International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 5 (May. 2024), PP. 102-116

Groundwater Potential Modelling In Awka South, Anambra State Using GIS and Remote Sensing

Adeboboye, A. J. Anyadiegwu, P.C. Aroh E.M.
Department of Surveying and Geoinformatics, Nnamdi Azikiwe University Awka, Nigeria

Abstract- *Groundwater is the safest and most reliable water source, use in domestic, irrigation, industries, and municipality purposes. In Awka South, groundwater is a source of domestic water in urban and rural areas, hence the only practical means of meeting rural communities in arid and semi-arid regions. Previous works on the development of ground water in Awka South were faced with the problem of failed (abortive) hand-dug wells and boreholes, which are as a result of the poor knowledge of the hydrogeological characteristics of the basement aquifers. Most of the groundwater investigation in Awka South has been centered on the use of Electrical resistivity method. None of these studies incorporated the use of Remote Sensing, GIS and multi-criteria decision-making analysis for groundwater mapping in the study area. Besides, each of them was localized to their immediate study area. Therefore, the study aimed to map groundwater potential using Geospatial Technology with the view of identifying areas with ground water availability in the study area. Its objectives are to: establish the geophysical factors needed for mapping groundwater potential in the study area; classify the established geophysical factors according to their level of suitability; calculate the reliability index of the classified geophysical factors and to determine the groundwater potential areas using analytical hierarchical process and weighted linear combination. The results reveal twenty-five potential locations for harvesting ground water. The sites selected were located at forested land or Agricultural areas, with sandstone, sand with silt and clay contents and within High rainfall Intensity Areas. The main considerations were accessibility and the environment and therefore satisfied the criteria for locating groundwater potential in the study area. However, the nature of this study posed a few inherent limitations (lack of field validation); therefore, it is recommended that any further research on ground water potential should include field validation to compare the potential volume of water held by existing boreholes in the study area.*

Keywords: *AHP, Awka, GIS, Groundwater, Remote Sensing*

Date of Submission: 05-05-2024 Date of Acceptance: 17-05-2024

I. Introduction

Groundwater is considered the safest and most reliable source of water for various purposes, including domestic use, irrigation, industrial processes, and municipal supply (Abebe, 2020). When it comes to water supply, the development of groundwater is favored over low-discharge springs and dug wells. These alternatives often prove inadequate during droughts, and many may even run dry, with little hope of recovery after prolonged dry spells.

The characteristics of groundwater, such as its occurrence, origin, movement, and chemical composition, are closely linked to geological and environmental factors. These factors include geology, geomorphology, drainage density, rainfall, geological structures, slope, land use, and soil types. Exploiting groundwater can be challenging, leading to well production failures and high investment costs (Abdul and Amare 2016). Proper evaluation and site selection are critical, given that groundwater is hidden beneath the surface, making direct observation impossible. Instead, its presence or absence must be inferred through the study of controlling parameters related to groundwater occurrence and distribution (Abebe, 2020).

To ensure the wise use of groundwater, a systematic evaluation is necessary, and various methodologies are available for locating and mapping groundwater distribution. In contemporary groundwater studies, both Geographic Information System (GIS) and Remote Sensing (RS) play essential roles, especially in extensive and complex systems (Ahmadi, Ziaei, Davary, Faridhosseini, Izadi and Rasoulzadeh, 2013). Remote sensing and GIS techniques provide the means to collect and integrate the input parameters needed for this assessment.

The integration of remote sensing and GIS has proven to be highly efficient in groundwater studies, enabling better data analysis and interpretation (Hyun, Yong-sung, Jong-kuk, Eungyu and Saro, 2011). One of the significant advantages of using remote sensing data for hydrogeological investigations and monitoring is its ability to provide spatial and temporal information. This information is vital for conducting successful analyses, making predictions, and validating findings (Imran, Sankar, and Dar, 2011).

Therefore, this study employs geospatial technology to map groundwater potential in Awka South, leveraging the benefits of integrated remote sensing and GIS techniques.

In Awka South, groundwater serves as the primary source of domestic water for both urban and rural areas, making it a practical solution to address the water needs of rural communities in arid and semi-arid regions (Kebede, 2013). Numerous studies have highlighted the issues related to the insufficient supply of safe water in Awka South, as documented by (Nwachukwu and Uzochukwu, 2020; Ibe and Uzochukwu, 2016; Ibe, Nwachukwu and Uzochukwu, 2020).

In response to these challenges, groundwater has been proposed as the most dependable source of fresh water for the local population. Previous attempts to develop groundwater resources in Awka South encountered problems, including failed hand-dug wells and boreholes. These failures were often attributed to a lack of understanding of the hydrogeological characteristics of the basement aquifers.

Historically, most groundwater investigations in Awka South relied on the Electrical resistivity method (Ibe and Uzochukwu, 2016; Ibe, Nwachukwu and Uzochukwu, 2020). However, none of these studies integrated Remote Sensing, Geographic Information Systems (GIS), and multi-criteria decision-making analysis for groundwater mapping in the region. Furthermore, these studies were limited to their specific local areas.

Recently, there has been an increasing trend in the use of remote sensing for groundwater investigations. Remote sensing offers advantages such as its ability to provide spatial, spectral, and temporal data covering vast and otherwise inaccessible areas in a relatively short time frame. This technology has emerged as a valuable tool for assessing, monitoring, and managing groundwater resources (Mogaji, Adeleke, Ibrahim, Ojo and Ajayi, 2015).

To gain a comprehensive understanding of groundwater potential zones in the area before embarking on exploration efforts, it is crucial to incorporate remote sensing into the study of groundwater potential in Awka South. This study aims to fill this gap, providing planners with the essential data required for the planning and management of groundwater resources in the region.

II. Material and Methods

2.1 Study Area

The study area is Awka South Local Government Area of Anambra State. Awka south is located at latitude 6°06'N and 6°15'N and Longitude 7°02'E and 7°08'E. Boundaries are formed by Awka North LGA to the North, Anaocha and Orumba North to the south, and Orumba North and Enugu State to the east, it has a land mass of about 175sqkm. According to 2006 population census, the total population of Awka south is about 189,654 (NPC 2006).

