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Utilizing Geographical Information System, Remote Sensing and AHP Methodologies for Groundwater Potential Assessment in Aniocha South Local Government Area of Delta State, Nigeria.

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Abstract

In this study, Remote Sensing (RS), Land-sat 8 digital data, and digital elevation models (DEMs) from the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), Food and Agricultural Organization (FAO) along with other stereotypical data such as geology and rainfall were digitized and analyzed to create various thematic maps (geology, land use/cover, soil, drainage density, rainfall and slope maps) required for groundwater modelling in the study area. These thematic maps were assigned well-chosen weights and different rankings to the individual categories within each thematic map using a manual Analytical Hierarchy Process (AHP). Parameters with high influence on groundwater potential assessment were given higher percentages based on some criteria and others were which had low impact given low percentages. The groundwater potential zones are achieved by overlaying the thematic maps using the spatial analysis tool in Arc-GIS 10.8. The resulting maps showed that 5.51%, 41.84%, 11.07%, and 0.0165% comprising about 47, 360, 352, 95 and 14 square kilometer areas of the study can be classified as excellent, good, moderate, fair or poor groundwater potential respectively. This showed that there is good groundwater potential in the LGA.
Keywords: Remote Sensing, Analytical Hierarchy Process, Groundwater Potential Assessment, GIS

1. Introduction

Water is an essential component of our existence. Being the only freshwater supply that has not yet been adversely affected by human activity, groundwater is an even more valuable natural resource. Since surface water development is more expensive and more demanding than groundwater development, groundwater that can be quickly established is given more focus. The importance of water as a natural resource to support human needs cannot be overemphasized, same can be said about the importance of groundwater as a source or major source of water based on purity and continuity compared to surface water (Thompson et al, 2019).

The low chemical composition, low contamination, accessibility and wider distribution have made groundwater a more desirable source of water. Although groundwater occurrence in various locations is not an independent event as it occurs due to some factors such as the climate of the region, the hydrological and geological nature of the region also contributes to the availability of groundwater in a particular place. Groundwater can be widely used in homes for various domestic activities, in agriculture for irrigation and for various industrial purposes. The lower pollution coefficient, chemical compounds, constant temperature, cost effectiveness and high reliability level of groundwater has made it the major source for communities, industries and agricultural uses in the world. In both urban and rural areas, groundwater has been considered as a fundamental source of applying fresh water (Akeem, 2021).

The dependence of individuals on groundwater as a source of water calls for this research on the potential of various areas to have groundwater. The unavailability of groundwater to most people because of the specific location of their house, industries or farms has become a problem and has caused many to spend a lot of money on the search for groundwater. About 34% of the world resources belong to groundwater and is an important source of drinkable water. Due to the country's rapid economic growth, urbanization, and population increase, countries like Nigeria are becoming more and more in need of groundwater.

Groundwater is deemed to be generally in most locations. Some methods of groundwater assessment testing such as the surface method which consists of techniques such as esoteric, geology, geomorphology, geophysics, hydrogeology or the ground survey methods; gravity method and seismic method. Some of these methods are done by trial by error (sub-surface method using drilling technique) which is expensive and time consuming. Those unable to afford such processes will extreme challenges accessing water within their location; hence they opt for other sources of water such as rainwater harvesting or surface water which are neither potable nor reliable for some domestic uses (Birkle et al, 2018).

The availability of groundwater as a source of water depends largely on the surface or sub-surface geology as well as the climate. The porosity and permeability of the geological formation controls its ability to hold and transmit water. Porosity is measured as a ratio of voids to total volume of rock material and is usually described in percentage. Regional groundwater exploration campaigns in the Basement Complex terrains often target areas where there is considerable thick weathered residuum and densely fractured and jointed subsurface zones. The use of surface or sub surface method for groundwater assessment has been found to be expensive and unreliable leading to the use of a more reliable, cost effective and long-term approach to groundwater assessment such as Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) techniques. GIS is a renowned approach that can be used to access a large amount of spatial data used to find groundwater in an area. AHP is a method used for analyzing and organizing complex decisions in modelling the groundwater problem. Groundwater research employing this technology has exploded as a result of technological advancement in the field of geospatial technologies and the associated rise in spatial precision. The flow and availability of groundwater are influenced by a variety of information, which may be managed and integrated using an integrated and goal-oriented platform provided by Remote Sensing and Geographic Information Systems. Often, this integration is carried out with the Multi-Criteria Decision Analysis (MCDA) method. The analytical hierarchy process (AHP) is a straightforward, trustworthy, efficient, and transparent method. By combining data from Remote Sensing and geographic information systems, the AHP approach may be easily and effectively identified.

In a GIS framework, groundwater factors including precipitation, aquifers, land use, and soil type are readily described as geographical data. One of the most popular MCDA methods is the Analytical Hierarchy Process. Recently, AHP has been used in a number of geological domains, but most significantly, it has been used in research pertaining to groundwater and has shown promising results, particularly in defining the groundwater potential zone (Ejepu et al., 2022).

Using AHP, GIS, and Remote Sensing yields a far more dependable and suitable solution that may be applied to most locations, particularly in densely populated and developing regions. Making maps that are useful for finding groundwater in this area is also beneficial to those who live in the area and those who intend to live in the area.

2. RESEARCH METHODOLOGY

2.1 Description of Study Area

Aniocha South is a local government area of Delta state Nigeria. Its headquarters is Ogwashi-uku. It has an area of 868 square kilometers (335 square mile) and a population of 140,604 according to the 2006 census. The Major occupations of the citizens are farming, and fishing. The major crops grown in the area include cassava, yam, maize, plantain, and vegetables. The people also engage in fishing, trading, and petty businesses. The map of the study area is shown in Figure 1

