Analyzing the Efficacy: A Comparative Study Between the Conventional AHP Model and Fuzzy- AHP Model for Groundwater Potentiality Prediction in Basement Terrain Using Geophysical Data Sets

Raheem Bodunde Salau*, Kehinde Anthony Mogaji

Department of Applied Geophysics, Federal University of Technology, Akure

***Corresponding Author**

DOI: https://doi.org/10.51244/IJRSI.2025.120800399

Received: 16 September 2025; Accepted: 24 September 2025; Published: 18 October 2025

ABSTRACT

This study integrates geophysical, geological, and remote sensing techniques to evaluate groundwater potential in the basement complex terrain of southwestern Nigeria, an area where sustainable groundwater development remains a critical challenge. To produce a comprehensive groundwater potential map, eight thematic layers known to influence groundwater occurrence and movement were derived from the available datasets. These include lithology, slope, recharge rate, lineament density, aquifer transmissivity, hydraulic conductivity, overburden thickness, and aquifer resistivity. Each parameter was carefully analyzed and weighted to reflect its relative significance in groundwater occurrence. The mapping process employed both the Analytical Hierarchy Process (AHP) and its advanced fuzzy-based extension (FAHP) to compare the performance of conventional and modified multi-criteria decision-making techniques. The integrated analysis delineated the study area into five distinct groundwater potential zones, namely very high, high, moderate, low, and very low. These classes provided a spatial framework for understanding the variability of groundwater occurrence across the region.

Validation of the models was carried out using the Receiver Operating Characteristics (ROC) curve approach. The FAHP-based groundwater potential model achieved a prediction accuracy of 81%, demonstrating a marked improvement over the conventional AHP model, which yielded 73%. Additional qualitative validation was conducted by correlating the FAHP-generated groundwater potential zones with the geological and hydrogeological attributes of the study area. The comparison revealed a high level of agreement of approximately 90%, confirming the robustness of the FAHP approach in capturing actual field conditions.

Overall, the findings highlight the effectiveness of integrating FAHP with geophysical, geological, and remote sensing datasets for reliable groundwater potential assessment in basement terrains.

Keywords: Groundwater potential, Geophysics, Remote sensing and GIS, AHP, FAHP

INTRODUCTION

Groundwater refers to water stored within subsurface aquifers, occupying pore spaces in rocks. It serves as a dependable source of water, particularly in remote areas where the development of surface water is limited (Adeyemo et al., 2017). However, increasing population growth and rapid urbanization have placed significant pressure on groundwater resources, posing challenges to their sustainable management.

In basement terrains, groundwater exploration typically targets aquifers within the weathered overburden or fractured crystalline rocks, especially those of Precambrian origin (Omosuyi et al., 2003). These crystalline rocks often contain fractures and fault zones formed by past tectonic activities. The identification and mapping of such hydrogeologic features are crucial for delineating groundwater-bearing zones in basement settings (Omosuyi, 2010). While fractured crystalline bedrocks can yield potable water, achieving high-yielding wells remains difficult due to the heterogeneity of fracture systems across regional scales. Groundwater occurrence in these formations is largely controlled by secondary porosity and permeability generated through weathering and fracturing. In hard rock environments, the subsurface profile generally consists of fresh bedrock overlain by an overburden or regolith, which is further divided into aeration and saturation zones separated by the water table (Omosuyi et al., 2012).

Effective groundwater management requires the application of remote sensing and geophysical methods to evaluate groundwater potential at both local and regional scales. As noted by Jyrkama and Sykes (2007) and Kaliraj et al. (2013), understanding groundwater recharge processes is fundamental to sustainable groundwater use. In Nigeria, groundwater remains a critical resource for domestic, agricultural, and industrial purposes, making its evaluation and sustainable exploitation essential (Ouedraogo et al., 2016; Yousefi et al., 2018). With the pressures of population growth, urban expansion, and climate change, groundwater resource management has become indispensable for ensuring both the quantity and quality of supply, especially in urban and semi-urban regions (Ouedraogo et al., 2016).

This study highlights the significance of geophysics in evaluating groundwater potential. Groundwater is located within cracks and pore spaces in subsurface, stored and flowing gradually through geologic formations like sediment, sand and rocks known as aquifer (Alabi et al., 2010). These geologic formations are precisely mapped or delineated using geophysical techniques for potential groundwater development. Among the various geophysical methods utilized in groundwater hydrology, the Electrical Resistivity Method (ERM) stands out to be most favoured approach (Alabi et al. 2010). Some of the techniques in ERM is the Electrical Resistivity Tomography (ERT) are the 3-D ERT, 2-D ERT and 1-d ERT to name a few. For the purpose of this research and based on availability, preference will be given to 1-D Electrical Resistivity Tomography (ERT) over other methods. 1-D ERT can also referred to as Vertical Electrical Sounding (VES). VES is commonly used due to its efficiency in mapping potential groundwater zones in comparison to other geophysical techniques (Oyedele et al., 2013). VES measurements are valuable in groundwater studies as they do not disturb the soil structure or dynamics (Adiat et al., 2009; Ariyo and Adeyemi, 2009). Various field configurations (arrays) are used to achieve VES techniques. There are roughly one hundred independent geo-electric arrays (Szalai and Szarka, 2008), but the Schlumberger array is set up to be more suitable and common in groundwater delineation.

Among the various geophysical techniques, the magnetic method is considered one of the most adaptable since it can be utilized for investigating both shallow and deep subsurface features (Dobrin and Savit, 1988). In groundwater exploration, it has gained prominence as an effective approach for detecting structural features such as faults, joints, and fracture zones, which often act as conduits for groundwater accumulation and storage (Al-Gharni, 2005; Abdulkareem et al., 2018; Oni et al., 2020). Recent improvements in magnetic survey acquisition and processing have further enhanced its application, particularly when integrated with Geographic Information Systems (GIS) for better interpretation (Oni et al., 2020). In this study, derivative aeromagnetic map (Lineament density) will be incorporated as thematic layers alongside other datasets to improve the delineation of groundwater potential zones.

The employment of Geographic Information System (GIS) and Remote Sensing (RS) techniques in the field of groundwater hydrology has proved excellent in the decision making process (Rahmati and Meselle, 2015 Rahmati et al., 2015; Manap et al., 2014). This is adduced to the fact that there is easy and quick access obtainable from satellite data base archive (Zare et al., 2013). For the driver of the proposed models in this study, the efficacy of geospatial techniques (RS and GIS) will be employed.

Various statistical decision-making models have been applied to interpret Vertical Electrical Sounding (VES) data in groundwater studies. Among these, Multi-Criteria Decision Analysis (MCDA) methods have gained prominence for assigning weights to parameters based on prior research (Chowdhury et al., 2009; Adiat et al., 2012; Mogaji & Lim, 2016). The Analytical Hierarchy Process (AHP) is one of the most widely used MCDA techniques, offering a structured framework for complex decision analysis through pairwise comparisons and expert judgment (Saaty, 1987). Despite potential subjectivity and inconsistency, AHP has been effectively employed in groundwater hydrology (Mogaji et al., 2017; Akinlalu et al., 2017).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

FAHP method systematically solves the selection problem that uses the concepts of fuzzy set theory and hierarchical structure analysis. Basically, FAHP method represents the elaboration of a standard AHP method into fuzzy domain by using Fuzzy numbers for calculating instead of real numbers.

In order to have a robust research, the FAHP based model will be applied in modeling the groundwater potentiality of the study area. The FAHP model will be used to integrate the derived parameters from the surface and subsurface source (lineament, lithology, slope, aquifer transmissivity, hydraulic conductivity, overburden thickness, aquifer resistivity and recharge rate) with the view of obtaining potentiality index which will help in categorizing the groundwater condition of potentiality the study area.

Methodology, study area and data used

METHODOLOGY

As indicated in Fig. 1, the study was carried out in four stages, employing geology, remote sensing, and geophysical data. The first stage required collecting, processing, and interpreting remote sensing, geology and geophysical characteristics for the groundwater potential evaluation. Following that, thematic maps of the conditioning factors were created in ArcGIS, and uniformly spaced fishnet points were placed to extract pixel values at those points. The third stage involved the use of FAHP and AHP for the development of groundwater potential index which was synthesized in GIS environment to produce the groundwater potential model maps of the study area. Finally, the models produced were validated using Receiver Operating Characteristics (ROC) to determine the efficacy of FAHP and AHP models in groundwater potential prediction.

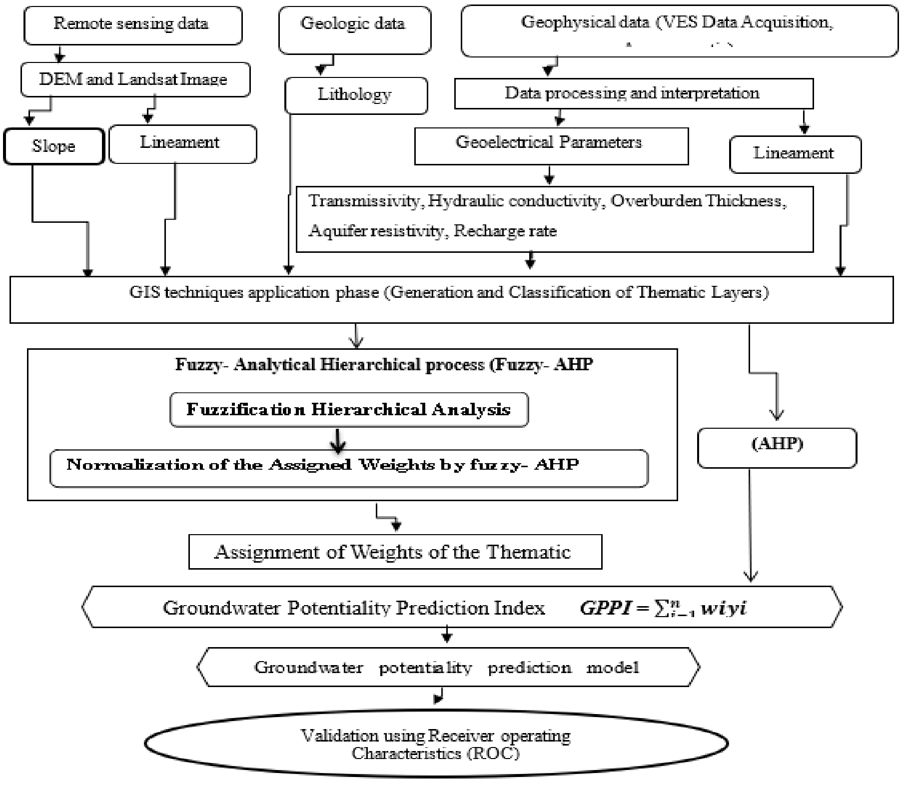

Fig. 1: The Flowchart for the Study Area

Description Of The Study Area

The study area is located at the southwestern part of Ado Ekiti, Ekiti State, Nigeria, as shown in Fig. 2. It falls within geographic grids extending between 5°10´0´´ to 5°13´0´´ (Eastings) and 7°36´0´´ to 7°38´30´´ (Northings). Ado-Ekiti is bounded by Ilawe at the West, Gbonyin at the east, Ikere at the North and Iyin at the South as shown in Fig. 2. The total area of the study area is about 6.6 square-km. The study area has the surface elevation ranging from 415 to 536 m above sea level. The western part of the study area is exhibited with high elevation while northern part exhibited low elevation.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

Ado Ekiti enjoys a tropical climate with two distinct seasons. These are the rainy season (April – October) and the dry season (November – March). Temperature ranges between 21ºC and 30ºC with high humidity. The guinea savanna predominates in the study area. The study area is underlain by the Precambrian basement complex of South-western, Nigeria (Rahaman, 1988). The lithological/rock units recognized in the area include Charnokite, Migmatite–gneiss and Quartzite. More than 45% of the area is underlain by Quatzite. Fig. 3 shows the geology map of the area.