Awka South just like other areas of Anambra is in the tropical rainforest zone of Nigeria and experiences two distinct seasons brought about by the two predominant winds that rule the area: the south-western monsoon winds from the Atlantic Ocean and the north-eastern dry winds from across the Sahara Desert. The monsoon winds from the Atlantic creates seven months of heavy tropical rains, which occur between April and October and are followed by five months of dryness (November - March). The Harmattan, also known as Ugulu in Igbo, is a particularly dry and dusty wind which enters Nigeria in late December or in the early part of January and is characterized by a grey haze limiting visibility and blocking the sun's rays.

The temperature in Awka South as with other areas of Anambra is generally 27-30 degrees Celsius between June and December but rises to 32-34 degrees Celsius between January and April, with the last few months of the dry season marked by intense heat.

Although annual rainfall is high in Awka South, ranging from 1,400mm to 2,500mm, it is concentrated in one season, with about four months of dryness, November to February. Consequently, the natural vegetation of Awka South is tropical dry or deciduous forest, which, in its original form, comprised tall trees with thick under growth and numerous climbers.

The typical trees (silk cotton, Iroko and oil bean) are deciduous, shedding their leaves in the dry season. Because of the high population density in the state, most of the forests have been cleared for settlement and cultivation.

What exists now is secondary regrowth, or a forest savannah mosaic, where the oil palm is predominant, together with selectively preserved economic trees.

Three soil types can be recognised in Awka South. They are:

a. Alluvial soils,
b. Hydromorphic soils, and
c. Ferallitic soils.

The alluvial soils are pale brown loamy soils. They differ from the hydromorphic soils in being relatively immature, having no well-developed horizons. They, however, sustain continuous cropping longer than the other two types.

Hydromorphic soils are developed where the underlying impervious clayey shale cause water logging of the soils during the rainy season. The soils are fine loamy, with lower layers faintly mottled; while the subsoil layers are strongly mottled and spotted, containing stiff grey clay. The soils are good for yam, cassava and maize, and for rice in the more heavily waterlogged areas.

2.2 Methods

The methodology employed in this research focuses on the assessment of relative priorities in modeling and mapping groundwater potential in Awka South. The process was initiated by compiling a comprehensive set of criteria crucial for evaluating groundwater potential.

To ascertain the relative importance of these criteria, the Analytical Hierarchical Process (AHP) was adopted. AHP facilitated the comparison and establishment of the hierarchy among the criteria through pairwise matrix comparisons, enabling the determination of their relative weights. This step ensured that the subsequent integration of these criteria into the ground water potential assessment would be reflective of their respective significance in contributing to groundwater potential.

Following the determination of relative weights, the Weighted Overlay technique was implemented. This technique enabled the synthesis of the various suitability criteria maps into a comprehensive potential map. By assigning appropriate weights to each criterion, Weighted Overlay facilitated the identification of areas with higher potential based on the combined influence of multiple factors.

III. Results

3.2. Identification and Establishment of criteria for Ground water Potential

This study modified the approach by Abebe (2020) to identify and establish criteria for locating ground water potential. These consisted of factors including; slope, LULC, geology, soil, drainage density, lineament density and rainfall. The parameters that were used is as shown in Table 4.1.

Table 4.1: Criteria and Requirements for locating ground water potential.

Criteria	Data Source	Requirement for suitability	Reason for Selection	Original Data Structure	Resolution / Feature Type
LULC	Landsat 8 OLI (Earthexplorer.usgs.gov)	Forested land or Agricultural areas	Classes like forest and agriculture land hold substantially high proportion of water than the built-up land, barren land and rocky surfaces.	Raster	30m
Geology	Department of Geography and Meteorology, Nnamdi Azikiwe University Awka	Sandstone and sand with silt and clay contents	Geologic setting plays a vital role in the occurrence and distribution of groundwater in any terrain.	Vector	Polygon
Lineament Density	Alor Palsar Dem (Earthexplorer.usgs.gov)	Lineament Density Distances not less than 1km	Intensity of groundwater potential decreases with increasing distance from the lineaments.	Raster	12.5m
Soil	Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka	Clayey – skeletal, kaolinitic, typic tropaquepts.	The soil texture and hydraulic characteristics are the main factors considered for estimation of rate of infiltration.	Vector	Polygon
Drainage Density	Alor Palsar Dem (Earthexplorer.usgs.gov)	Low Drainage Density	High drainage density represents less infiltration and hence do not favor much on the groundwater potential of the area. Low drainage density represents high infiltration and hence contributes more to the groundwater potential	Raster	12.5m
Slope	Alor Palsar Dem (Earthexplorer.usgs.gov)	Flat and Gentle Slopes	Surface runoff and rate of infiltration are influenced essentially by slope of the surface. Larger slopes produce smaller recharge because the water received from precipitation flows rapidly down a steep	Raster	12.5m

			slope during rainfall. Therefore, it does not have sufficient residence time to infiltrate and recharge the saturated zone.		
Rainfall	Department of Geography and Meteorology, Nnamdi Azikiwe University Awka	High Intensity Areas > 1200mm	Infiltration depends on the intensity and duration of rainfall. High intensity and short duration rain influence less infiltration and more surface runoff; Low intensity and long duration rain influences high infiltration than runoff.	Interpolated Raster Surface	100m

4.2. Classification of the criteria and factors according to their rank of suitability for locating Ground water Potential Zones

4.2.1 Land Use Land Cover (LULC).

LULC gives the essential information on infiltration, soil moisture, groundwater, surface water etc., in addition to providing indication on groundwater requirements. LULC classes like forest and agriculture land hold substantially high proportion of water than the built-up land, barren land and rocky surfaces. Therefore, the LULC data were reclassified with forested areas and Agricultural land classified as suitable and other classes classified as unsuitable as shown in figure 4.1.