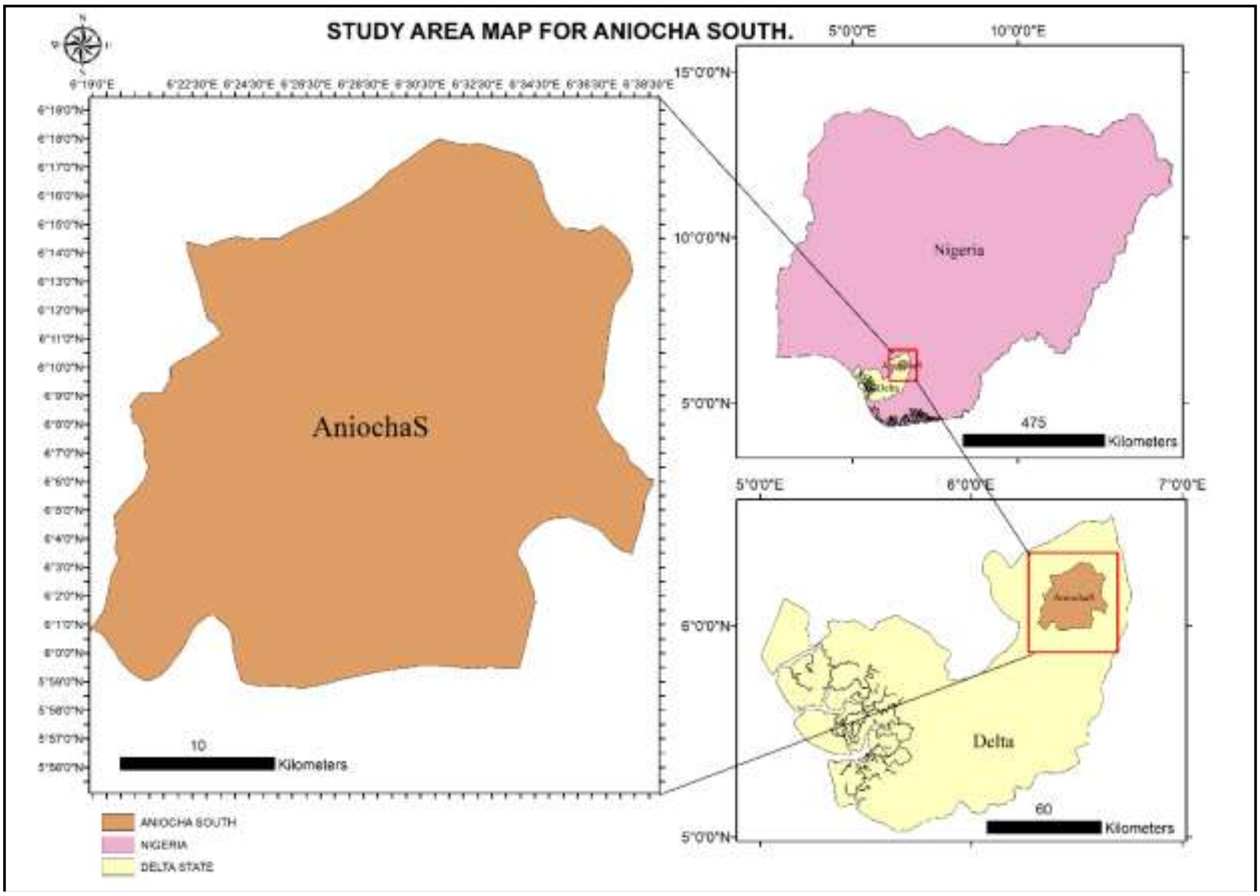

Figure 1: Study area map created on ARCMAP.

2.2 Data Requirement

Both remotely sensed data and field data were collected for this study. Table 1 shows the data type and source,

Table 1: List of data required for the study

S/n	*Data / Scale*	*Type*	*Obtained from*
1.	Landsat 8 Satellite imagery (30m Resolution)	Remotely sensed	Open Topography
2.	SRTM Data (30m DEM Resolution)	Remotely sensed	Open Topography
3.	Topographical map 1:100,000	Digital Copy	ESRI, Sentinel 2
4.	Geological Map (1:500,000)	Digital copy	USGS
5.	FAO Soil Data	Remotely Sensed	FAO
6.	Rainfall Data	10 years Annual Data	CHRS

2.3 Data Acquisition

2.3.1 Landsat 8 Data

The Landsat 8 data products were downloaded from USGS EROS Center, the downloaded image was processed and imported to ArcMap. Landsat Program has provided over 40 years of calibrated medium spatial resolution data of the Earth's surface to a broad and varied user community. Landsat 8 is the latest in a continuous series of land remote sensing satellites.

2.3.2 Shuttle Radar Topographic Mission (SRTM 30m Resolution)

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. The data was downloaded from the Open Topography Website.

2.3.3 Topographical and Geological Maps

Topographical Map and Geological map were acquired from the USGS.

2.3.4 World Soil Geodatabase

The Food and Agricultural Organization (FAO) has provided digital soil data for over 80% of the globe. The data was downloaded from the FAO website

2.4 Satellite Data processing

i. All acquired satellite imageries were projected to the UTM coordinate system. Also, all hard copy maps were scanned and geo-referenced to the UTM coordinate system (WGS84 UTM32N)

ii. Using a specified boundary extent as the Area of interest all acquired data were clipped using the Clip tool in the Arc map Environment to the specified Area of interest.

2.5 Generation of Groundwater Potential Thematic Maps

The thematic data which include; precipitation, drainage density, topography, slope, soil and land use land cover, were generated in raster format using ArcGIS version 10.8 The step-by-step methodology employed to generate the various raster data was created based on previous works done and is shown in the schematics presented in Figures 2 – 6 respectively.