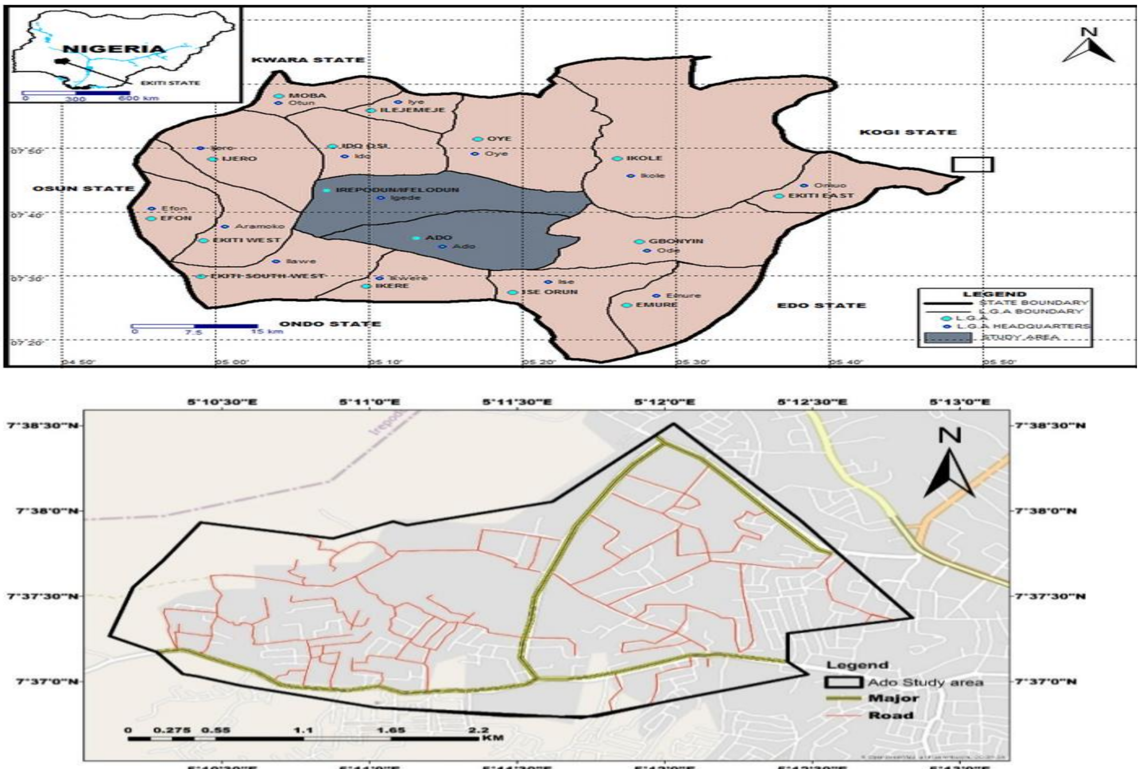

Fig. 2: Base Map of the Study Area

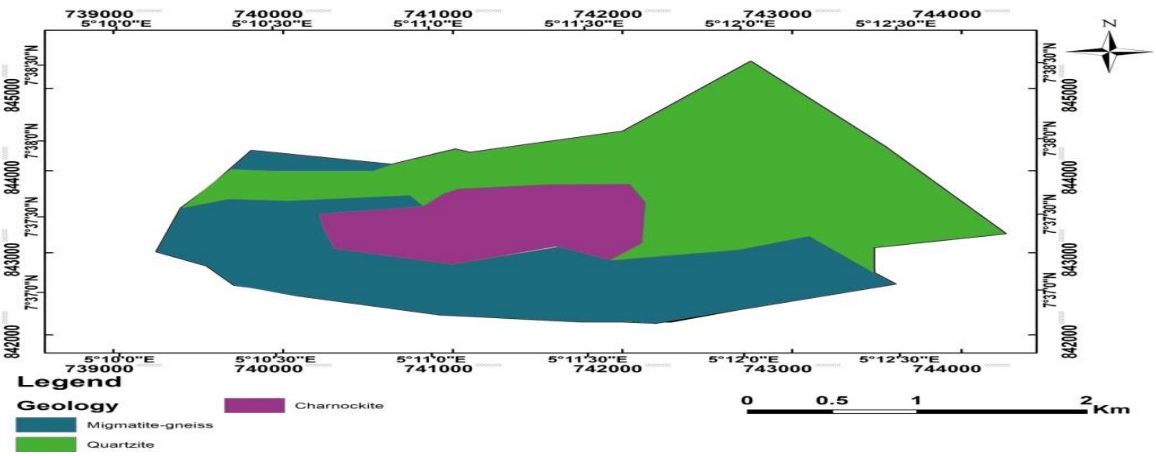

Fig. 3: Geologic Map of the Study Area

DATA USED

Lithology

The lithology map used in the research was derived from geological survey conducted in the study area. An important hydrologic factor that affects the groundwater quantity in a specific region is lithology. In areas with hard rock terrain, the underlying rocks are often brittle and prone to fracturing, leading to increased water flow,

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

accumulation, porosity, and permeability in the weathered and fractured basement of the rock units. The Euclidean function available on the spatial analyst of the ArcGIS software was used to produce the proximity maps of the lithologic units using a buffer of 50 m. The weight, calculated using the FAHP was multiplied with class scores of the proximity map of the lithologic units. The weighted proximity map was subsequently integrated using fuzzy sum operator. The resulting map was thereafter fuzzified using the fuzzy membership function large to produce the fuzzified lithologic map of the study area. This tool converts the crisp lithology map into a fuzzy lithology map by selecting the lithology class with the highest degree of membership at each pixel. Fig. 4 shows the fuzzified lithologic map of the study area.

Remote Sensing

A Digital Elevation Model (DEM) was downloaded from the United States Geological Survey USGS through (https://asterweb.jpl. nasa.gov/gdem.asp, last access: 20 November 2019) with a spatial resolution of 15 m. The Digital Elevation Model (DEM) data was imported into the ArcGIS environment (ArcGIS 10.3). The ArcTool box on the ArcGIS 10.3 has various spatial tools for producing various groundwater conditioning factors from the DEM. In this research work, the slope was extracted from the DEM and the lineament was extracted from the Landsat Imagery.

Slope Degree

The slope degree indicates the extent of surface runoff, which varies across different locations. This gradient significantly impacts potentiality, areas with lower slope degrees experience reduced runoff and enhance water infiltration, whereas it is vice versa for areas with high slope degree (Ouedraogo et al., 2016). This factor will be derived from the ASTER digital elevation model (DEM) data of the study area using the slope analysis tool in ArcGIC 10.3 software package.

Lineament Density

In this study, remote sensing was utilized to extract lineaments from LANDSAT 8 imagery covering the study area. These extracted lineaments were then integrated with aeromagnetic lineament data, and both datasets were superimposed in ArcGIS to produce a composite lineament map. A common approach for analyzing such features is through the development of lineament density maps (Zakir et al. 1999).Equation (i) expresses the Ld definition mathematically:

$$Ld = \sum_{i=1}^{i=n} \frac{Li}{A} \, (Km^{-1}) \qquad \text{i}$$

Where ΣLi = total length of all the lineaments (km) and A = area of the grid (km^2).

Geophysical investigation

Data acquisition and interpretation

The geophysical data in the study area were collected using the electrical resistivity techniques. The Schlumberger array was utilized to collect 55 vertical electrical soundings (VES) data from 1 to 200 m utilizing half-electrode spacing (AB/2). This approach takes into account vertical differences in the apparent resistivity of the ground, which were measured with a fixed centre of the array. The survey was carried out by increasing the electrode spacing around a fixed centre of the array. Electrodes are positioned in a straight line, with a pair of potential electrodes placed between two pairs of current electrodes. In this work, the Global Positioning System (GPS) was utilized to spatially identify VES sites for spatial analysis in a GIS setting. The apparent resistivity of the VES data is the product of the resistance and the matching geometric factor (G) of the electrode spacing for each spread length (AB/2). On a log–log graph sheet, these apparent resistivity values were plotted against the electrode spacing. The VES curves that were generated were displayed and divided into types. These classifications demonstrate the qualitative character of subsurface lithology. In addition, quantitative interpretations of the partial curve matching findings, which are the layer thickness and layer resistivity, were determined. The results were entered into the WinResistTM Software as model parameters

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

(Vander-Velper 2004). The theoretical model curve, the primary geoelectric parameters (layer resistivity, layer thickness), and the depth to the top of each layer provide good insight into the aquifer's subsurface information, which is vital for groundwater potential research. Fig. 4 and Table 1 show typical curves depending on underlying geology and a summary table representation of geoelectric characteristics respectively.