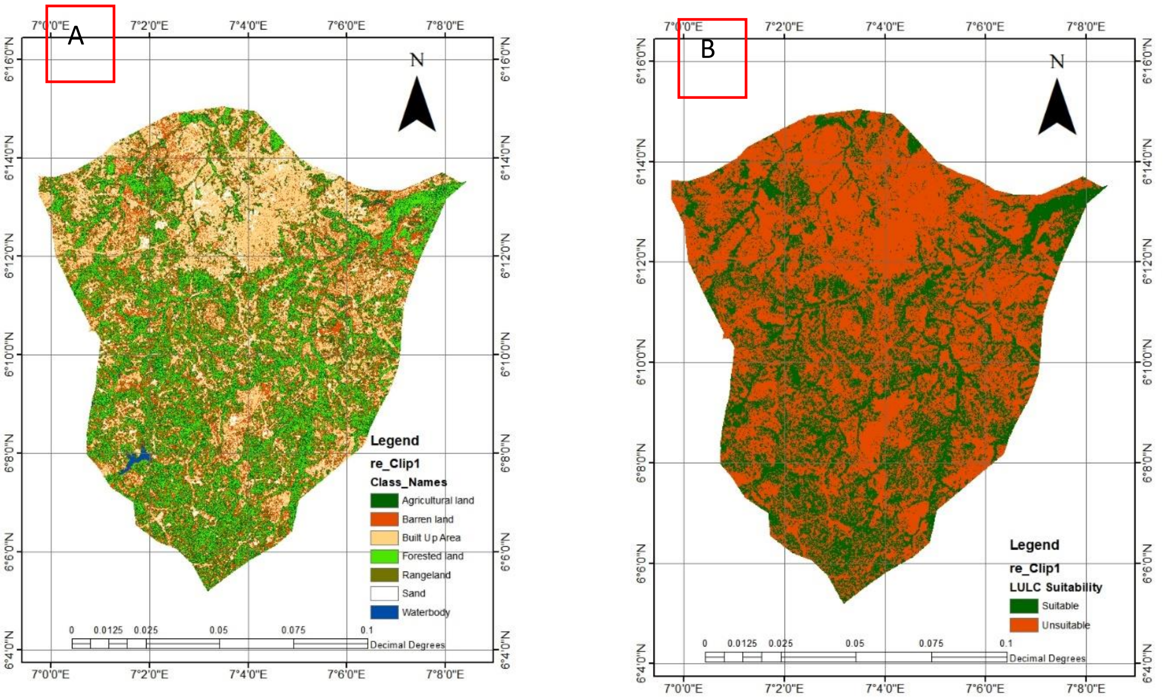

Figure 4.1: (a) Landcover/landuse data (b) Reclassified Landcover/Landuse

4.2.2 Geology.

Geologic setting plays a vital role in the occurrence and distribution of groundwater in any terrain

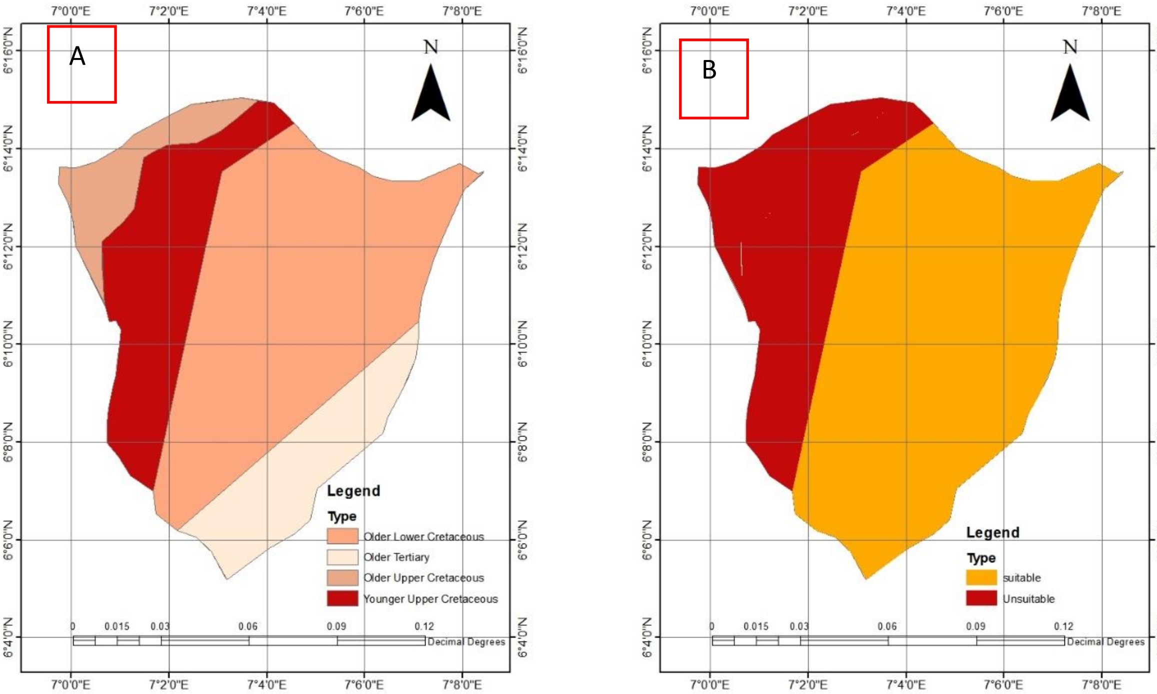

Figure 4.2: (a) Geology data (b) Reclassified Geology data

4.2.3 Lineament Density.

Lineaments are structurally controlled linear or curvilinear features. It can be identified from the satellite imagery by their relatively linear alignments. Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. Lineaments of the study area were extracted from Hill shade from Alos Palsar Data. The lineament density data was then prepared using line density. The ranks are given for lineament density based on proximity of lineaments. The intensity of groundwater potential decreases with increasing distance from the lineaments. Hence, values > 1.21 km/km2 were classified as suitable and others as unsuitable as shown in figure 4.3.

