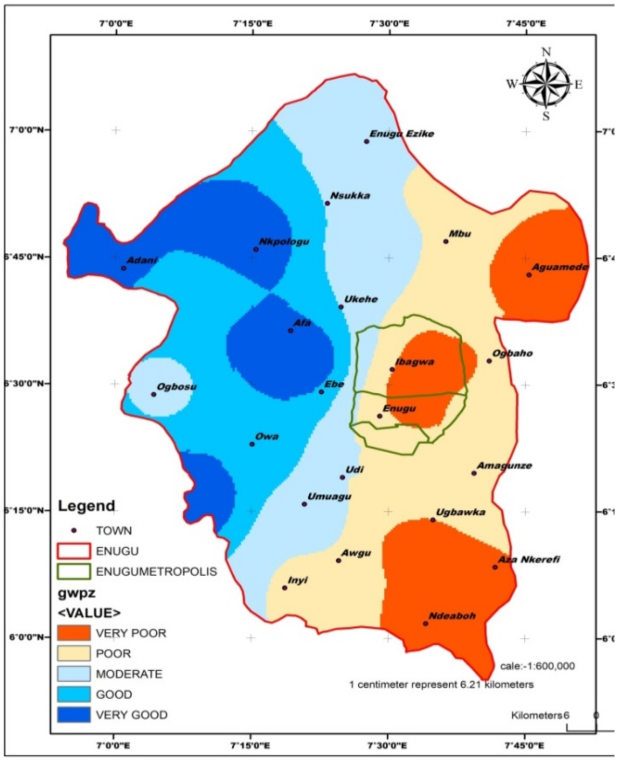

Figure 14: Enugu State Showing Its Ground Water potential Zones

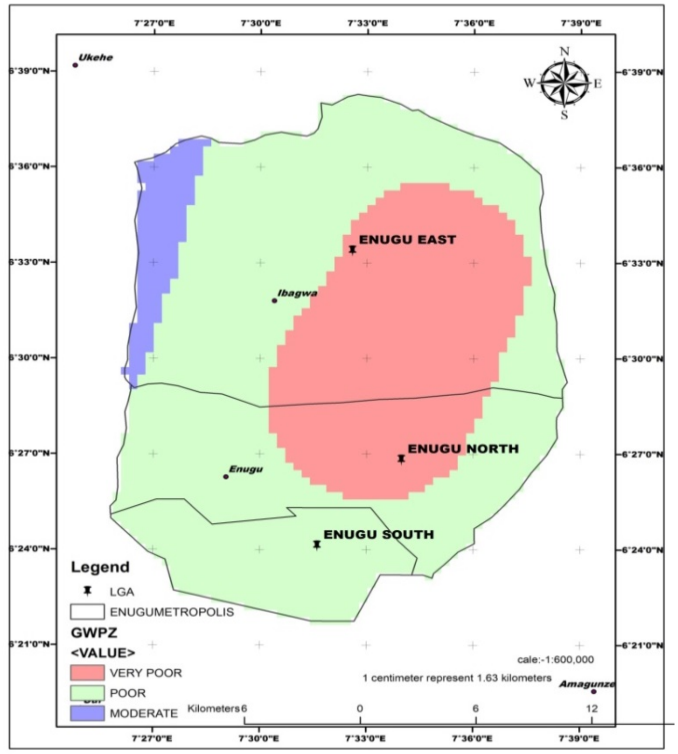

Figure 15: Enugu Metropolis Showing Its Ground Water potential Zones

4.2 Validation of Groundwater Potential Zone Mapping

The spatial distribution of the well yield, which was utilized to define the density of the well yield (See Figure 17), and the prospective groundwater map of the research region were the sources of data used in the validation procedure. According to the presumption that groundwater potential increases with well yield, reclassifying the well yield map was based on that assumption. To compare the observed and model groundwater potential maps, we first used the borehole yield map to clip the observed groundwater potentials map (Figure 13) to produce a potential groundwater modeling map. Finally, we compared the two maps using the minus tool in the spatial analyst tool of ArcGIS 10.5, which produced a suitability difference map as shown in Figure 18 for validation purpose.