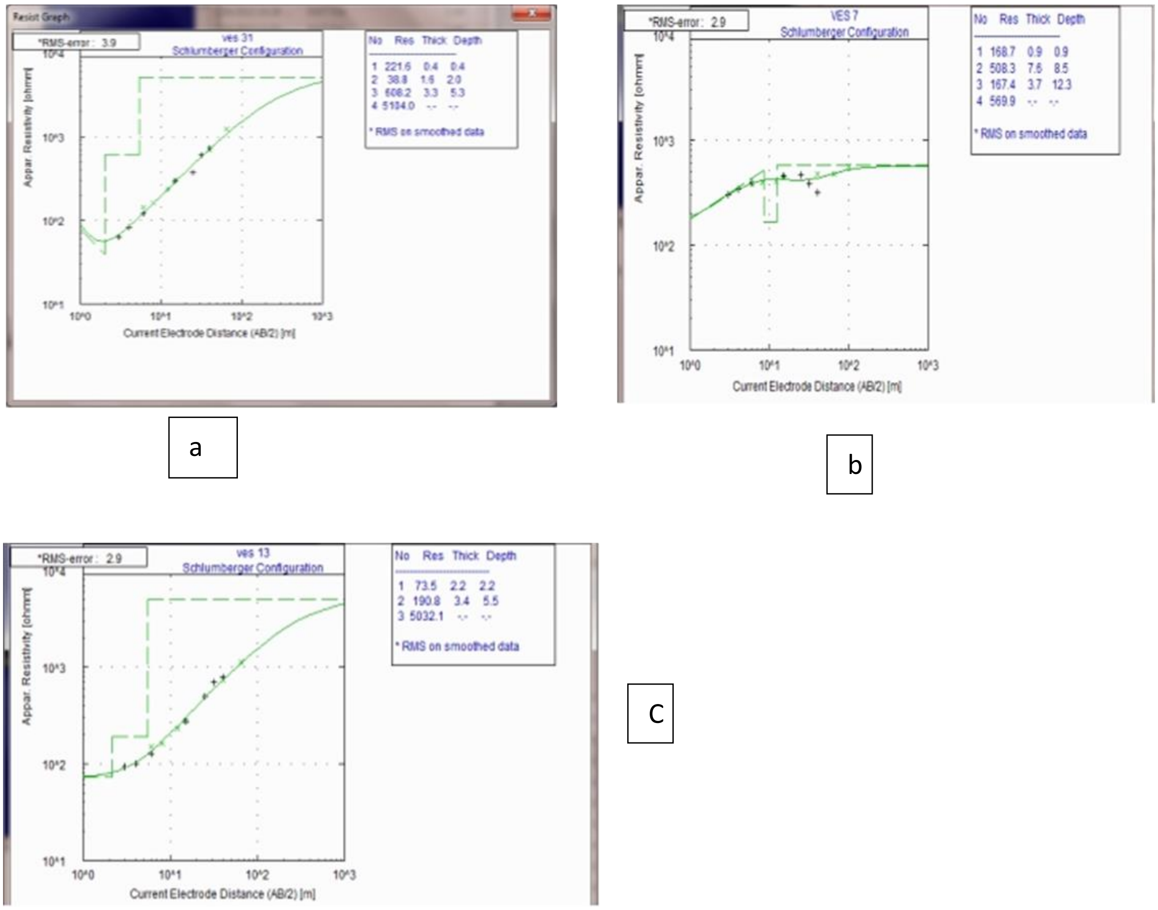

Fig. 4: Typical resistivity model curves obtained in the study area; a. charnockite, b. quartizite series and c. migmatite gneiss rock unit.

Table 1: Summary of the interpreted results Geoelectric parameters.

VES Pt	Curve	Layer	Apparent Resistivity (Ωm)	Thickness (m)	Depth (m)	Layer Description
1	AA	1	64	0.5	0.5	Top soil
		2	37	1.8	2.3	Clayey layer
		3	534	3.2	5.5	Weathered basement
		4	748	….	…..	Fresh Basement
2	HA	1	152	0.6	0.6	Top soil
		2	72	2.6	3.2	Clayey layer
		3	432	5.2	8.4	Weathered basement
		4	719	----	….	Fresh Basement

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

3	A	1	43	1.4	1.4	Top soil
		2	251	8.2	9.6	Weathered basement
		3	700	----	----	Fresh bedrock
4	HA	1	238	0.6	0.6	Top soil
		2	55	1.9	2.5	Clayey layer
		3	571	4.4	7.0	Weathered basement
		4	953			Fresh bedrock
5	HA	1	212	0.4	0.4	Top soil
		2	56	2.2	2.6	Clayey layer
		3	567	2.9	5.5	Weathered basement
		4	863	----	----	Fresh bedrock
6	KH	1	204	1.0	1.0	Top soil
		2	453	5.4	6.4	Sandy Layer
		3	281	4.7	11.1	Weathered basement
		4	509	…..	……	Fractured basement
7	KH	1	169	0.9	0.9	Top soil
		2	508	7.6	8.5	Sandy Layer
		3	167	3.7	12.3	Weathered basement
		4	570	…..	…..	Fresh basement
8	KH	1	143	0.7	0.7	Top soil
		2	534	5.8	6.5	Sandy Layer
		3	257	4.3	10.8	Weathered basement
		4	503	…..	…..	Fractured basement
9	?	?	?	?	?	?

55	KH	1	169	1.1	1.1	Top soil
		2	1261	7.3	8.4	Laterite
		3	403	2.6	10.9	Weathered basement
		4	641	----	---	Fresh bedrock

The derived secondary geoelectric parameters

The primary geoelectric parameters, layer resistivity and layer thickness, were utilised to determine the secondary geoelectric parameters, which are important conditioning variables in delineating groundwater potential zones in the research region. The validation method takes into account hydraulic conductivity (*K*), aquifer transmissivity (*T*), recharge rate (R), aquifer resistivity (AQR) and overburden thickness (OVT). The primary geoelectric characteristics in Table 1 were analysed using Eqs. ii - iv, to generate the aforementioned groundwater conditioning factors.

Table 2 displays the values of the calculated *K*, *T*, *R*, AQR and OVT parameters. Hydraulic conductivity, K (m/day), is given by:

$K = 0.0538e^{-0.0072\rho}$ ii

Where, ρ is the resistivity of the aquifer.

Transmissivity, $T=K\times h$ iii

Where K is the hydraulic conductivity as shown in equation 3.

Recharge rate, $R = 34.41\log10(\rho) + 1.05(D) + 128.38$ iv

Where D is the depth (m) to the aquifer.

Table 2: Summary of interpreted geo-electric parameters.

Ves No	Northing	Easting	TR	K	AQR	R	OVT
1	843014.4	739710	0.00267	0.001151	534	189.4053	5.5
2	843015	739893	0.007675	0.002399	432	202.2536	8.4
3	842738	739803	0.012361	0.008829	251	204.4274	9.6
4	843200	843200	0.002204	0.000882	571	205.4804	6.9
5	842770.9	740171	0.02467	0.009488	241	204.3037	5.5
6	843554.6	743202	0.04553	0.007114	281	221.694	11.1
7	8436615	739615	0.137406	0.016165	167	224.3471	12.2
8	843783	739951	0.054964	0.008456	257	222.2471	10.8

9	843848	740594	0.076545	0.011776	211	223.5768	10.2
10	844065	740961	0.086678	0.012747	200	219.3848	10.2
11	844060	739950	0.00326	0.002138	448	185.0819	4.3
12	844062	740256	0.033528	0.02794	91	184.7669	2.9
13	843355	740352	0.02992	0.0136	191	195.0103	5.6
14	843171	740383	0.008392	0.001785	473	199.3505	8.2
15	843295	740659	0.008141	0.001661	483	194.46	8.3
16	843574	740994	0.005278	0.001056	546	194.565	9.2
17	843151	742499	0.041911	0.02794	91	192.5655	8.4
18	843205	740996	0.001974	0.000581	629	185.9118	6.8
19	842992	741427	0.009335	0.001638	485	195.6752	9.4
20	843416	740290	0.025895	0.019919	138	165.5793	3
21	843384	739984	0.007605	0.001358	511	196.0562	10.5
22	842376	741092	0.005888	0.004206	354	207.7009	4.3
23	842741	740477	0.001563	0.000489	653	196.2609	6.2
24	842742	740600	0.001321	0.000426	672	194.5813	6.6
25	842775	740998	0.029871	0.018669	147	171.4938	3.7
26	842654	741428	0.03241	0.019077	144	174.1669	4.2
27	842963	741733	0.001518	0.000399	681	200.0249	7.1
28	842435	740632	0.002352	0.001176	531	198.7676	5.4
29	842315	741338	0.001781	0.000775	589	203.1279	6.2
30	842472	741981	0.003177	0.001513	496	199.3301	5.8
31	842718	741980	0.001351	0.000675	608	203.2208	5.3
32	842784	742807	0.001339	0.000638	616	203.5539	5.5
33	842107	742566	0.000747	0.000356	697	203.5539	5.6
34	843545	741332	0.013055	0.010879	222	179.9611	3.3
35	843208	741548	0.001085	0.000329	708	211.1721	6.9
36	843391	741425	0.001164	0.000388	685	211.1139	6.5
37	843485	741731	0.001203	0.000388	685	214.4147	7.4

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

38	843485	741731	0.001787	0.000577	630	208.516	6.6
39	843364	742099	0.002105	0.000726	598	209.5591	6.5
40	843155	743357	0.026745	0.003222	391	236.0358	11.9
41	843492	743018	0.055988	0.006912	285	236.545	12.5
42	843458	742497	0.148678	0.022191	123	224.3159	12.7
43	844441	742308	0.087321	0.012655	201	226.4954	11.1
44	844376	741421	0.110649	0.018139	151	221.3562	12.3
45	843916	741790	0.12449	0.0211	130	218.3118	10.8
46	844378	742063	0.024873	0.003316	387	209.4487	11.1
47	844903	742521	0.005312	0.000435	669	243.5218	14.3
48	844535	742707	0.04185	0.004267	352	236.97	13.3
49	844228	742800	0.037767	0.004392	348	237.1551	12.7
50	845058	742827	0.018811	0.002138	448	237.0794	12.1
51	844875	743011	0.061076	0.006863	286	236.606	13.9
52	844507	743228	0.138785	0.015594	172	225.1593	17.2
53	844139	743322	0.118125	0.013897	188	224.7177	16.5
54	843710	743692	0.043847	0.00522	324	236.0309	16.7
55	843404	743908	0.024826	0.002956	403	235.4167	11

Groundwater potentiality conditioning factors

Groundwater potentiality conditioning factors and production of their thematic layers in the GIS environment. The groundwater potential of the research was evaluated using eight (8) factors: lithology, hydraulic conductivity, lineament, aquifer transmissivity, recharge rate and slope. Thematic maps of these factors were generated using Arc- GIS 10.3's inverse distance weighting (IDW) approach, and data from Table 2 were utilized to develop the geo-electrically linked thematic layers; hydraulic conductivity, overburden thickness, aquifer transmissivity, aquifer resistivity and recharge rate are displayed in Figs. 8, 9, 10, 11, and 12, respectively.