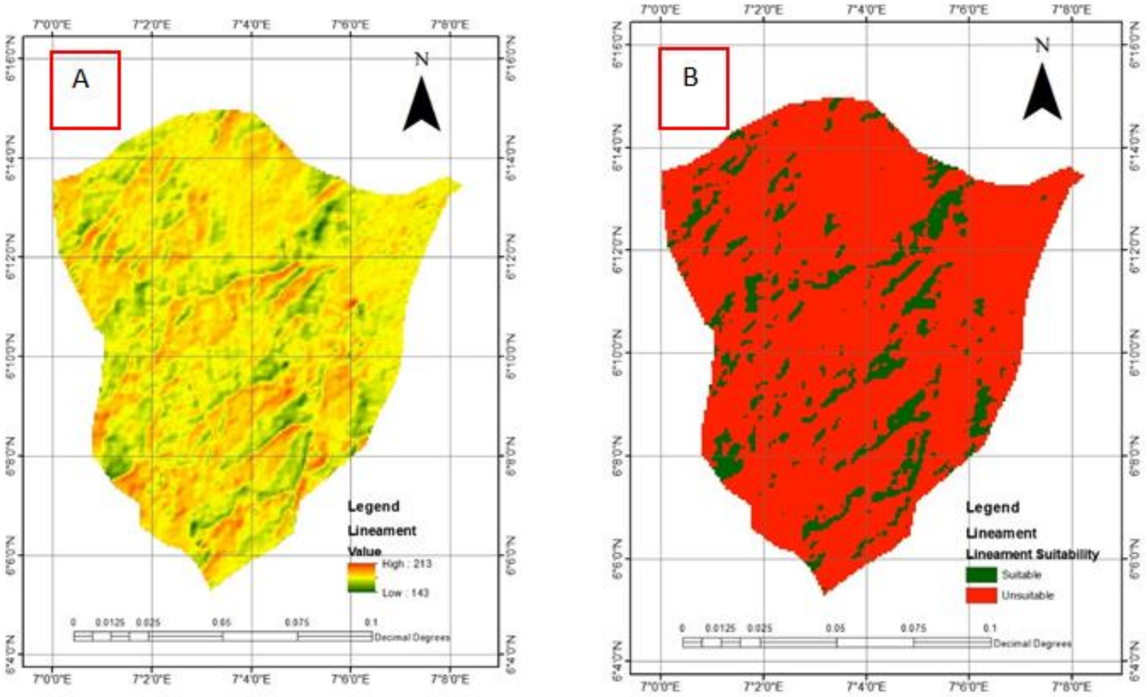

Figure 4.3: (a) Lineament Density data (b) Reclassified Lineament Density

4.2.4 Soil.

Soil types play an important role on the amount of water that can infiltrate into the subsurface formations and hence influence groundwater recharge. The soil texture and hydraulic characteristics are the main factors considered for estimation of rate of infiltration. Therefore, all Clayey – skeletal, kaolinitic soils where classified as suitable as shown in figure 4.4.

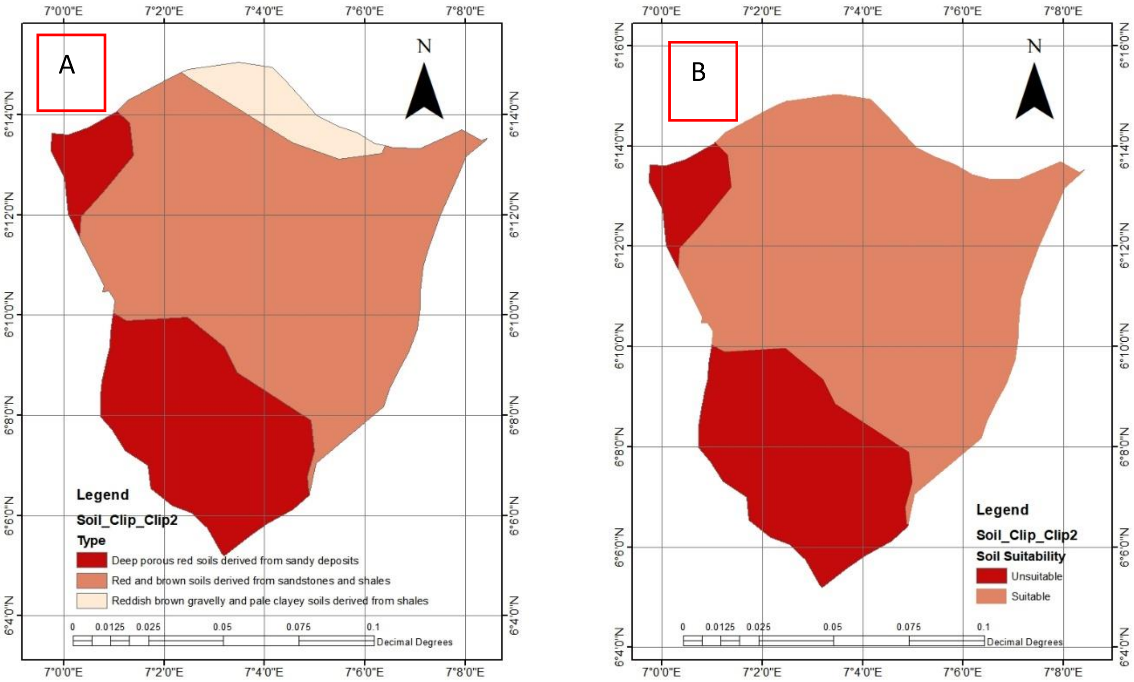

Figure 4.4: (a) Soil data (b) Reclassified Soil Data

2.5 Drainage Density

Drainage density plays a very crucial role in groundwater availability and contamination. The drainage network depends on lithology and it provides an important index of infiltration rate. Drainage density is an inverse function of permeability. Therefore, it is an important parameter in the delineation of the groundwater potential zone. Drainage density is obtained by dividing the total length of all the rivers in a drainage basin by total area of the drainage basin. High drainage density represents less infiltration and hence do not favor much on the groundwater potential of the area. Low drainage density represents high infiltration and hence contributes more to the groundwater potential. The drainage density was reclassified and categorized with values 1.37km – 6.56km classified as suitable and values > 6.56km classified as unsuitable, as shown in figure 4.5.