The research discovered that available borehole Yield inventory data may be used to clearly identify groundwater potential zones utilizing a Geographic Information System and integrated remote sensing techniques. A reasonable description of the outcome was suggested because the number of boreholes in the low-potential area was not very high. The absolute Concordance between the observed groundwater potential map and the bore hole yield map was 33.04 percent, based on the comparative assessment results obtained as in (Table 6) with no contrast. The model's errors are within acceptable bounds, with an underestimation of 15.35% (average difference -2.31) and accuracy of84.65% (average difference -1.12 to 0.9).

Table 5: Classes and Area of Borehole yield point map and Ground water potential zones in Enugu State

		Area of Borehole yield point map		Area of Ground water potential zones	
Class	**Yield Class**	**Area (Km^2)**	**Percentage (%)**	**Area (Km^2)**	**Percentage (%)**
1	Very Low	1160.72	15.35	1274.19	16.85
2	Low	2111.61	27.92	2012.49	26.62
3	Moderate	1681.90	22.24	1692.80	22.39
4	High	1481.30	19.59	1476.73	19.53
5	Very High	1125.60	14.89	1104.92	14.61
TOTAL		**7561.13**	**100**	**7561.13**	**100**

Table 6: The difference between the observed data and the model Output

Average Diff.	Deference class	Area (Km^2)	Percentage (%)	Validation (%)
-2.31	Not Perfect	579.86	15.35	15.35%
-1.12	Closely Perfect	1611.25	27.92	
-0.48	Nearly Perfect	1464.61	22.24	**84.65%**
0	Perfect	2498.31	19.59	
0.9	Almost Perfect	1407.10	14.89	
TOTAL		7561.13	100	

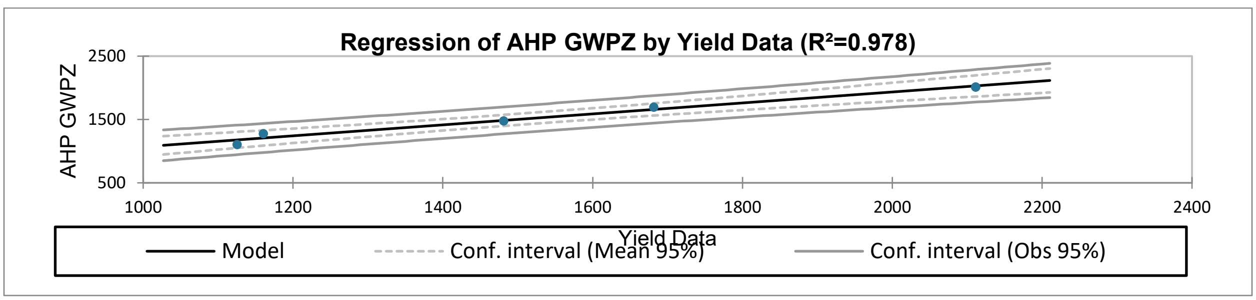

Figure 16: correlation of Classified Areas of Ground Water Potential Zones and Borehole Yield