The groundwater potential conditioning factors (GPCFs) thematic maps shown in Figs. 5, 6, 8, 9, 10, 11 and 12. These factors were used as decision making to create AHP the FUZZY AHP groundwater potentiality model of the research region. The fishnet point map was created for ease of computation to ensuring uniformly dispersed fishnet points (Fig. 13) over the study area.

MODELS REVIEW

The Analytical Hierarchy Process

Thematic map weighting was performed using the Analytic Hierarchy Process (AHP), a widely applied GIS-based multi-criteria decision analysis (MCDA) technique for delineating groundwater potential zones

(Arulbalaji et al., 2016). Eight factors were considered in this study: lithology, slope, recharge rate, lineament, aquifer transmissivity, hydraulic conductivity, overburden thickness, and aquifer resistivity. These parameters directly influence groundwater storage and movement in the area. AHP, introduced by Saaty (1987), remains the most widely adopted MCDA approach, with successful applications reported in geological and groundwater investigations (Adiat, 2013; Fashae et al., 2014; Mogaji et al., 2014).

Mathematical Model of AHP

If there are n elements which are compared, the comparison results create matrix form A with dimension n x m.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \quad \text{v}$$

The elements of matrix, or ratio between compared criteria are expressed by the formula:

$$\tilde{a}_{ij} = \frac{wi}{wj} \quad \text{vi}$$

Considering the first axiom for reciprocal we have:

$$a_{ij} = \frac{1}{aij} \quad \text{vii}$$

The next step is to obtain a normalized matrix **B** = [$\boldsymbol{b_{ij}}$]. The elements of the matrix B are calculated as:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \text{viii}$$

The calculation of the weights i.e. eigenvector $\boldsymbol{w = [w_i]}$ form the normalized matrix B is performed by calculating the arithmetic mean for each row of the matrix according to the formula:

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \quad \text{ix}$$

Fuzzy–Analytical Hierarchical Process (FAHP)

Despite its wide range of applications, the conventional AHP approach may not fully reflect a style of human thinking. One reason is that decision makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values. As a result, FAHP and its extensions are developed to solve alternative selection and justification problems. The FAHP is a popular technique which has been applied for MCDM problems (Abedi et al., 2013; Wu et al., 2013). This method was proposed by Van Laarhoven and Pedrycs (1983). In the fuzzy extension of AHP, the weights of the nine-level fundamental scales of judgments are expressed via the triangular fuzzy numbers (Table 3) in order to represent the relative importance among the hierarchy criteria (Karimi et al., 2011).

Weighting of the thematic maps was carried out using the Fuzzy Analytical Hierarchical Process (FAHP). This method helps in integrating all the eight (8) different thematic factors for this research; the thematic factors include lithology, slope, recharge rate, lineament, aquifer transmissivity, hydraulic conductivity, overburden thickness and aquifer resistivity. The eight thematic factors influence the movement and storage of water in the area. Thus equation (xi) is used to weight the importance of each criteria.

The weight vector is then given by:

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

$$W' = \left(d'(B_1),\ldots,d'(B_m) \right)^T \qquad \text{x}$$

Where Bi(i=1,…,m) has m elements.

Calculate normalized weights

Via normalization, the normalized weight vectors are:

$$W = \left(d(B_1),\ldots\ldots, d(B_m) \right)^T \qquad \text{xi}$$

Where W is a non-fuzzy number. As pointed out by Wang et al., (2008).

Table 3: Fuzzy linguistic scale (Radionovs and Užga-Rebrovs, 2016)

Linguistic scale	Triangular fuzzy scale	Reciprocal
Just equal	1, 1, 1	1, 1, 1
Equally important	1/2, 1, 3/2	2/3, 1, 2
Weakly more important	1, 3/2, 2	1/2, 2/3, 1
Strongly more important	3/2, 2, 5/2	2/5, 1/2, 2/3
Very strongly more important	2, 5/2, 3	1/3, 2/5, ½
absolutely more important	5/2, 3, 7/2	2/7, 1/3, 2/5

Table 4: Ratings, groundwater storage potential type- classification, AHP and FAHP weight of the GPCF produced thematic layers.

Lithology	High	Quatzite	0.2623	0.19655
	Medium	Charnockite		
	Low	Migmatite Gneiss		
Aquifer Resistivity	Very High	91 - 258Ωm	0.1958	0.16501
	High	258 - 345Ωm		
	Medium	345- 441Ωm		
	Low	441- 543Ωm		
	Very Low	543 - 708Ωm		
Lineament	Very High	0.0063- 0.0084	0.1566	0.14362
	High	0.0046- 0.0063		
	Medium	0.0029- 0.0046		
	Low	0.0009 – 0.0029		
	Very Low	0- 0.00099		

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

Hydraulic Conductivity	Very High	0.0164- 0.0279m/day	0.1203	0.12453
	High	0.0112- 0.0164m/day		
	Medium	0.0076- 0.0112m/day		
	Low	0.0044- 0.0076m/day		
	Very Low	0.0003- 0.0044m/day		
Overburden Thickness	Very High	13.5- 17.2m	0.0884	0.11445
	High	10.5- 13.5m		
	Medium	8.4- 10.5m		
	Low	6.4- 8.4m		
	Very Low	2.9- 6.4m		
Recharge Rate	Very High	223.96- 243.52Ltr/d	0.0684	0.10218
	High	210.52- 223.96Ltr/day		
	Medium	200.43- 210.52Ltr/day		
	Low	191.57- 200.43Ltr/day		
	Very Low	165.57- 191.57Ltr/day		
Aquifer Transmissivity	Very High	0.0889- 0.1487m^2/day	0.0633	0.09103
	High	0.0610- 0.0889m^2/day		
	Medium	0.0396- 0.0610m^2/day		
	Low	0.0193- 0.0396m^2/day		
	Very Low	0.0007- 0.0193m^2/day		
Slope	Very High	0- 2.79^o	0.0335	0.06260
	High	2.79- 5.29^o		
	Medium	5.29- 8.56^o		
	Low	8.56- 13.57^o		
	Very Low	13.57- 24.54^o		

RESULTS AND DISCUSSION

Discussion of groundwater potential conditioning factors

Lithology

Lithology plays a crucial role in groundwater accumulation, influencing both its quality and quantity. The study area comprises three major rock units: migmatite gneiss, charnockite, and quartzite schist (Fig. 3). Among them, quartzite exhibits the highest degree of fracturing, whereas charnockite shows the least. The

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

extent of rock weathering significantly affects groundwater potential, rocks with higher weathering capacity generally yield greater groundwater potential. According to the fuzzified lithologic map (Fig. 5), quartzite-dominated zones are associated with high weightage values, migmatite gneiss with medium weightage, and charnockite with medium to low weightage value. Quartzite occupies about 42% of the study area, while migmatite gneiss and charnockite cover the remaining portions.

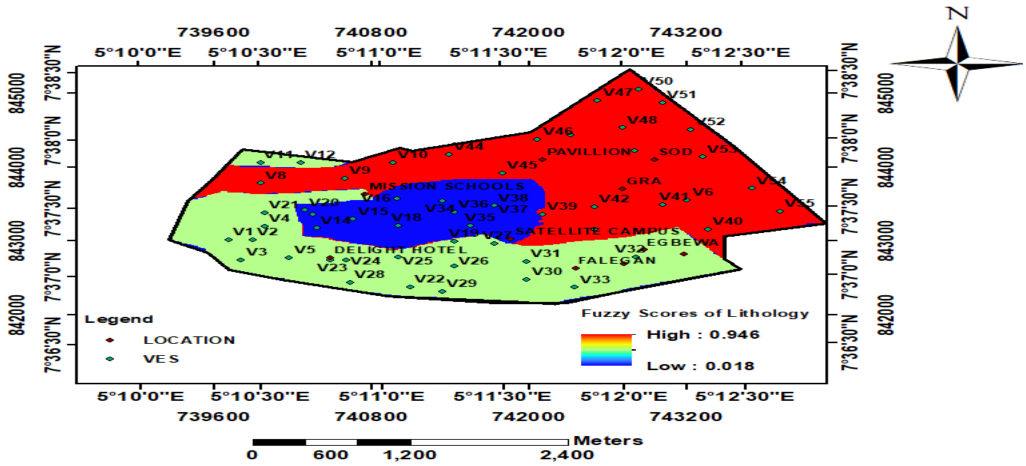

Fig. 5: Fuzzified lithologic map of the study area

Slope Degree

Haujie et al. (2016) reported that groundwater flow is primarily governed by surface forces, with terrain boundaries often coinciding with shallow aquifer limits. Fig. 6 illustrates the slope map generated from remote sensing data and classified into five categories using ArcGIS. Very low (0°–2.79°) and low slopes (2.79°–5.29°) dominate the north-central, central, southern, south-western, and parts of the north-eastern and eastern sectors. Moderate slopes (5.29°–8.56°) occur in the northern, central, eastern, and north-western zones, while high to very high slopes (8.56°–24.54°) are concentrated in the north, north-east, east, and localized pockets of the central and southern regions. Areas with low slope gradients constitute potential groundwater accumulation zones.