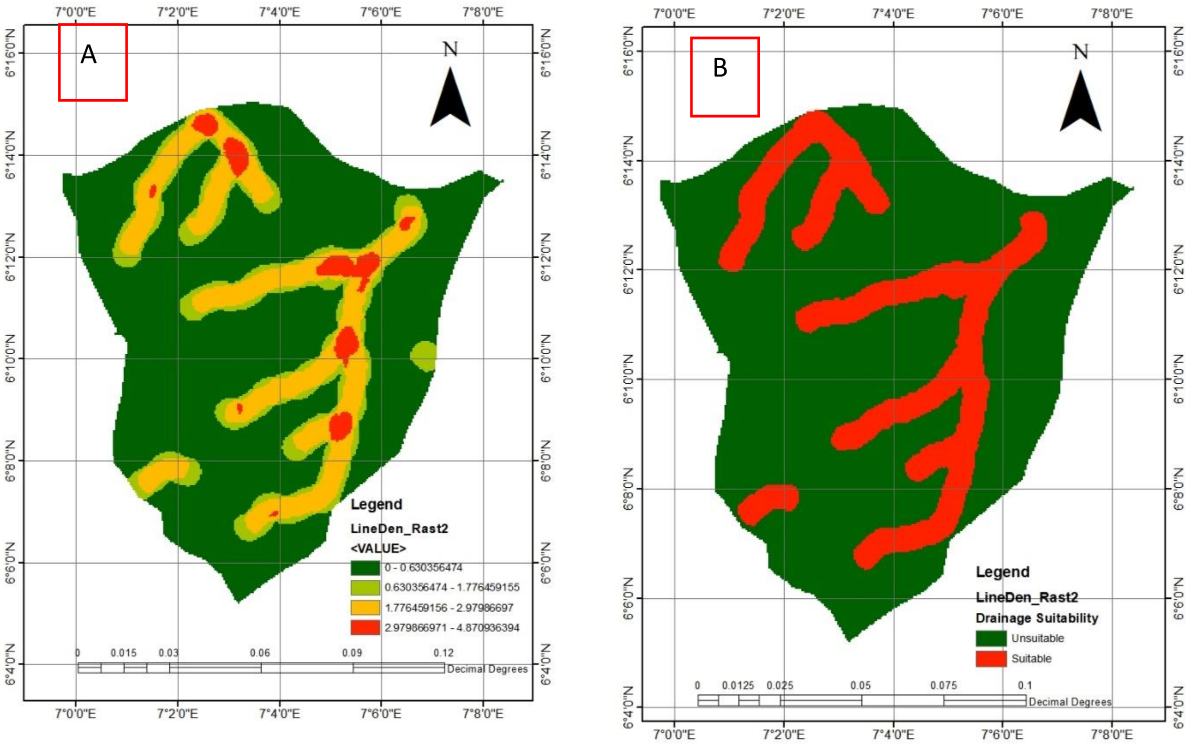

Figure 4.5: (a) Drainage density data (b) Reclassified Drainage Density

4.2.6 Slope.

The slope is a significant terrain characteristic, which express the steepness of the ground surface. Slope gives essential information on the nature of the geologic and geodynamic processes operating at regional scale. Surface runoff and rate of infiltration are influenced essentially by slope of the surface. Larger slopes produce smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall. Therefore, it does not have sufficient residence time to infiltrate and recharge the saturated zone.

The slope values were reclassified with fat (0–3.98) and gentle (3.98–8.37), classified as suitable and medium (8.37–14.95), steep (14.95–24.32) and very steep (24.32–50.85) classified as unsuitable as shown in figure 4.6.