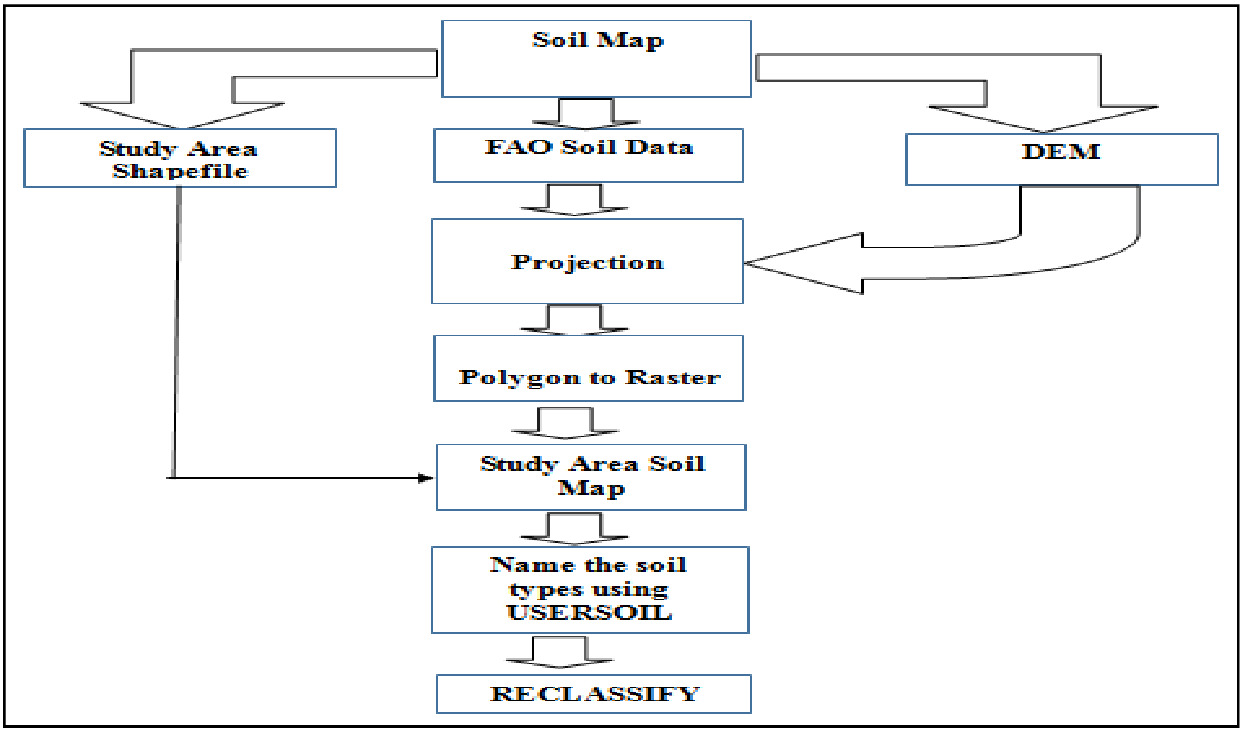

Figure 2: Schematics for generating soil map

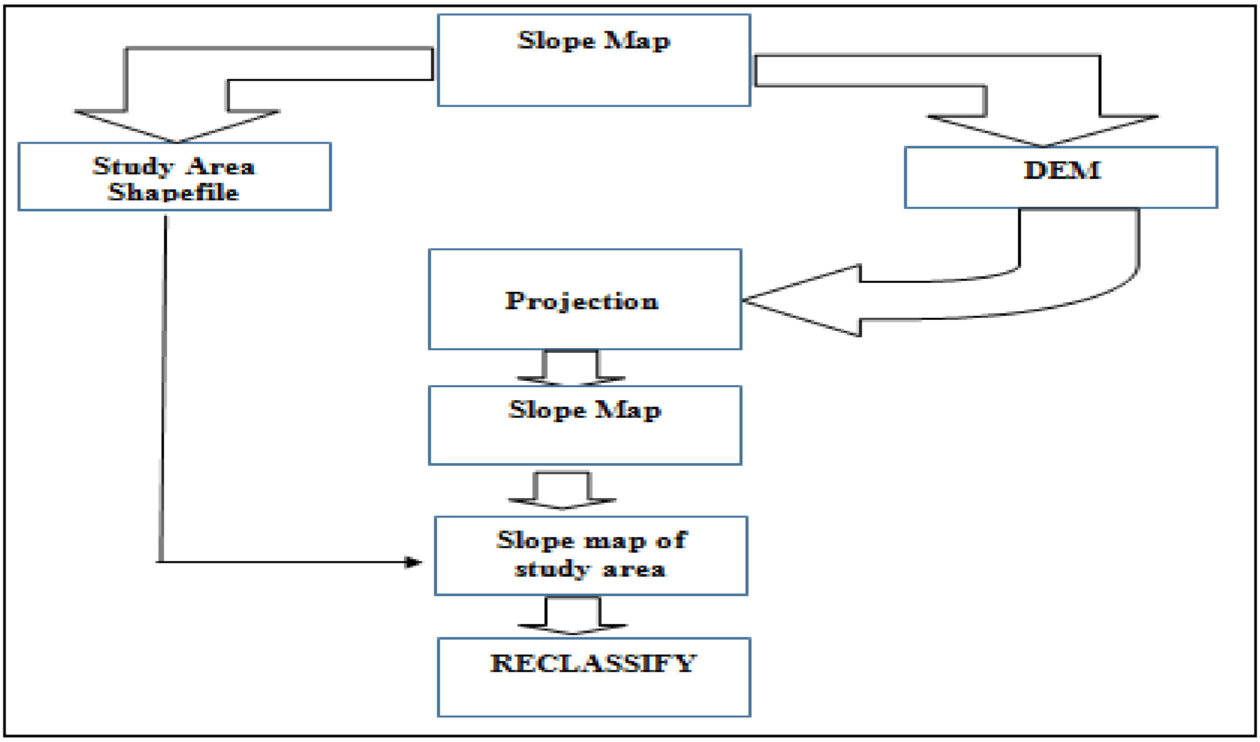

Figure 3: Schematics for generating slope map

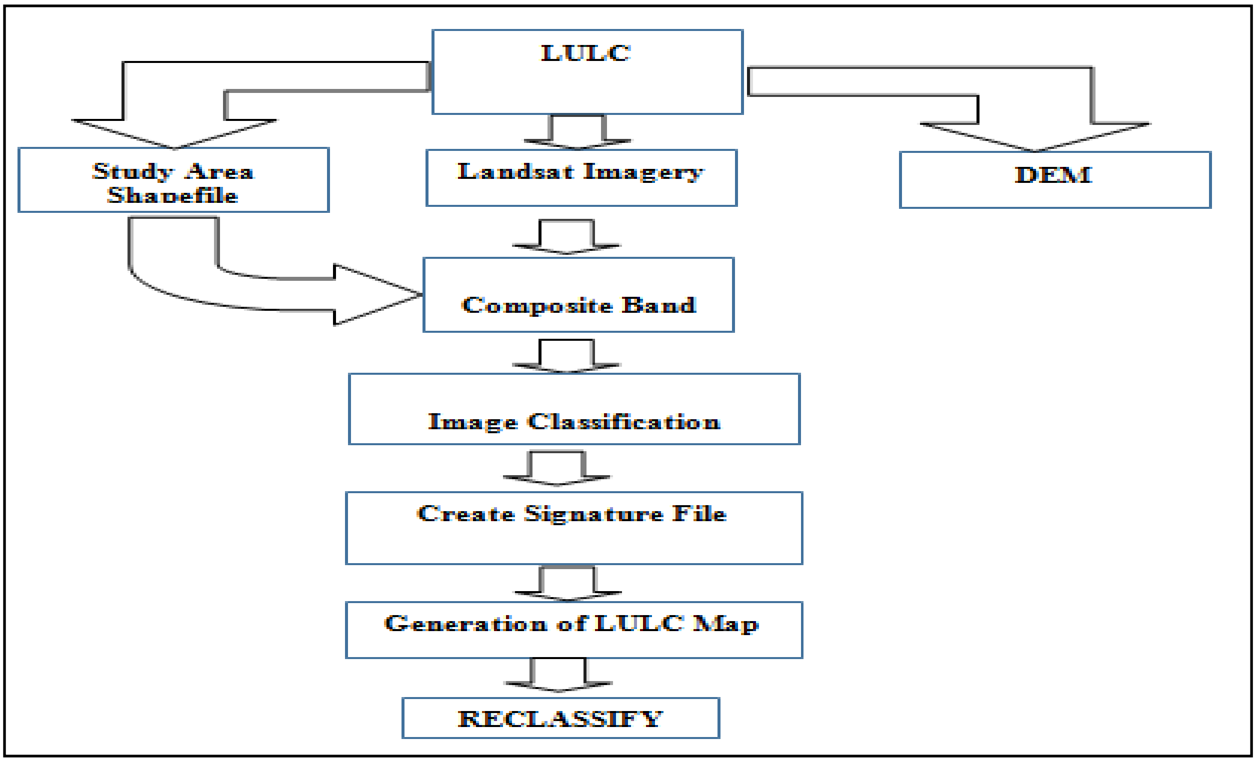

Figure 4: Schematics for generating LULC map

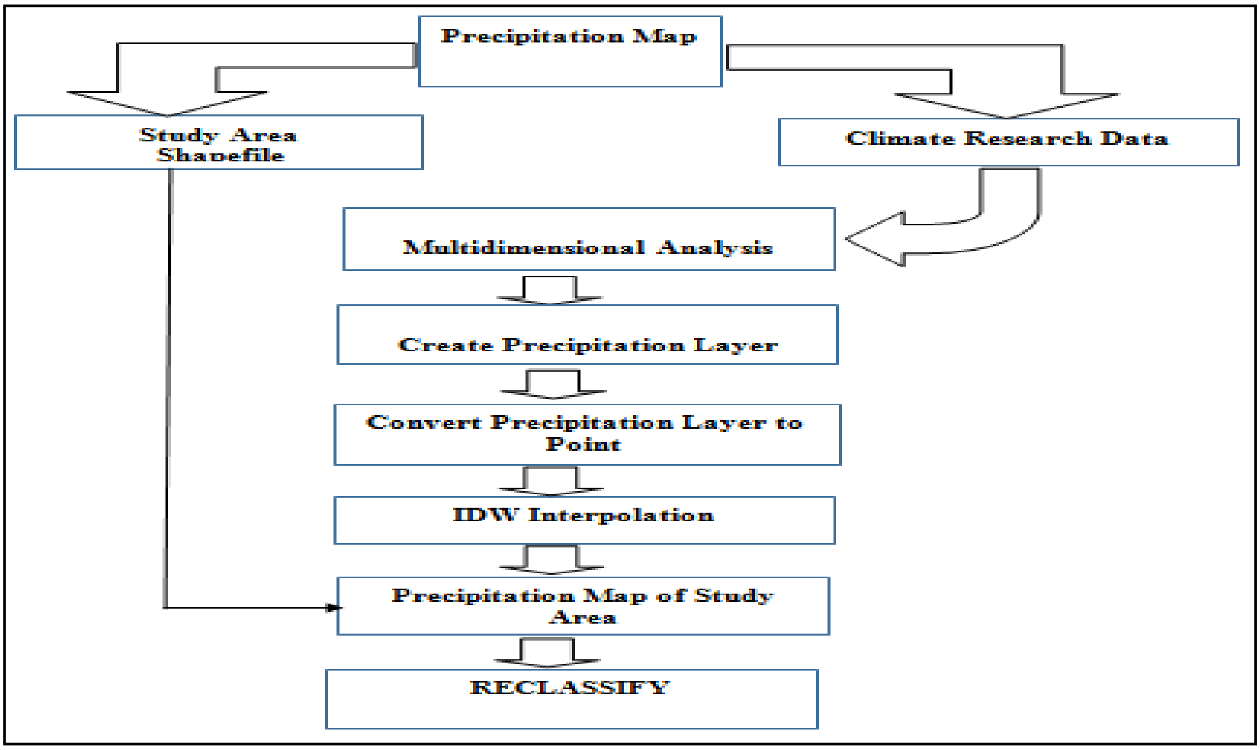

Figure 5: Schematics for generating rainfall map

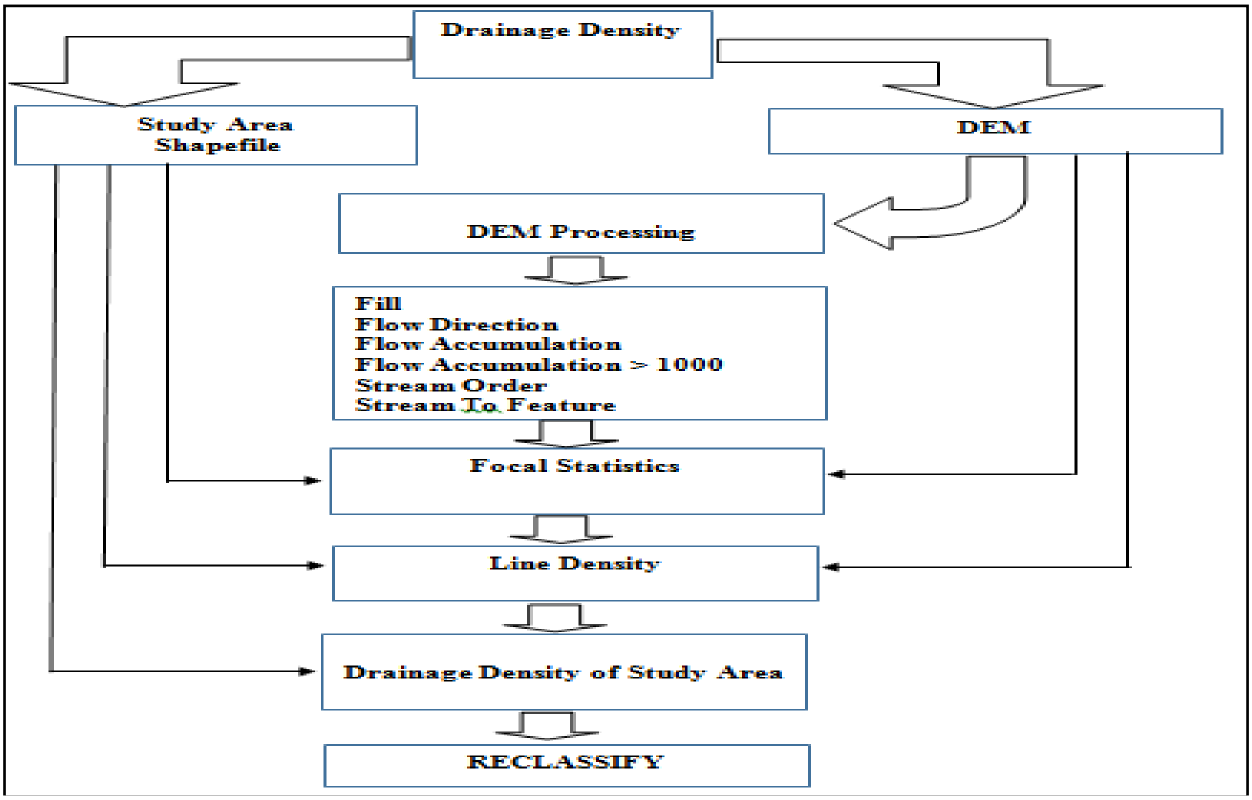

Figure 6: Schematics for generating drainage density map

3.0 Results and Discussion

Maps showing the rainfall, Soil, slope, LULC, drainage density and geology distribution of the study area germane for the determination of the groundwater potential are described below:

3.1 Rainfall Distribution Map

The rainfall map is shown in Figure 7. Rainfall recharge aids in replenishing groundwater storage, which in turn maintains baseflow in rivers and streams, nourishes ecosystems that rely on groundwater, and supplies a steady supply of water for