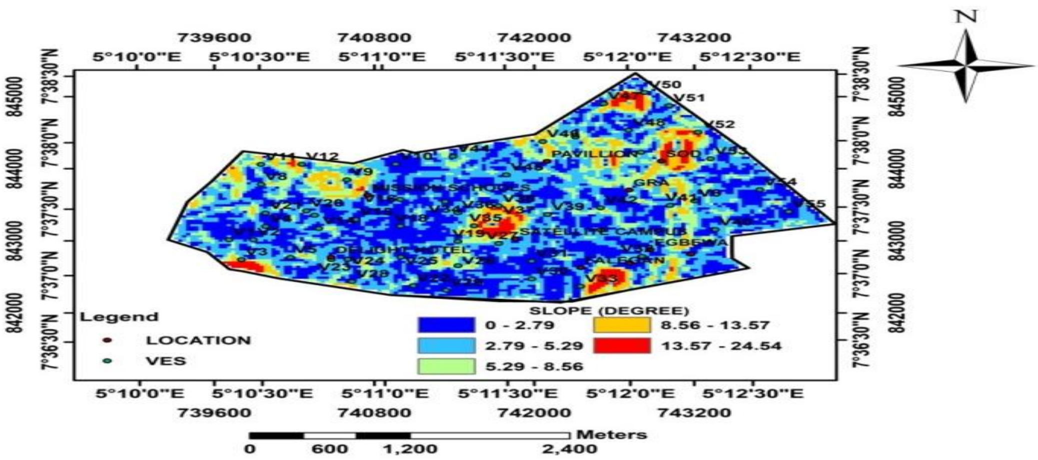

Fig. 6 : Slope Degree map of the study area

Lineament Density

Lineament is defined as observable geomorphic linear features typified weak zones that have characteristic of fissures/joint, fractures and probably weathered formation and can be attributed to geological structures, notably fractures or lithologic contacts (Chowdhury et al., 2009). And it was extracted from aeromagnetic and remote sensing data. The distribution of the lineament density map (Fig. 7) shows that eastern part of the study

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

area is underlain by high to very high density of lineament. However, the zones with high groundwater potential in the study area is due to the occurrence of secondary porosity and permeability developed occasioned zones characterized with high lineament density (Olabode, 2019).

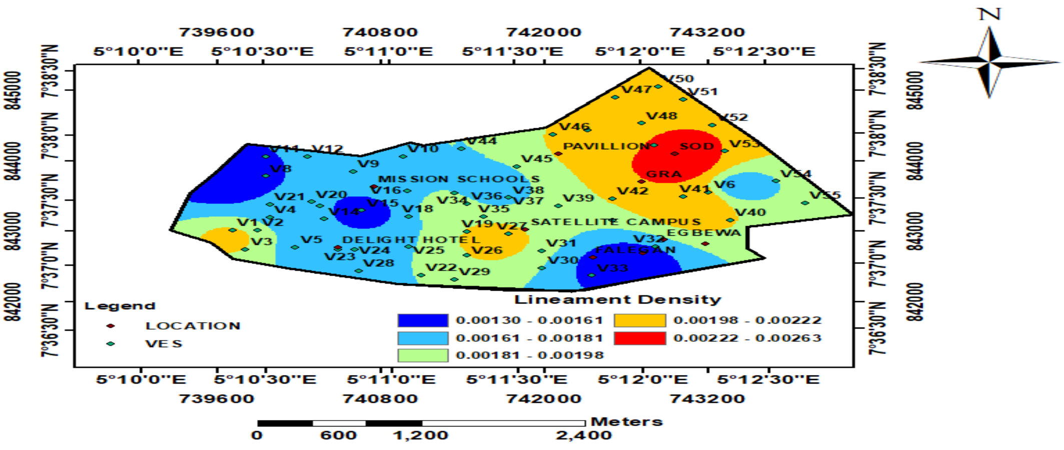

Fig. 7: Lineament Density Map of the Study Area

Hydraulic Conductivity

The hydraulic conductivity is a measure of how easily water can pass or flow through soil or rock. The hydraulic conductivity (Fig. 8) values obtained for the investigated area generally varies from (0.00032-0.0279 m/day) using Eq. 2, and means value of 0.014 m/day. The hydraulic conductivity generated for the investigated area was classified into very low (0.00032-0.0044 m/day), low (0.0044 -0.0076 m/day), moderate (0.0076 - 0.0112 m/day), high (0.0112-0.0164 m/day) and very high (0.0164-0.0279 m/day) hydraulic conductivity. The areas with low and very low hydraulic conductivity characterize low rate at which water moves through the aquifer which results to low groundwater potential and less resilience to droughts and fluctuation in groundwater availability. According to Adeniji et al. (2017) areas with high hydraulic conductivity are most likely to possess good aquifer recharge quality and hence the high groundwater potential. Therefore, in this study, area with moderate, high and very high hydraulic conductivity values are more likely to possess significant groundwater potential.

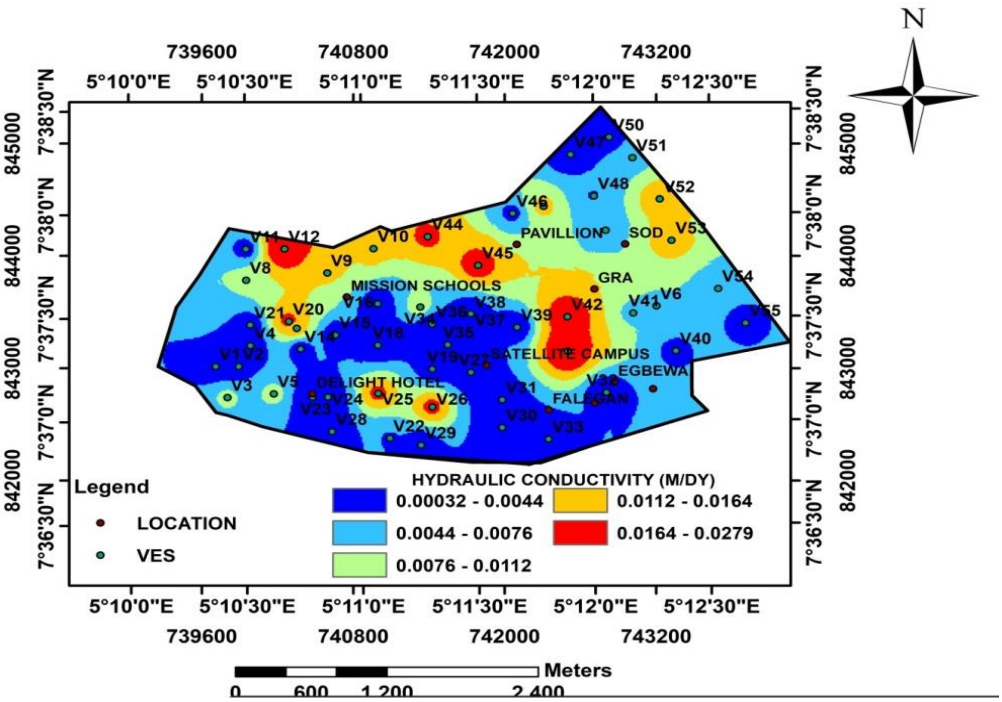

Figure 8: Hydraulic Conductivity map of the study area

Overburden Thickness

Figure 9 reveals that, the overburden thickness values in the study area generally range from 2.9- 17.2 m having a mean value of 10.05 m. Generally, areas with thick overburden values with low percentage of clay content and characterized with expected pronounced inter-granular flow are expected to have high groundwater potential, particularly in Basement Complex terrain (Okhue and Olorunfemi, 1991). Moreover, the weathered layer, the partly weathered/fractured basement and the fractured basement constitutes the major aquifer unit with significant hydrogeologic importance within the study area. Therefore, the zones that are characterized by medium, high and very high overburden thickness values can be considered as prospective zones for possible location of borehole in the study area.

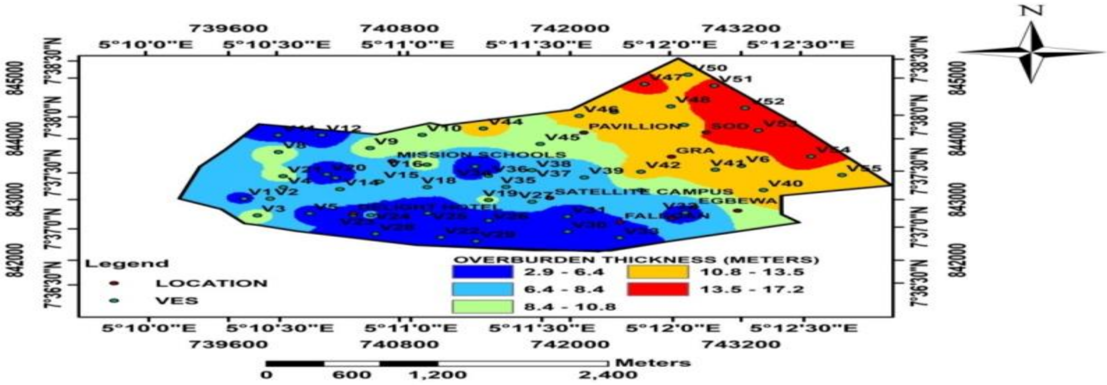

Fig. 9: Overburden Thickness map of the study area

Aquifer Transmissivity

The Aquifer transmissivity is the discharge rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. The Aquifer transmissivity values obtained for the investigated area generally varies from (0.00001644-0.029 m²/day) using Eq. iii, with a mean value of 0.014 m^2/day. The aquifer transmissivity map generated for the investigated area (Fig. 10) was classified into very low (0.000744-0.019 m²/day), low (0.0193-0.0396) moderate (0.0396-0.0610 m²/day), high (0.0610 -0.0889 m²/day), and very high (0.0889-0.1487 m²/day). The areas that are characterized by very low and low characterize the area with low groundwater potential. The regions with moderate high and very high aquifer transmissivity values can be identified as area of high water bearing potential and aquifer materials are known to be relatively permeable to fluid movement (Akintorinwa *et al*. 2020).