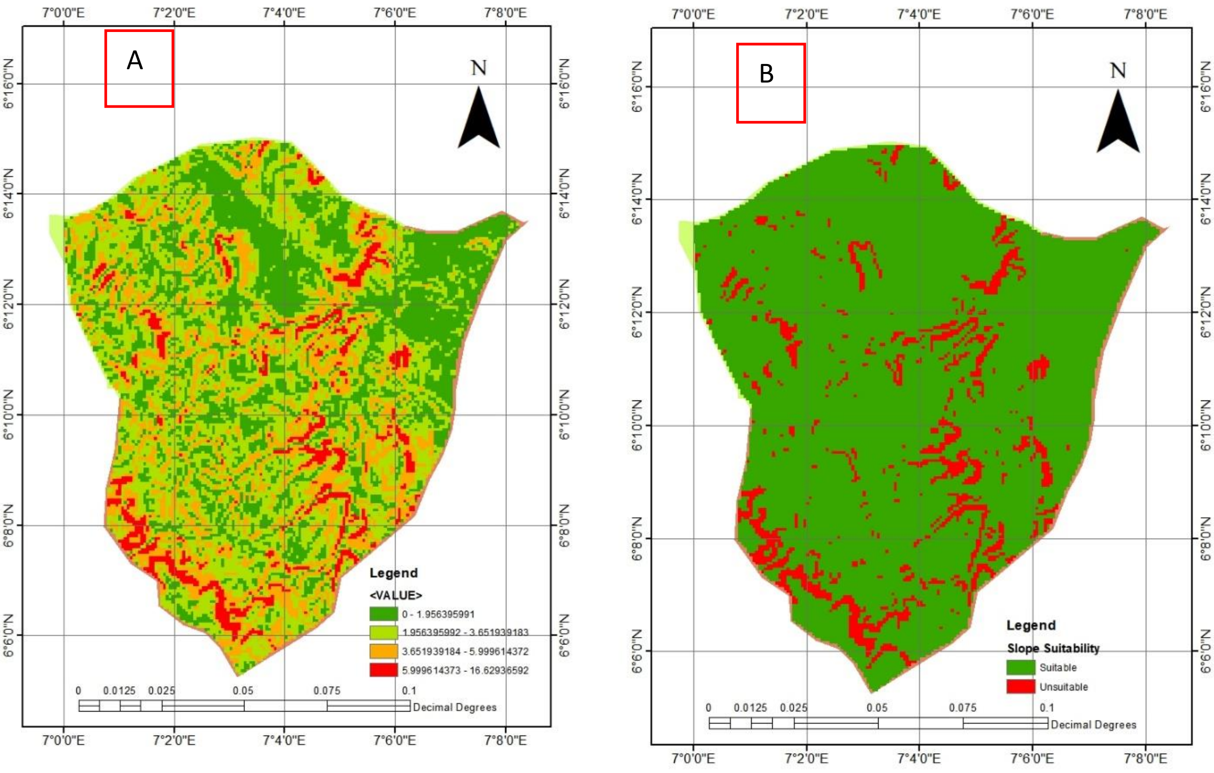

Figure 4.6: (a) Slope data (b) Reclassified Slope

4.2.7 Rainfall.

Rainfall is the major water source in the hydrological cycle and the most dominant influencing factor in the groundwater of an area. The annual rainfall ranges from 1035mm to 1788mm. The spatial distribution map of rainfall was prepared using IDW interpolation method. Based on the maximum and minimum values, the rainfall has been reclassified such that => 1679mm were classified as suitable while =< 1679mm were classified as unsuitable, (figure 4.7). Infiltration depends on the intensity and duration of rainfall. High intensity and short duration rain influence less infiltration and more surface runoff; Low intensity and long duration rain influences high infiltration than runoff.

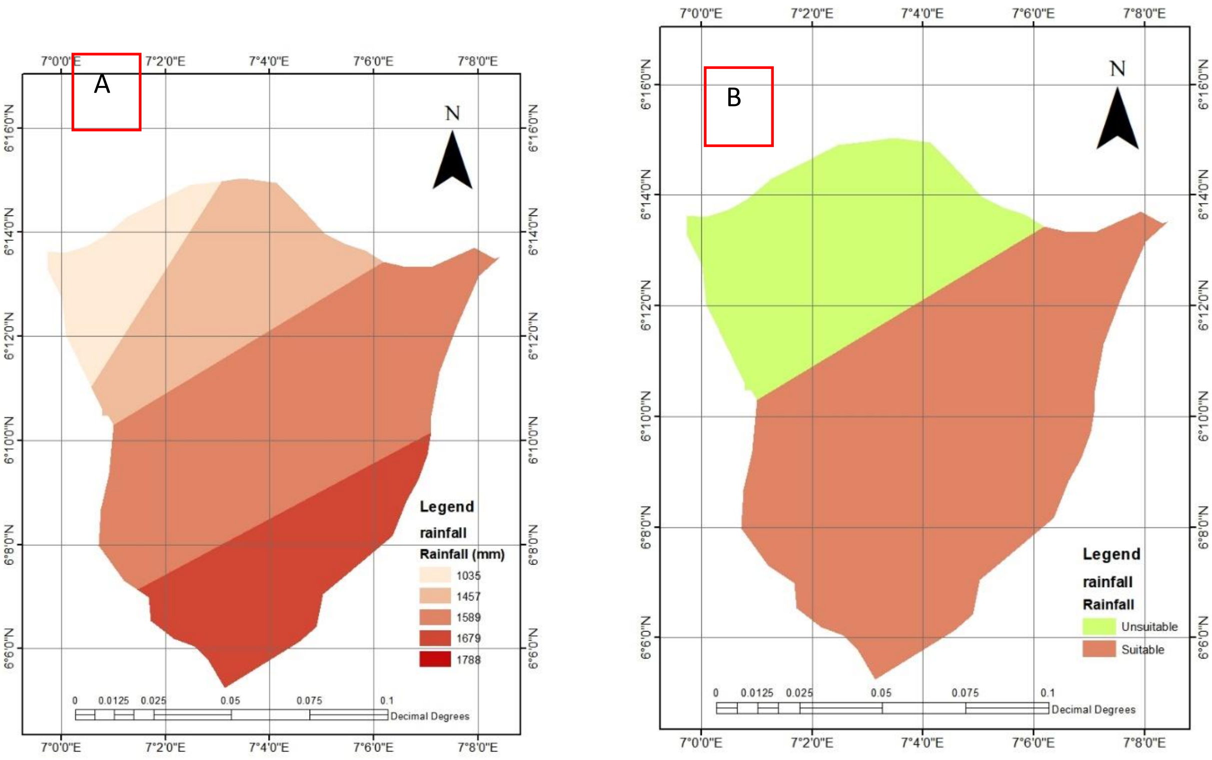

Figure 4.7: (a) Rainfall data (b) Reclassified Rainfall data

4.3 weighted linear combination of the classified criteria and factors for locating Ground water Potential Zones

4.3.1 Development of the Pairwise Comparison Matrix

In order to ensure that each criterion was evaluated based on its relative importance, using a variable numeric range for the various criteria depending upon the relative importance of each criterion was considered.

In this study, the pairwise comparison method was adopted to assign weights to each criterion. This method provides an organized structure for group discussions and helps the decision-making group focus on areas of agreement and disagreement when setting criterion weights. Saaty (1990) proposed the pairwise comparison method in the context of the analytical hierarchy process. This method is an effective method for the determination of relative importance. The method uses a ratio matrix to compare one criterion with another. The matrix of pairwise comparisons represents the intensities of the expert's preference between individual pairs of criteria. They are usually chosen according to a given scale ranging from 1 to 9 for a given 'n' number of criteria, where 1 represents criteria of equal importance and 9 represents a criteria with extreme importance compared to the other.