industrial, agricultural, and human uses. In order to simulate recharge processes and predict groundwater levels under various climatic conditions and water management scenarios, groundwater potential maps frequently incorporate rainfall data. This understanding of the relationship between rainfall and groundwater recharge is essential for sustainable groundwater management.

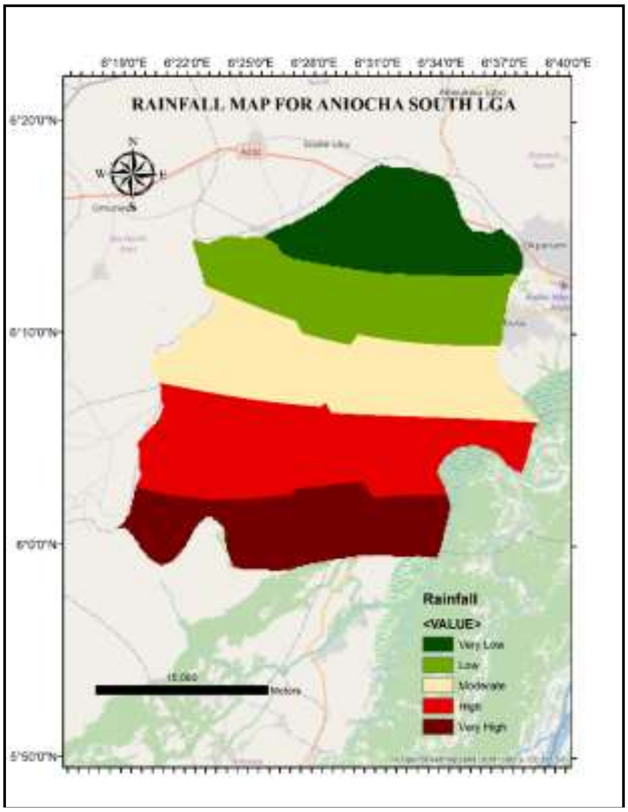

Figure 7: Rainfall map of the study area

Since rainfall is the primary source of groundwater and also naturally regulates groundwater recharge, it is expected that areas with high rainfall availability will have higher levels of infiltration and percolation, while areas with low rainfall availability will have lower levels of infiltration. Figure 7 shows the thematic map of the average annual rainfall. Following the discovery of the spatial distribution of rainfall, the entire local government area was divided into five regions using equal intervals. Appropriate weighting was then assigned to each class, taking into account the significance of rainfall for groundwater prospects. The area with the highest rainfall amount was assigned a value of 5, and the area with the lowest amount was assigned a value of 1, taking into account the short interval between the amounts of rainfall.

3.2 Slope Distribution Map

The slope map of the study area is presented in Figure 8. Because of its impacts on groundwater recharge, the land's slope has a major impact on groundwater availability. Surface water runoff is frequently accelerated by sloping topography as opposed to level or slightly sloping regions. However, sloped regions can also encourage rainfall infiltration into the soil, contingent upon soil properties and vegetation cover. Slopes have the ability to capture and focus groundwater flow, particularly in areas where the subsurface contains impermeable or low-permeability layers.