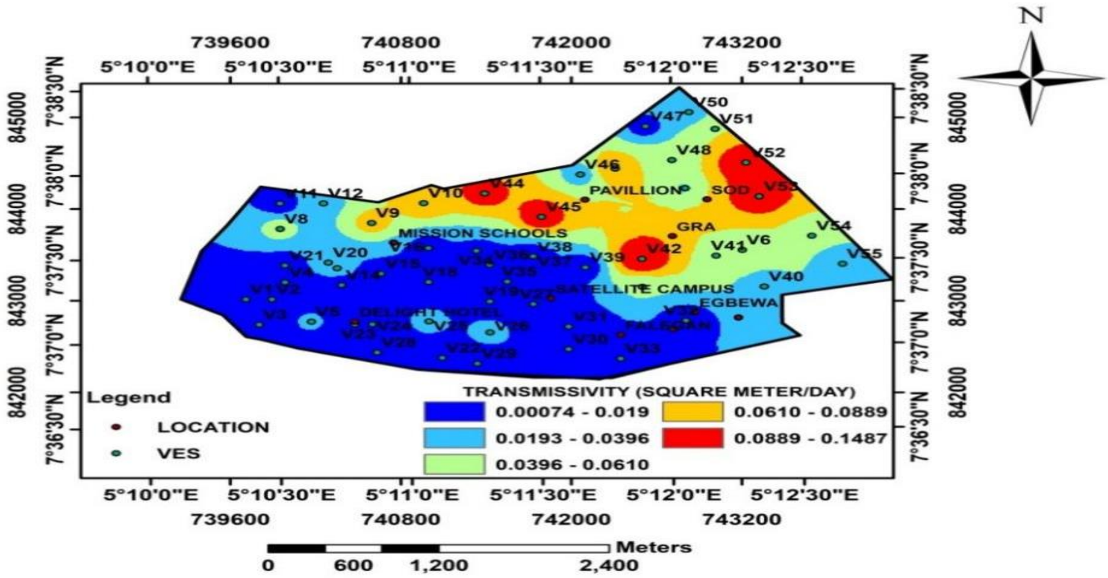

Fig. 10: Transmissivity map of the study area

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

Aquifer Resistivity

The aquifer resistivity map was prepared by determining the resistivity of the aquifer layer. Clay has low resistivity value but generally, areas with low values with low percentage of clay content and characterized with are expected to have high groundwater potential, particularly in basement complex terrain (Okhue and Olorunfemi, 1991). Moreover, the weathered layer the partly weathered/fractured basement and the fractured basement constitutes the major aquifer unit with significant hydrogeologic importance within the study area. Therefore, the zones that are characterized by very low, low and moderate aquifer resistivity values can be considered as prospective zones for high groundwater potential.

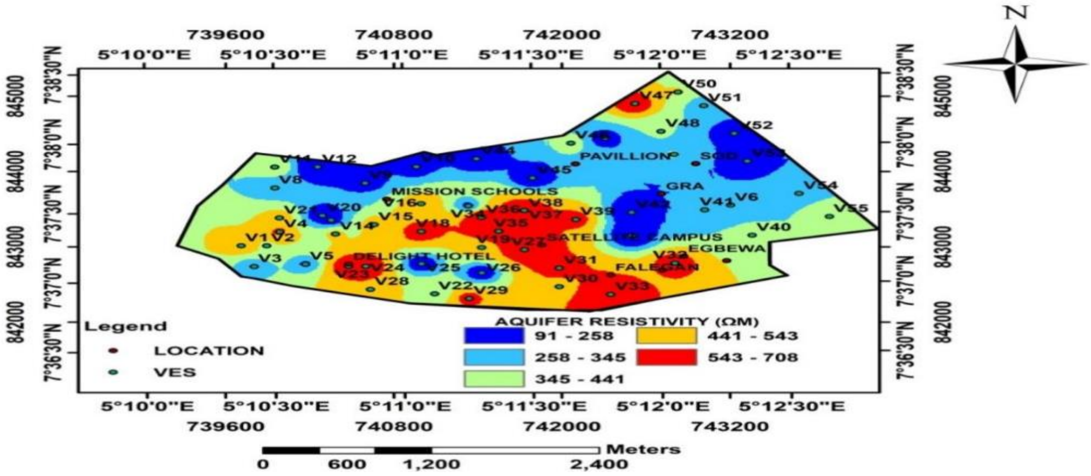

Fig. 11: Aquifer Resistivity map of the study area

Recharge rate map

The recharge rate (R) of an aquifer denotes the quantity of water per unit area that infiltrates the subsurface, either from surface infiltration or accumulated ponded water, and eventually contributes to groundwater storage (Anderson et al., 2015). Aquifers with higher recharge rates are typically associated with greater groundwater potential, as recharge directly influences groundwater availability. Using the values in Table 2, derived from (eqn. iv) (Mogaji et al., 2015), the recharge rate within the study area was estimated to range between 165.57 and 243.52 litres per day. A thematic map of recharge (Figure 12) illustrates the spatial distribution of recharge levels, categorized into five classes: very low, low, medium, medium-high, and high. According to the map, the northern and eastern sections of the study area fall predominantly within the high recharge zone, indicating areas of substantial groundwater potential. Conversely, the southwestern, southern, and parts of the north-central zones are characterized by low to very low recharge, which corresponds to areas of limited groundwater potential (Mogaji et al., 2015).

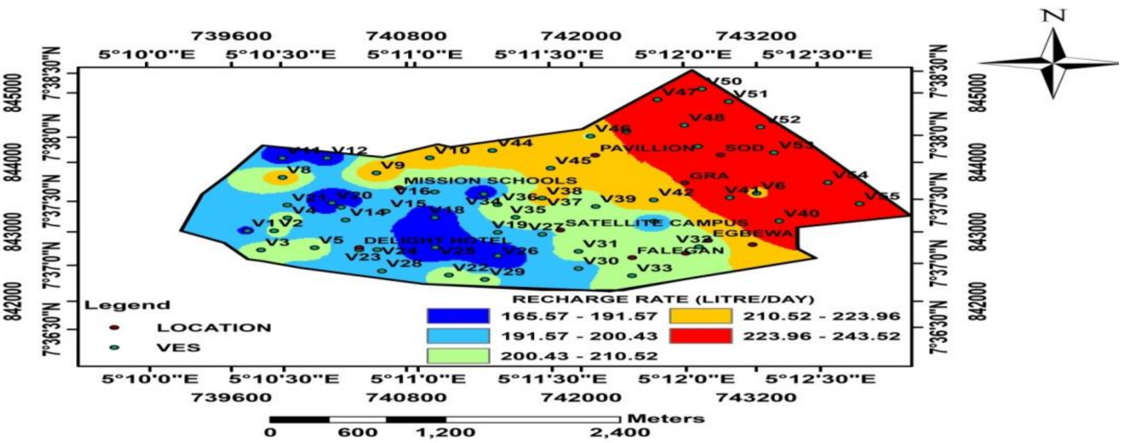

Fig. 12: Recharge rate map of the study area

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

THE AHP AND FAHP RESULTS

Groundwater Potential Map

In order to generate the Groundwater Potential Index Evaluation (GWPE) map for the study area. Eight different thematic analyzed maps comprising Overburden Thickness, Aquifer Resistivity, Lineament Density, Recharge Rate, Hydraulic Conductivity, Aquifer Transmissivity and Slope Degree. The groundwater index for the evaluation for the study area was computed using Eq. xii. The fishnet ensures the evenly distributed of points data on the study area (Fig.13) which the groundwater potential maps for AHP and FAHP models was generated using ArcGis 10.3.

$$GWPI = \Sigma W_i R_i \qquad \text{xii}$$

where W is the weight of parameter 'i' and R is the rating score of parameter 'i'.

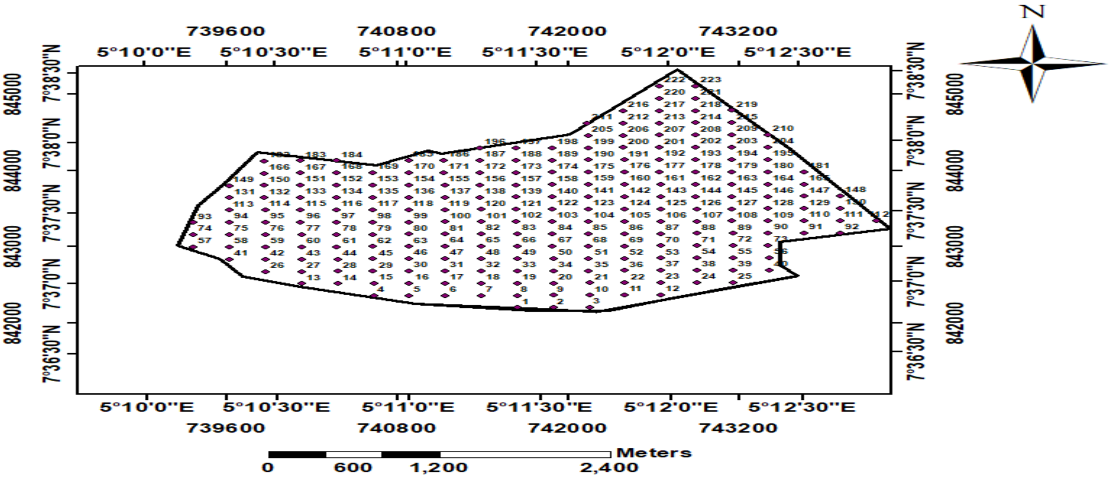

Fig. 13: Fishnet template map of the study area

Groundwater Potential Map Obtained from AHP

The Groundwater Potential Map from Analytical Hierarchy Process is divided into five classes of very low, low, moderate, high and very high in (Fig. 14). The groundwater potential index evaluation map of the study area shows that the very low and the low index values are found to occupy the south, southwest, central and a small portion of the northwestern part of the study area. The moderate class occupies the northwest, central and small portions in the southeast of the study area. The high and very high class of groundwater potential index evaluation is found to occupy the north, northeast and eastern part of the study area. Area with high to very high groundwater potential index values is the probable area for good groundwater potential.

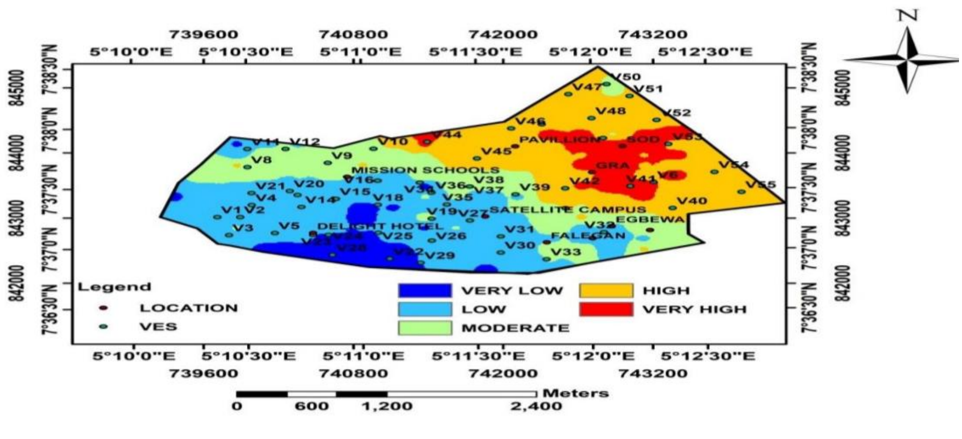

Fig. 14: Groundwater Potential map of the study area from the AHP Model

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

Groundwater Potential Map Obtained from FAHP

The Groundwater Potential Map from Fuzzy Analytical Hierarchy Process is divided into five classes of very low, low, moderate, high and very high (Fig. 15). The groundwater potential index evaluation map of the study area shows that the very low and the low index are found to occupy the south, southwest, central and a small portion of the northwestern part of the study area. The moderate class trend from the northwest to the south through the central and also occupies small portions at the northeastern part of the study area. The high and very high classes of groundwater potential index evaluation is found to occupy the north, northeast and eastern part of the study area. Areas with high to very high groundwater potential index values are the probable area for good groundwater potential.