Table 4.2: Scale for Pairwise Comparison, Saaty (1990).

INTENSITY OF IMPORTANCE	DEFINITION
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

The judgment table (comparison matrix) was represented by a 7 x 7 matrix and then multiplied by itself to obtain eigenvectors.

Table 4.3: Pairwise Comparison of the Evaluated Criteria

Criterion	LULC	Geology	Lineament Density	Soil	Drainage Density	Slope	Rainfall
LULC	1	2	3	4	5	5	9
Geology	0.5	1	3	5	6	6	7
Lineament Density	0.3	0.3	1	5	6	6	7
Soil	0.25	0.2	0.16	1	2	3	4
Drainage Density	0.2	0.16	0.16	0.5	`1	2	3
Slope	0.2	0.16	0.16	0.3	0.5	1	4
Rainfall	0.11	0.14	0.14	0.25	0.3	0.25	1
Total	2.59	4.0	11.5	16	20.8	23.25	35

4.3.2 Computation of the Criterion Weights

This procedure involved the following operation

a) Sum the values in each column of the pairwise comparison matrix;

b) Divide each element in the matrix by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix)

c) Compute the average of the elements in each row of the normalized matrix, that is, divide the sum of normalized scores for each row by 3 (the number of criteria). These averages provide an estimate of the relative weights of the criteria being compared. Using this method; the weights are interpreted as the average of all possible ways of comparing the criteria.

Table 4.4: Relative Weight of Criteria

Criterion	LULC	Geology	Lineament Density	Soil	Drainage Density	Slope	Rainfall	Relative Weight
LULC	0.38	0.5	0.26	0.25	0.24	0.21	0.25	0.29
Geology	0.19	0.25	0.26	0.31	0.28	0.25	0.2	0.25
Lineament Density	0.12	0.08	0.08	0.31	0.28	0.25	0.2	0.19
Soil	0.09	0.05	0.01	0.06	0.09	0.12	0.11	0.07
Drainage Density	0.07	0.02	0.01	0.03	`0.04	0.08	0.08	0.047
Slope	0.07	0.02	0.01	0.02	0.02	0.04	0.11	0.041
Rainfall	0.04	0.03	0.01	0.01	0.01	0.01	0.03	0.02

4.3.3: Estimation of the Constituency Ratio

The value of pairwise comparism relies on subjective judgment which might lead to arbitrary result which could be bias. A numerical index, called consistency ratio (CR) is used for evaluating the consistency of pairwise comparism matrix (Saaty 1990). The index indicates the ration of the consistency index (CI) to the average consistency index, which is also called Random Index (RI). This is given as:

CR = Consistency index (CI)/Random Consistency Index (RI) …. Equation 1
The value of Random Consistency Index (RI) can be found in the table, prepared according to number of criteria involved (Saaty, 1990), as shown in table 4.5.

Table 4.5: Random Consistency Index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The value of Consistency index, CI can be calculated from the preference matrix according to equation 2

$$CI = \frac{\lambda\text{max} - \text{n}}{\text{n}-1} \qquad \text{……… Equation 2}$$

λ***max*** is the Principal Eigen Value; ***n*** is the number of factors
λmax = Σ of the products between each element of the priority vector and relative weights
λmax = (2.59*0.4) + (4*0.25) + (11.5*0.19) + (16*0.07) + (20.8*0.047) + (23.25*0.041) + (35*0.02)
= 1.036 + 1 + 2.185 + 1.12 + 0.97 + 0.95 + 0.7
λmax = 7.661
CI = (7.661 – 7)/ (7-1) = 0.11
CR = 0.11/1.32 = 0.083

CR = 0.083 < 0.10 (Acceptable)

The consistency ratio (CR) is design in such a way that if CR<0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, CR ≥ 0.10, the values of the ratio are indicative of inconsistent judgments. From the judgment a Consistency Ratio (CR) of 0.083 was achieved which was less than the maximum allowable ratio of 0.10.

4.4 Suitability Calculation

The weighted linear combination (*WLC*) model has become popular in recent year and for the study, WLC methods was used over the Boolean method. Site suitability was calculated by using raster calculator in ArcGIS 10.5. The criteria were standardized to a continuous scale of suitability from the least to the most suitable, thus giving flexibility in the site selection.
The weighted linear combination equation is the following:

$$\text{S} = \Sigma wixi \text{ x } \Pi cj \qquad \text{…..…. Equation 3}$$

Where:
S – is the composite suitability score
xi – factor scores (cells)
wi – Weights assigned to each factor
cj – Constraints (or Boolean factors)
Σ -- Sum of weighted factors
Π -- Product of constraints (1-suitable, 0-unsuitable)
Using the formula to calculate for ground water potential in ArcGIS raster calculator
S = ((F1 * 0.4) + (F2 * 0.25) + (F3 * 0.19) + (F4 * 0.07) + (F5 * 0.047) + (F6 * 0.041) + (F7 * 0.02)),
The output presented potential sites with the highest potential for ground water. The result is shown in figure 4.8 and table 4.6.

Note: F1, F2, F3, F4, F5, F6 & F7 are thematic layers representing the constraints.