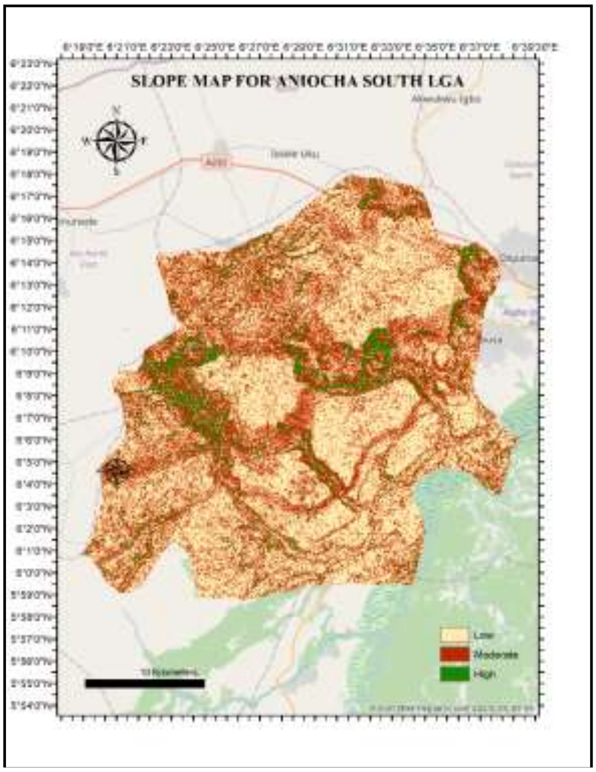

Figure 8: Slope map of the study area

These layers may serve as impediments to the flow of groundwater, allowing it to build up and release at the slope's base in the form of seeps or springs. The water table's depth can be affected by the land's slope. In sloping terrain, the water table may be nearer the surface at the slope's base than it is at the ridge or hilltop. Because groundwater discharge increases at lower elevations and recharging occurs more quickly on steeper slopes, the water table may be shallower. The thickness and properties of subterranean aquifers can be influenced by slope. Slope affects sediment movement and erosion processes, which might have an effect on the rate of groundwater recharge. Soil can be removed by erosion, revealing underlying geological formations. The study area's slope map was created. The slope was graded for each of the three groups (low, moderate, high). A nearly level area has the best groundwater potential accumulation zone when it rains because runoff is slow and takes longer to percolate. Conversely, a very high slope area encourages high runoff, which reduces the amount of time it has to accommodate rainwater. As a result, infiltration is less in strong, sloppy areas, which leads to poor groundwater potential.

3.3 Soil Texture Map

The soil map of the study area is presented in Figure 9. In times of drought, soil moisture helps maintain groundwater levels by acting as a buffer against them. Water moves from the surface of the land to subterranean aquifers through the soil. Under the influence of capillary forces and gravity, water can descend vertically once it has penetrated the soil. By recharging aquifers with precipitation and surface runoff, this process—also referred to as percolation or vertical drainage—contributes to the recharge of groundwater.

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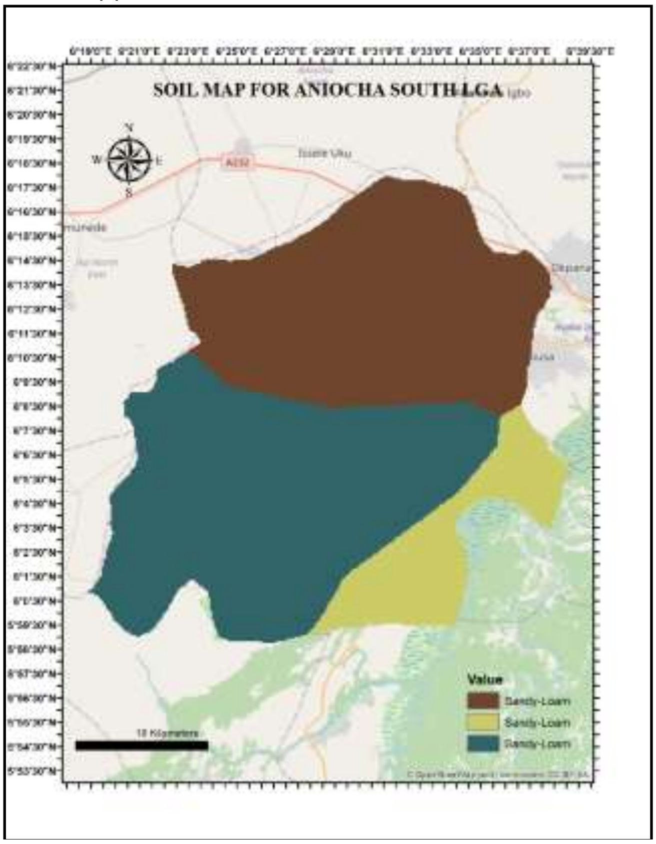

Figure 9: soil map of the study area

Because they absorb surplus surface water and lower peak runoff rates, soils can help lessen the effects of flooding. The soil type in the study area was studied and created using FAO soil data and soil type details were obtained. It was found that the soil type in this area is the same- Dystric Nitosol (Nd), but are in varying concentrations. Dystric Nitisols are typically sandy loam soils and have quite good water retaining characteristics, Because of the clay and organic matter content of these nitisols, they frequently have a high water-holding capacity. Seasons can affect how Dystic Nitisols behave with groundwater. Saturation of these soils during the rainy season may result in decreased infiltration and possible surface discharge. As soil moisture gradually decreases during the dry season, on the other hand, they might show greater potential for groundwater recharge. The soils were given the same rating as they are all of the same type and influence groundwater potential in the same way.

3.4 Land Use Land Cover Map

The soil land use land cover map of the study area is presented in Figure 10. Various land components have their own impact on groundwater potential and on how well they allow rainwater penetrate the ground to encourage groundwater recharge. Urban regions having tarred roads and so many buildings do not have the likelihood of encouraging groundwater recharge as the tarred roads and building encourage runoff but does not permit infiltration.