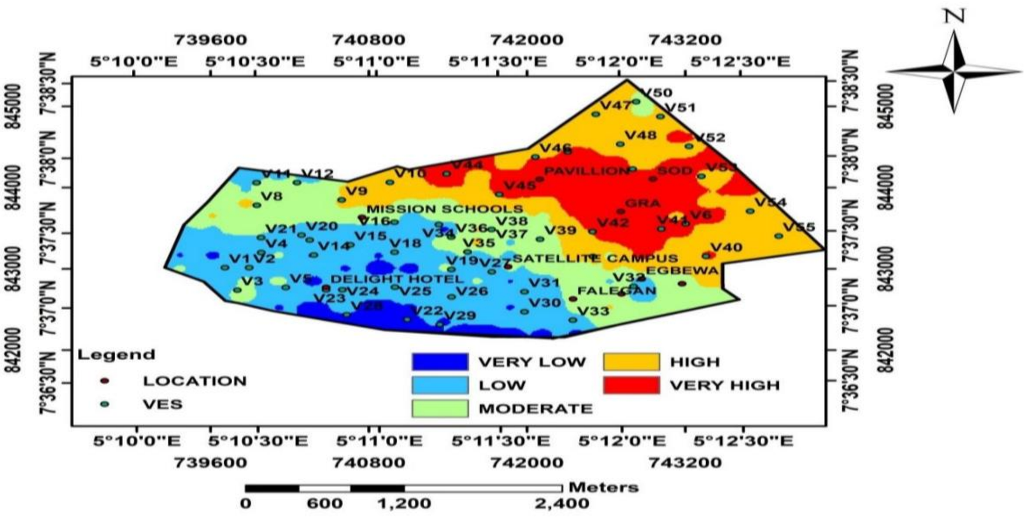

Fig. 15: Groundwater Potential map of the study area from the FAHP Model

Validation and Comparative Analysis of the produced GPM map

In order to test the efficacy and reliabilities of the developed models in this study, validation was carried out on the produced AHP and FAHP based groundwater potential model maps of the study area. The validation was executed qualitatively and quantitatively. The quantitative validation was carried out, using the ROC (Receiver Operating Characteristic) curve. The ROC curve in Fig. 16 is the plot of the false positive rate (FPR) against the true positive rate (TPR). The ROC curve was applied on the AHP and FAHP based groundwater potential model maps. Also, the binary cut-off which states (True (1) or False (0) cut off points (Atenidegbe et.al 2023), with values between 2.9 and 11.3 as True and 1.29 and 2.9 as False, for the determined water column parameter values of the study area. The corresponding values of the predicted groundwater potential index (GPI) were extracted from GPM maps at different cut-point compared with the actual water column values of the study area. The True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN) were determined by the comparison of the water column values with the corresponding GPI values. The TPR (Sensitivity) and FPR (1-Specificity) was computed using eqn. xiii and xiv, respectively. The ROC curve was plotted using python and the Area Under Curve (AUC). The ROC curve prediction accuracy was categorized into five classes (Ekelund, 2011). The categorization is as follows: 0.9 – 1.0 (very good), 0.8 – 0.9 (good), 0.7 – 0.8 (fair), 0.6 – 0.7 (poor) and 0.5 – 0.6 (fail).

Based on the results obtained from this study as shown in figures 16, the AUC value of the prediction rate for the FAHP based model is 0.81 which indicate 81% prediction accuracy while the prediction rate for the AHP based model is 0.73 representing 73% prediction accuracy. It can be concluded that the performance of the developed FAHP based model is 'bet*ter'* compared to the conventional AHP model which performed below the developed one.

The qualitative validation was carried out via correlation of produced groundwater potentiality model maps (FAHP) with geology of the study area.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue IX September 2025

$$\text{Sensitivity} = \text{TPR} = \frac{FP}{TN+FP} \quad \text{xiii}$$

$$\text{Specificity} = \text{FPR} = \frac{TP}{TN+FP} \quad \text{xiv}$$

Table 5: Confusion Matrix application in generating the ROC curves

Predicted Values

Cut-point	High Potential (1)	Low Potential (0)
High Potential (1)	True Positive(TP)	False Positive(FP)
Low Potential (0)	False Negative(FN)	True Negative

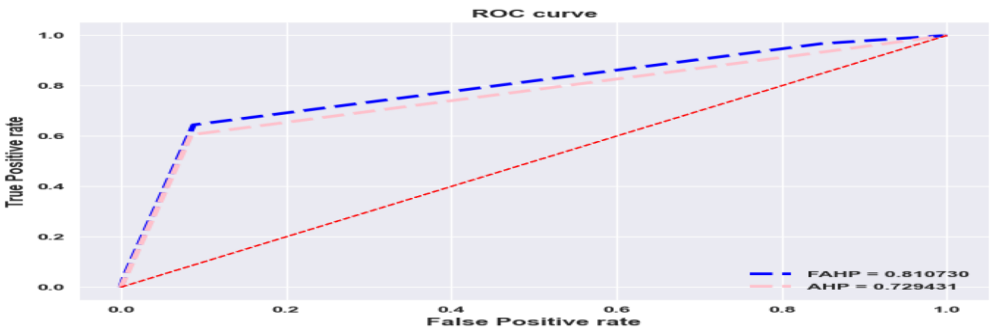

Fig 4.16: ROC Curves for the FAHP and AHP Model Maps

CONCLUSION AND RECOMMENDATION

This study has demonstrated the application AHP and FAHP in multi criteria decision analysis (MCDA) technique to geophysical, remote sensing and well parameters in establishing groundwater potential assessment of the western part of Ado- Ekiti, Southwestern, Nigeria. The MCDA technique was implemented on the produced thematic maps of the study area. The thematic maps were gotten through the application of GIS on the processed data from geophysical, geological and remote sensing data. Fifty five Vertical Electrical Sounding (VES) data were acquired and the data were interpreted qualitatively and quantitatively. The qualitative interpretation reveals three to five layers with curve types A, AA, AKQ, AKH, KH, HA, and HKH Curve.

Both the Fuzzy Analytical Hierarchy Process (FAHP) and Analytical Hierarchy Process (AHP) methods were utilized to assign weights to the groundwater potential conditioning factors in the study area. These factors include overburden thickness, aquifer resistivity, lineament, lithology, recharge rate, aquifer transmissivity, hydraulic conductivity and slope degree. These factors were integrated to create the groundwater potential index map for the study area. The results indicate that the lithology of the study area has the highest weight and the slope degree having the lowest weight. The results obtained from FAHP address both the imprecision and uncertainty that arise from the AHP approach.

The ROC curve was used quantitative validation, indicating an 81% AUC for the FAHP model, surpassing the conventional AHP's 73% AUC. Based on these validation results, it's evident that the FAHP outperforms the conventional AHP in prediction accuracy. The qualitative validation demonstrated that groundwater potential model maps generated using Fuzzy- AHP, based on geological information of the study area, exhibit favourable prediction accuracy.

This study effectively categorized the study area into high potential and low potential groundwater zones. These findings have significant implications for guiding groundwater development within the study area. The delineation of these zones provides valuable insights for making informed decisions about groundwater resource utilization and management.

This study has been able to establish the reliability of FAHP MCDA technique vis-à-vis its performance when applied to surface and subsurface geo- parameters for groundwater resources mapping and management.

The comparison between FUZZY AHP and FUZZY TOPSIS method would be really effective for decision making in groundwater resource management.

AKNOWLEDGEMENTS

This research is not connected to any profitable agency.

Author contributions : KAM performed conceptualization, review and editing, and supervision. RBS contributed to study conceptualization and design, data collection, data analysis, software and writing original draft preparation. Both author read and approved the final manuscript.

Declarations; I affirm that this thesis is my original work and has not been submitted to any journal house or article.

Conflict of interest: On behalf of other author, the corresponding author state that there is no conflict of interest

REFERENCE

1. 20.Ekelund, S. (2011). Acute care testing. ROC curves- what are they and how are they used? Acutecaretesting.org
2. Abdulkareem, M., Akrby, A., Fakhry, M. and Mostafa, M., (2018). Using of remote sensing and aeromagnetic data for predicting potential areas of hydrothermal mineral deposits in the central eastern desert of Egypt. Journal of Remote Sensing. 7(1), pp.1 – 13.
3. Abedi, M, Norouzi, G.H. and Fathianpour, N. (2013). Fuzzy Outranking Approach: a knowledge-driven method for mineral prospectivity mapping. Int J Appl Earth Obs Geoinf 21:556–567.
4. Adeyemo, I. A., Omosuyi G.O. and Ojo B.T. (2017) Groundwater Potential Evaluation in Typical Basement Complex Environment Using GRT Index - A C ase Study of Ipinsa – Okeodu Area, near Akure, Nigeria. Journal of Geoscience and Evironmental Protection, Vol. 5 No. 3.
5. Adiat, K.A.N. (2013) Development of Models for Predicting Groundwater Resources Potential of Alluvial Aquifer Using Artificial Intelligence Techniques. Unpublished Ph.d Thesis University Sains Malaysia , p. 4
6. Adiat, K.A.N., Nawawi, M.N.M. and Abdullah, K. (2012) Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool–A case of predicting potential zones of sustainable ground water resources. J Hydrol 440–441:75–89.
7. Adiat, K.A.N., Olayanju, G.M., Omosuyi, G.O. and Ako, B.D. (2009). Electromagnetic Profiling and Electrical Resistivity Soundings in Groundwater Investigation of a Typical Basement Complex – A Case Study of Oda Town South-western Nigeria. Ozean J. Appl. Sci. 2(4): 333-359.
8. Akinlalu A.A., Omosuyi G.O., Oni T.E. (2017). Groundwater vulnerability assessment using hydrogeologic and geoelectric layer susceptibility indexing at Igbara Oke, Southwestern Nigeria. Journal of Astronomy and Geophysics. http://dx.doi.org/10.1016/j.nrjag.2017.04.009.
9. Akintorinwa O.J., Atitebi M.O. and Akinlalu A.A. (2020). Hydrogeophysical and aquifer vulnerability zonation of a typical basement. complex terrain: A case study of Odode Idanre southwestern Nigeria. Heliyon 6 (2020) e04549.
10. Alabi, A.A., Bello, R. Ogungbe, A.S. and Oyerinde, H.O. (2010). Determination of groundwater potential in Lagos State University, Ojo; Using geoelectric methods (Vertical electrical sounding and Horizontal profiling). Rep. Opin., 24: 68- 75.
11. Albayrak, E. and Erensal, Y. (2004). Using analytic hierarchy process (AHP) to improve human performance: an application of multiple criteria decision making problem. J Intell Manuf 15:491–503.