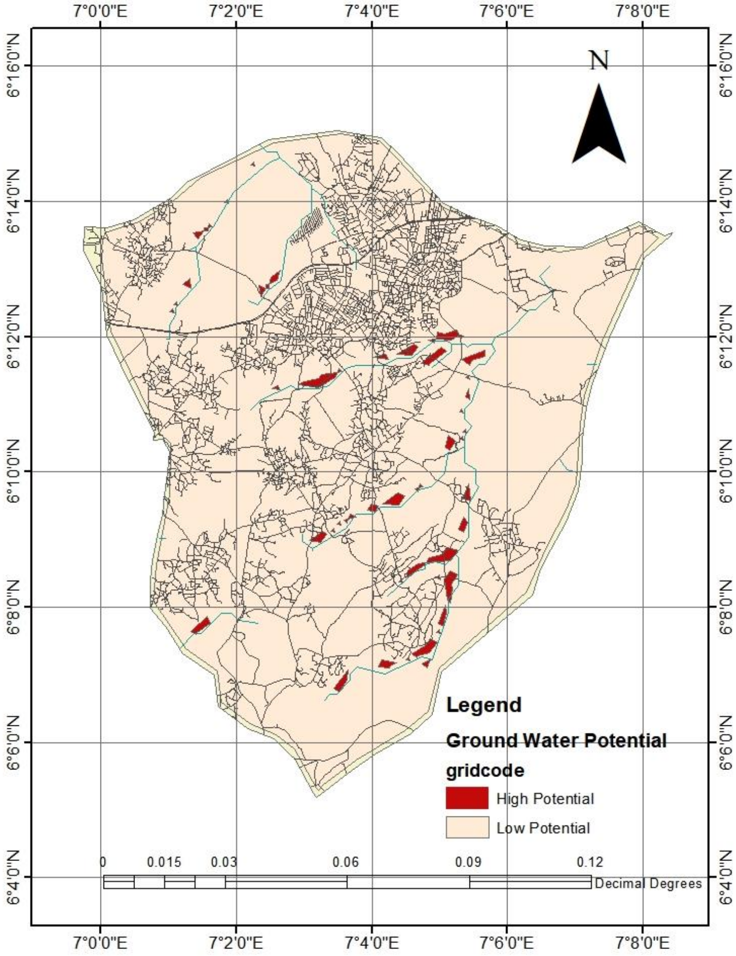

Figure 4.6: Derived Ground water potential Map

Table 4.6: High Potential Ground Water Sites

FID	EASTING	NORTHING
1	281390.704	688497.213
2	281102.398	687123.903
3	283449.399	687317.290
4	283084.131	686995.260
5	284652.576	684483.282
6	286353.986	685123.827
7	287123.327	685323.142
8	288217.009	685723.403
9	287850.746	685118.401
10	288983.713	685195.162
11	288206.527	682813.085
12	286744.759	681322.746
13	286055.840	681001.861
14	284637.076	680238.991
15	281472.619	677865.639
16	285188.837	676194.766
17	286485.713	676796.427
18	287579.832	677277.568

19	288111.995	679013.795
20	288074.286	679781.940
21	287263.703	679380.630
22	288606.000	681396.898
23	288521.763	680467.505
24	287987.156	678044.123
25	287537.351	676711.817

From table 4.6, the results reveal twenty-five potential locations for harvesting ground water. The sites selected were located at forested land or Agricultural areas, with sandstone, sand with silt and clay contents and within High rainfall Intensity Areas. The main considerations were accessibility and the environment and therefore satisfied the criteria for locating ground water potential in the study area.

V. Conclusion

In Awka South, groundwater is a source of domestic water in urban and rural areas, hence the only practical means of meeting rural communities in arid and semi-arid regions. Several works have enumerated the problems of inadequate supply of safe water in Awka South and inadequate data on suitable sites for potential groundwater. In respect of the above problem, groundwater been suggested as the most reliable source of fresh water to the populace. The development of groundwater in Awka South is faced with the problem of failed (abortive) hand-dug wells and boreholes, which are as a result of the poor knowledge of the hydrogeological characteristics of the basement aquifers, therefore this study aimed at mapping groundwater potential using Geospatial Technology with the view of identifying areas with ground water availability in the study area. The results reveal twenty-five potential locations for harvesting ground water. The sites selected were located at forested land or Agricultural areas, with sandstone, sand with silt and clay contents and within High rainfall Intensity Areas. The main considerations were accessibility and the environment and therefore satisfied the criteria for locating ground water potential in the study area.

5.2 Conclusion

Ground water potential selection can be accomplished by spatial decisions, spatial decisions typically involve a large set of feasible alternatives. Remote sensing and GIS has demonstrated its effectiveness through the use of remotely sensed data in providing the necessary spectral and spatial information for generating information layers for mapping ground water potential. The GIS as a decision-making tool, being facilitated, combined various information layers as well as implementing the necessary analysis on the data, although the GIS methodology makes the decision-making process more objective, there is still an element of subjectivity associated with the allocation of map weights and scaling. This also allows flexibility to the planners to incorporate varying degree of importance to each criterion based on their experience.

The study was able to apply spatial decision making in using the different criteria available to map ground water potential in Awka South LGA. The study located Twenty-five sites satisfying all siting criteria where ground water potential is high, with all sites satisfying and exhibiting the best balance between all established criteria.

5.3 Recommendation

Throughout the course of this research, our primary objective was to deliver a robust and comprehensive analysis of the available data. Nevertheless, it is crucial to acknowledge that certain inherent limitations were encountered in this study, particularly the absence of field validation. Therefore, we recommend the following actions for any future research endeavors concerning groundwater potential in this region:

1. To enhance the reliability and accuracy of the findings, it is strongly advised that subsequent studies include field validation. Field visits and assessments should be conducted to corroborate the data obtained from geospatial techniques with real-world observations. This validation process should involve the measurement of actual groundwater levels in existing boreholes within the study area.
2. In addition to field validation, conducting hydrogeological surveys is recommended. These surveys should encompass a thorough investigation of the geological characteristics, aquifer properties, and groundwater flow dynamics in the study area. Such data will provide valuable insights into the local hydrogeological conditions and help refine the accuracy of groundwater potential assessments.
3. Establishing a long-term groundwater monitoring network is advisable. This will allow for continuous data collection, tracking changes in groundwater levels over time, and assessing the sustainability of groundwater resources in the study area. Regular monitoring is vital for making informed decisions and adapting strategies as conditions evolve.

4. Future research should consider employing multi-criteria decision-making analysis to evaluate various factors influencing groundwater potential. This holistic approach can provide a more nuanced understanding of the interplay between geological, hydrological, and environmental factors that affect groundwater availability.

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