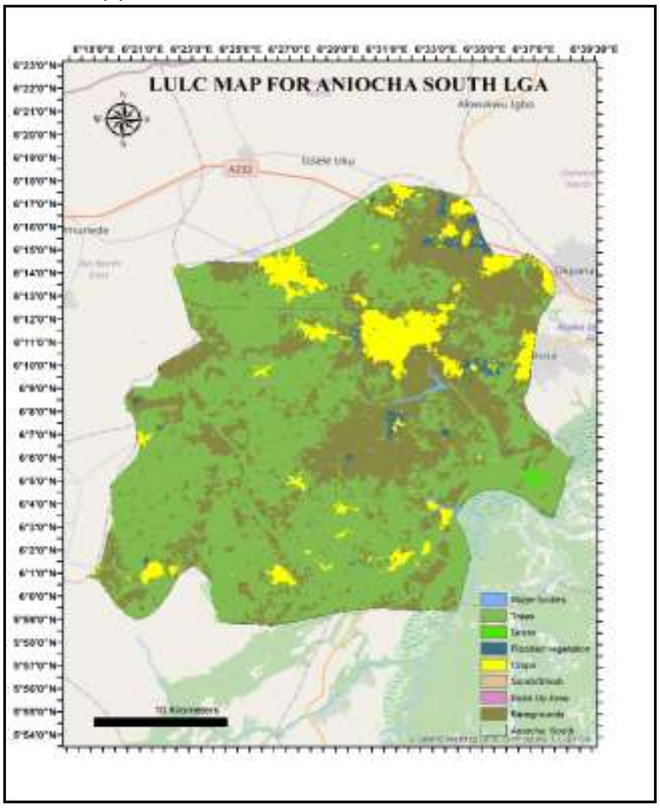

Figure 10: LULC map of the study area

Whereas areas having vegetation, crops, water bodies etc encourage the penetration of water and encourages groundwater recharge, presence of trees and crops covers the ground surface and reduces the rate of evaporation of water from the ground surface. Activities such as mining, deforestation and urbanization causes groundwater depletion, these activities do not encourage groundwater recharge which makes the depth at which water is increase. By changing infiltration rates, recharge rates, and groundwater storage dynamics, land use and land cover have a direct impact on the availability of groundwater.

Figure 11 displays the land use/cover map of the research area, which is divided into four primary categories: flooded vegetation, trees, crops, and barren ground. Bare land has the least influence on penetration, whereas vegetation encourages it the greatest. The factors such as trees, crops, flooded vegetation encourage infiltration of water into the soil and are indicators of the presence of groundwater in a particular area, bur bare ground shows low or no groundwater present.

3.5 Drainage Density Map

The drainage density map of the study area is presented in Figure 11. The frequency and abundance of natural or man-made drainage features, such as rivers, streams, and channels, within a landscape is referred to as drainage density. The amount and distribution of groundwater recharge are determined by the drainage density of an area. Surface water runoff is more common in high drainage density regions, which limits the amount of rainfall that can penetrate the soil and replenish the groundwater system.

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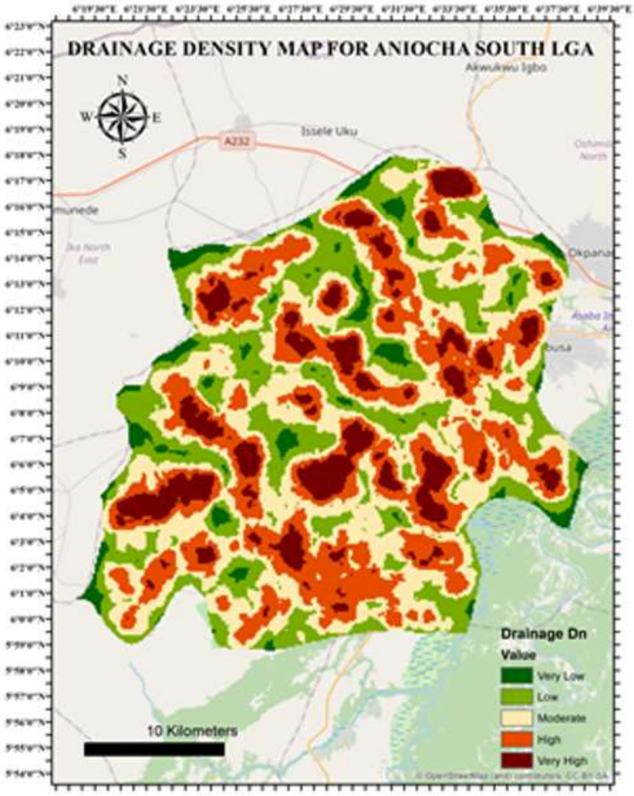

Figure 11: Drainage density map of the study area

On the other hand, less surface water runoff is more common in low drainage density regions, like semi-arid or arid regions, which permits more rainfall to penetrate the soil and replenish the groundwater system. Since it determines how well or poorly a watershed drains, drainage density is a significant factor in Potential Groundwater Zones. All of the drainage areas are dispersed throughout the study area, as can be seen from the map following analysis of the results, and the drainage densities were divided into five categories: very low, low, moderate, high, and very high. The study area's low delineated areas were distributed and located near its edge, whereas the moderate and high delineated areas are uniformly distributed throughout the study area. Low drainage areas are rated based on how long they hold onto water, which encourages infiltrations more than high drainage areas. It is ranked low for high drainage and high for low drainage density.

3.5 Geology Map

The geology map of the study area is presented in Figure 12. Aquifers are subterranean layers of rock or sediment that have the ability to store and transfer water. Geology affects how aquifers originate and what their properties are. The geological composition and structure of aquifers determine their porosity, permeability, and storage capacity. Different geological materials have different hydraulic qualities, which affect the amount of groundwater that flows and may be stored. For instance, although impermeable formations like clay or shale limit the movement and storage of groundwater, porous and permeable formations like sandstone or gravel permit water to flow more freely and can store large amounts of groundwater. Groundwater recharge zones are places where surface water seeps into the subsurface to resupply aquifers. Geology defines these zones' locations and features. In geological formations where water can easily percolate through the ground and replenish aquifers, such as karst landscapes, cracked rock, or alluvial deposits, recharge zones are frequently linked. Water interacts with geological materials as it passes through the subsurface, which is how geology affects the quality of groundwater. The chemical makeup of groundwater can be altered by the dissolution of minerals or other pollutants found in some geological formations. Additionally, toxins may migrate into aquifers through geological features like faults or fractures. The state of confined or unconfined aquifers is determined by geology. Unconfined aquifers are not restricted by impermeable formations above them, but confined aquifers are tucked between impermeable layers. The degree of confinement is determined by the geological setting, which also influences groundwater storage, pressure, and contamination susceptibility.