12. Al-Gharni M.A., (2005). Application of Magnetic and Electrical Geophysical Methods in the Exploration of Groundwater Resources of Wadi Malakan, Saudi Arabia. Journal of King Abdulaziz University: Earth Science. 16:67-93.
13. Ariyo, S.O. and Adeyemi, G.O. (2009). Role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Areas: A Case Study from Fidiwo/Ajebo Areas of Southwestern Nigeria. Pac. J. Sci. Technol. 10(1):483-486.
14. Arulbalaji, P., and Gurugnanam, B., (2016). An Integrated Study to Assess the Groundwater Potential Zone Using Geospatial Tool in Salem District, South India. J. Hydrogeol. Hydrol. Eng.
15. Atenidegbe O.F. and Mogaji, K.A. (2023). Development of Promethee- Entropy data mining model for groundwater potentiality modeling: a case study of multifaceted geologic setting in south-western Nigeria. Acta Geophysica. http//doi.org/10.1007/s11600-023-01095-4.
16. Bojadziev, G., and Bojadziev, M. (1998). Fuzzy sets and fuzzy logic applications, Singapore: World Scientific.
17. Carranza, E.J.M. (2008). Geochemical Anomaly and Mineral Prospectivity Mapping in GIS. Handbook of Exploration and Environmental Geochemistry, vol. 11. Elsevier, Amsterdam, p. 351
18. Chowdhury, A., Jha, M.K., Chowdary, V.M., Mal, B.C., (2009). Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal India. Int. J. Remote Sensing. 30 (1), 231–250.
19. Clark, L. (1985) Groundwater Abstraction from Basement Complex Area of Africa. Quarterly Journal of Engineering Geology and Hydrogeology, 18, 25-34.
20. Dobrin, M.B., Savit, C.H., (1988). Introduction to geophysical prospecting. McGraw-Hill Book Co, Singapore.
21. Fashae, O.A., Moshood N.T., Talabi A.O,.Adedeji O.I. (2014). Delineation of Groundwater Potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. Appl Water Sci 4:19-38. https://doi.org 10.1007/s13201-013-0127-9.
22. Haujie, D., Zhengdong D. and Feifan D. (2016). Classification of groundwater potential in Chaoyang area based on QUEST algorithm: International Geoscience and Remote Sensing.
23. Kaliraj, S. Chandrasekar, N., Magesh, N.S., (2013): Identification of potential groundwater recharge zone in vagai upper basin,Tamil Nadu, using GIS- based analytical hierarchical process (AHP) technique.
24. Karimi, A.R., Mehrdadi, N., Hashemian, S.J., Nabi-Bidhendi, G.R., and Tavakkoli-Moghaddam, R., (2011). Using of the fuzzy TOPSIS and fuzzy AHP methods for wastewater treatment process selection. International of Academy Research, 3, 780–786.
25. Manap, M.A., Nampak, H., Pradhan, B., Lee, S., Sulaiman, W.N.A. and Ramli, M.F. (2014) Application of probabilistic-based frequency ratio model in groundwater potential mapping using remote sensing data and GIS. Arab J Geosci 7:711–724.
26. Moayeri M., Shahvarani A., Behzadi M. H. and Hosseinzadeh-Lotfi F. (2015). Comparison of Fuzzy AHP and Fuzzy TOPSIS Methods for Math Teachers Selection. Indian Journal of Science and Technology. Vol 8(13).
27. Mogaji, K.A. and Lim, H.S. (2016). Groundwater potentiality mapping using geoelectrical-based aquifer hydraulic parameters: GIS-based multi-criteria decision analysis modeling approach. Terr. Atmos. Ocean Sci. (2016). 10.3316/TAO.2016.11.01.02.
28. Mogaji, K.A. and Omobude, O.B. (2017). Modeling of geoelectric parameters for assessing groundwater potentiality in a multifaceted geologic terrain, Ipinsa Southwest, Nigeria- A GIS-based GODT approach. Journal of Astronomy and Geophysics. 6: 434-451.
29. Mogaji, K.A., Lim, H.S. and Abdullah, K. (2014). Modeling groundwater vulnerability prediction using geographic information system (GIS)-based ordered weighted average (OWA) method and DRASTIC model theory hybrid approach. Arab J Geosci. doi:10.1007/s12517-013-1163-3.
30. Mogaji, K.A., Lim, H.S. and Abdullah, K. (2015b). Modeling of groundwater recharge using a multiple linear regression (MLR) recharge model developed from geophysical parameters: a case of groundwater resources management. Environ Earth Sci (2015) 73:1217–1230. DOI 10.1007/s12665-014-3476-2.
31. Okhue E.T. and Olorunfemi, M.O. (1991). Electrical resistivity investigation of a typical basement complex area- Obafemi Awolowo University campus case study. J. Mining Geol. 27(2):66- 70.

32. Omosuyi, G.O. (2010) Geoelectric Assessment of Groundwater Prospect and Vulnerability of Overburden Aquifers at Idanre, Southwestern Nigeria. Ozean Journal of Applied Science, 3, 19-28.
33. Omosuyi, G.O. and Oseghale, A. (2012) Groundwater Vulnerability Assessment in Shallow Aquifers Using Geoelectric and Hydrogeologic Parameters at Odigbo, Southwestern Nigeria. Journal of Scientific and Industrial Research, 3, 501-512.
34. Omosuyi, G.O., Ojo, J.S. and Enikanselu, P.A. (2003) Geophysical Investigation for Groundwater around Obanla-Obakekere in Akure Area within the Basement Complex of Southwestern Nigeria. Journal of Mining and Geology, 39, 109-116.
35. Oni, A.G., Adediran, T.A., Olorunfemi, M.O., Eniola, P.J., (2020). Evaluation of the Groundwater Potential of Modomo, Ile- Ife, Southwest Nigeria, using Integrated Geophysical Techniques. Sustainable water Resources Management. DOI: 10.1007/s40899-02000467-8.
36. Ouedraogo I., Defourny P. and Vanclooster M. (2016). Mapping the groundwater vulnerability for pollution at the pan African scale. Science of the Total Environment 544 939–953.
37. Oyedele, E. A. A., Oyedele, T. and Oyedele, K., (2013). Geo-electrical data analysis to demarcate groundwater pockets in Ado – Ekiti, southwest, Nigeria. 5(11): 610-611.
38. Pazand, K., Hezarkhani, A. and Ghanbari, Y. (2014). Fuzzy analytical hierarchy process and GIS for predictive Cu porphyry potential mapping: a case study in Ahar-Arasbaran Zone (NW, Iran). Arab J Geosci 7: 241–251.
39. Radionovs, A. and Uzga- Rebrovs, O. (2016). Fuzzy Analytical hierarchy process for ecological risk assessment. Information Technology and Management Science, 19(1): 16-22
40. Rahaman, M.A. (1988). Recent advances in the study of the basement complex of Nigeria. In: Geological Survey of Nigeria (Ed) Precambrian Geology Nigeria, 11–43 pp.
41. Rahmati, O. and Meselle, A. M., (2015). Application of Dempster–Shafer theory, spatial analysis and remote sensing for groundwater potentiality and nitrate pollution analysis in the semi-arid region of Khuzestan, Iran. Science of the Total Environment 568 (2016) 1110 1123.
42. Rahmati, O., Nazari Samani A., Mahdavi, M., Pourghasemi, H. R. and Zeinivand, H. (2015). Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab J Geosci. 8:7059–7071.
43. Saaty T. L. (1987). Rank generation, preservation and the reversal in the Analytical Hierarchy Process. Decis. Sci
44. Szalai S. and L. Szarka (2008). Geoelectric Prospecting on the classification of surface geoelectric arrays, 56: 159-160.
45. Van Laarhoven. P.J.M. and Pedrycs, W. (1983) A Fuzzy Extension of Saaty's Priority Theory. Fuzzy Set and Systems, 11, 229-224.
46. Vander-Velper BPA. (2004) WinRESIST Version 1.0 Resistivity Depth Sounding Interpretation Software M.Sc. Research Project. ITC, Delft Netherland.
47. Wright, E.P. and Burgess, W.G. (1992) Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society London Special Publications, 66, 1-27. https://doi.org/10.1144/GSL.SP.1992.066.01.01.
48. Wu, J., Huang, H. and Cao, Q. (2013). Research on AHP with interval-valued intuitionistic fuzzy sets and its application in multi-criteria decision making problems. Appl. Math. Modell. 37, 9898–9909.
49. Yousefi, H., Zahedi, S. and Niksokhan, M.K., (2018). Modifying the analysis made by water quality index using multi-criteria decision making methods. Journal of African Earth Sciences 138 (2018) 309-318.
50. Zadeh, L.A., "Fuzzy Sets," Information and Control, vol.8, pp.338-353, 1965.
51. Zakir, F.A, Mohammed, H.T., Qari, M.E. Most (1999). A new optimizing technique for preparing lineament density maps. International Journal of Remote Sensing 20(6): 1073-1085.
52. Zare, M., Pourghasemi, H.R., Vafakhah, M. and Pradhan, B. (2013) Landslide susceptibility mapping at Vaz Watershed (Iran) using an artificial neural network model: a comparison between multilayer perceptron (MLP) and radial basic function (RBF) algorithms. Arab J Geosci 6:2873–2888.