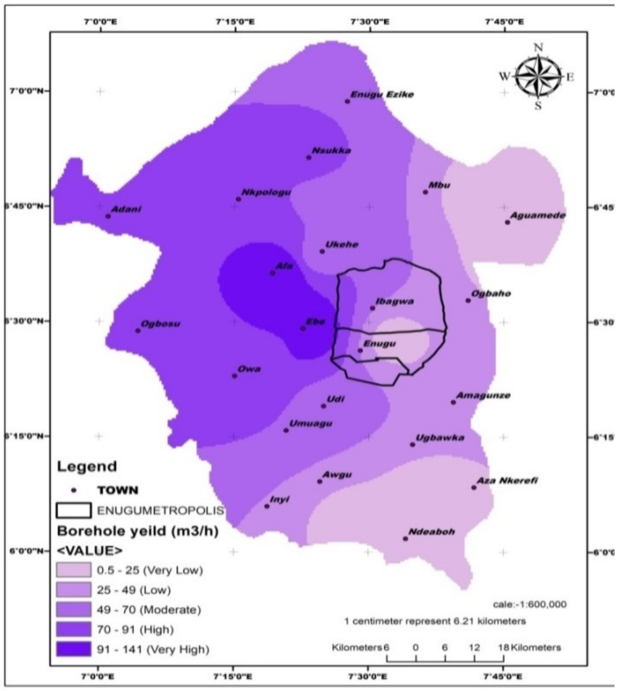

Figure 17: Borehole Yield thematic Map for Enugu Metropolis.

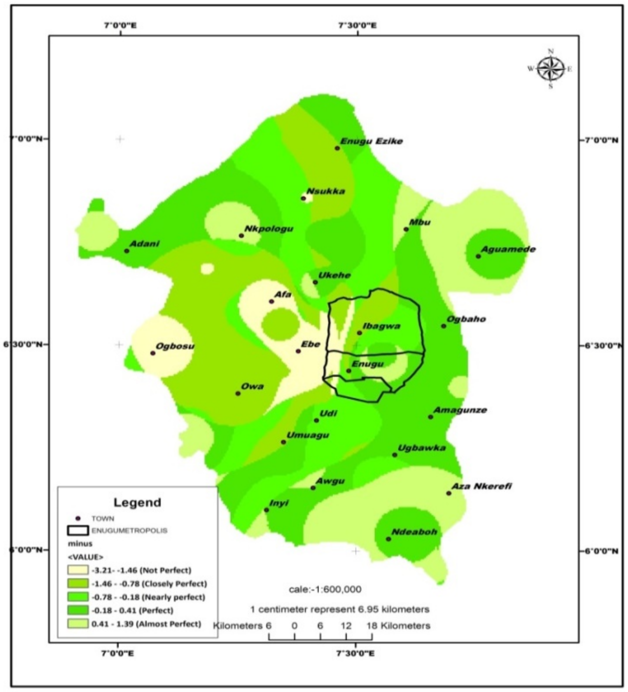

Figure 18: Showing Contrast thematic MapResult between Yield Map data and Groundwater potential map data.

5.0 CONCLUSION

This research was able to confirm the use of Geographic Information System and Remote Sensing for determination and evaluation of the viable and safe areas for Urban Water supply scheme siting within Enugu state and its metropolis by demarcating the study area groundwater potential zones. It has been determined that the Enugu metropolis has low groundwater potential and is unable to adequately meet the needs of its population for domestic water supply because more than 450 km^2 of the total land area, or 73% of the study area, was determined to be unsuitable for groundwater development.

Remote sensing and GIS methods were found to be effective in reducing the amount of time, labor, and money required to identify groundwater potential zones in Enugu State. This enables quick decision-making for groundwater planning and sustainable management.

The thematic layers of geology, soil type, geomorphology, lineament density, drainage density, slope, rainfall distributions, and land use were created using satellite and conventional data.

The groundwater potential zone map of the research region was constructed after several theme layers were given the appropriate weighting and integrated into the ArcGIS environment. As a result, the groundwater potential map of the study area was divided into five distinct zones, namely Very High, High, moderate, Low, and Very Low which covered 1104.92 km^2, 1476.72 km^2, 1692.80 km^2, 2012.49 km^2, 1274.19 km^2 respectively. Data from pumping tests and boreholes used to validate the results showed a good comparison to the groundwater potential zones that had been detected. While boreholes with yields between 70m^3/hr and 141m^3/hr were indicative of locations with High and very high groundwater potential zones, those with yields more than >25 m^3/hr are consistent with Low and Moderate groundwater potential zones.

It is recommended that this provided groundwater potential locations should be combined with precise geophysical test for a quantitative evaluation of groundwater potential.

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