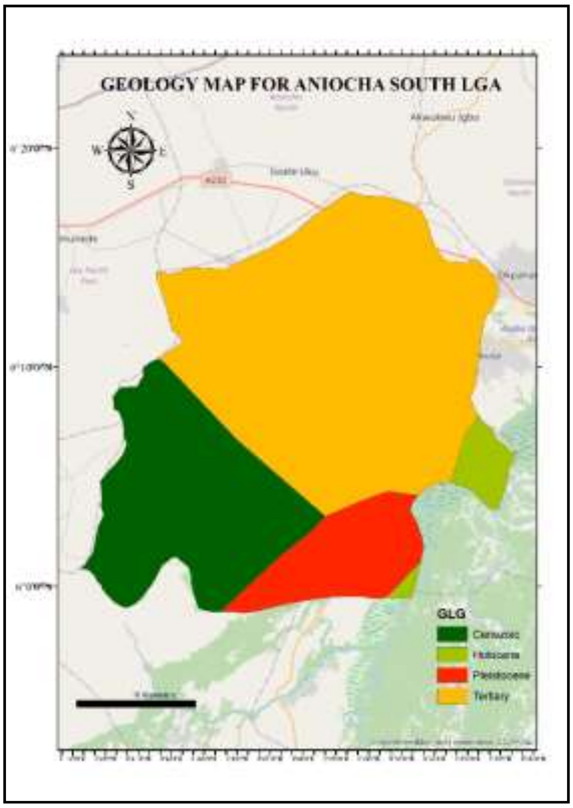

Figure 12: Geology map of the study area

3.6 Estimation of Groundwater Potential Using AHP

The estimated weight of influence of the different thematic data from the AHP analysis is presented in Table 3. The table above shows the various parameters, their relative weight, the factors obtained from these parameters and the rank of each factor. These factors were ranked based on order of importance and based on the highest to the lowest influence the factor has in contributing to groundwater availability. Those with highest influence were given number 5 while those with decreasing influence were given other numbers in descending order, this was done for all factors except soil, which had all numbers being the same because all the factors had one influence. The final ground water potential map was generated using weighted overlay and result is presented in Figure 13.

Table 2: Estimated weight of influence of the different

Parameter	Relative Weight (%)	Factors	Ranking
Rainfall (mm)	7	Very low Low Average High Very high	1 2 3 4 5
Drainage density (km/km^2)	8	Very Low Low Moderate High Very High	5 4 3 2 1
Geology	41	Pleistocene Holocene Cenezoic Tertiary	1 2 3 4
Slope (degrees)	20	Low Moderate High	3 2 1
Soil	14	Dystric Nitosol 17 Dystric Nitosol 18 Dystric Nitosol 21	3 3 3
Land Use/Land Cover	10	Water bodies Flooded vegetation Trees Crops Bare ground	1 2 3 4 5

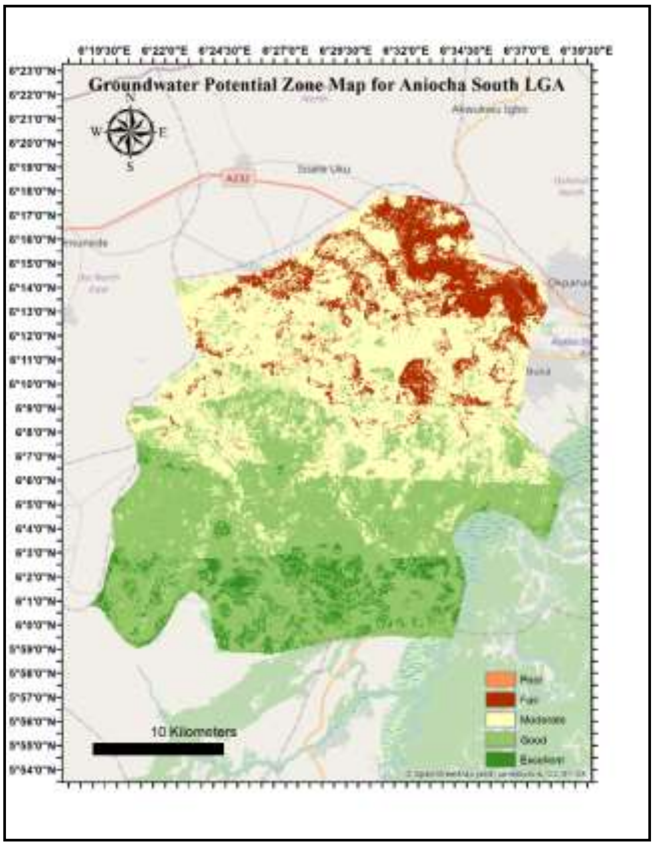

Figure 13: Final Groundwater Potential Map of the Study Area

4. Conclusion

After proper overlay of all the thematic maps used, the delineation and depiction of the groundwater potential zones with poor, fair, moderate, good, and outstanding occurrences over the whole region is shown above in figure 13. The groundwater potential map's results indicate that the high potential zones are located in the south, the low potential zones are in the north, and the moderate potential zones are dispersed throughout the entire study area. The poor potential zone is hardly visible, and the high potential zones are located in the south as small to scattered patches. The overall analysis reveals that a larger portion of the research region is occupied by the good potential zone. The zones of good and moderate groundwater potential in the research region are appropriate for groundwater expansion and irrigation, and they can be used to safely supply water to all areas of the development there. Of the total land area, the result from the Groundwater potential map showed that A total of 5.51% of the 47km² area is classified as having excellent groundwater potential; 41.84% of the 360 km² area is classified as having good groundwater potential; 41.5% of the 352 km² area is classified as having moderate groundwater potential; 11.07% of the 95 km² area is classified as having fair groundwater potential; and 0.0165% of the 14 km² area is classified as having poor potential. From the analysis of the presented maps areas such as Ubulu-Uku, Ofeogbeje, Ogwashi-Uku have fair and moderate groundwater potential, while Ashama has moderate groundwater potential and areas like Egbudu, Adonte, Olodu, Alidima, Umute etc have good and excellent groundwater potentials.

The overall analysis reveals that a greater area of the research region is occupied by the good potential zone. The study area's moderate potential zones and good groundwater potential zones, are suitable for irrigation and groundwater expansion, and they can be used safely to supply water to all sectors of the development there.

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