

Groundwater Potential Mapping of Zaria Sheet 102 NE, North Central Nigeria: A GIS And Remote Sensing Approaches

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Abstract

Investigation of groundwater potential of Zaria, Sheet 102NE, was conducted using GIS and remote sensing approach. The primary objective was to establish a cost-effective approach for exploring and exploiting groundwater resources in this specific region. In this endeavour, remotely sensed Digital Elevation Model data played a crucial role in generating thematic maps encompassing slope, lineament, elevation, drainage, and drainage density. Additionally, traditional soil maps were digitized and integrated into the model, along with geological data derived from on-site field mapping. The model revealed the existence of four distinct potential zones classified as poor, low, moderate, and high occupying respective areas of 1.22Km²(0.16%), 289.65Km²(37.62%), 449.70Km²(58.40%) and 29.43Km²(3.82%) respectively. The validation of the model, through the incorporation of geophysical data obtained from Vertical Electrical Sounding (VES), demonstrates a satisfactory level of concurrence with the outcomes derived from the remote study. Consequently, this investigation advocates the adoption of remote sensing data as a preferred approach for assessing groundwater potential within a geographic area.

Keywords: Remote sensing, GIS, Weighted overlay, Thematic maps.

INTRODUCTION

Groundwater refers to water present within the subsurface zone of saturation, occupying the interstitial spaces between sediments, rocks, cracks, and crevices. This vital global resource constitutes approximately 96% of the Earth's freshwater (Aladejana, 2012). In regions characterized by crystalline basement terrain, the intricate occurrence of groundwater, coupled with a high incidence of well and borehole failures, often results from insufficient pre-drilling and hydrological investigations (Fashea *et al.*, 2014). The escalating growth in population, coupled with expanding agricultural and industrial developments, has led to an increased demand for essential public utilities, particularly the supply of water for

domestic and agricultural purposes. Traditional methods, such as geological, hydrogeological, and photogeological techniques, in combination with geophysical approaches which are quite expensive have been employed for decades to determine the groundwater potential of a region (Srivastava and Bhattacharya, 2006). Nevertheless, the integration of remote sensing and geographical information system techniques has proven to enhance the precision of delineating groundwater potential zones while simultaneously reducing costs (Rao and Jugran, 2003). Also, the incorporation of local field observation into the conventional GIS-based models helps improve local results (Adeyeye, 2015; Umaru and Kankara, 2020). In the examined region during the

dry season, farmers encounter water scarcity, which significantly impacts irrigation and livestock farming. Consequently, there is a pressing need for guidance on identifying areas with the potential for groundwater resources to support their agricultural activities. This research is thus designed to leverage Remote Sensing (RS) and Geographic Information Systems (GIS) for groundwater investigations within the Zaria Sheet 102NE area. The primary objective is to delineate groundwater potential zones, thereby facilitating their utilization for agricultural purposes and household water needs.

Location and Geological setting of the area

The study area is located within Latitudes 11° 15' and 11° 30' N, to Longitudes 07° 45' and 08° 00' E making up Zaria Sheet 102NE. It covers an area of approximately 770 km² and can be accessed through a major and minor road that runs from Zaria to Kano. It can also be accessed through various footpaths (Figure 1). Geologically, Zaria is characterized by a diverse range of rock formations and geological features. The area is situated within the Nigerian Basement Complex, which lies east of the West African Craton and north west of the Congo Craton. This basement complex was affected by the Pan African Orogeny (Black *et al.*, 1979; Ajibade *et al.*, 1987). Three main groups of rocks are identified namely: The migmatite gneiss complex with ages ranging from Liberian (~2800 Ma) to Pan-African (~600 Ma) whose metamorphism is

generally in the amphibolite facies grade (Wright *et al.*, 1985; Dada, 1999). The schist belts are mainly N–S to NNE–SSW trending belts of low grade (mainly greenschist facies) supracrustal (and minor volcanic) assemblages (Turner, 1983; Fitches *et al.*, 1985; Ajibade *et al.*, 1987; Dada, 1999). They are considered to be Late Proterozoic cover in-folded into the migmatite gneiss complex (Ajibade *et al.*, 1987). The schist belts and the migmatite gneiss complex are concentrated in the western half of Nigeria and are seldom found east of longitude 8°E, so, also are the syntectonic to late-tectonic Pan-African granitoids which intrude both the schist belts and the migmatite gneiss complex (Fitches *et al.*, 1985; Ajibade *et al.*, 1987). They Comprise of gabbro, charnockite, diorites, granodiorites, granites, syenites, aplite and pegmatites (Ajibade *et al.*, 1987). The Pan-African granitoids in Nigeria are referred to as the Older Granites to distinguish them from the Mesozoic anorogenic granite ring complexes (the Younger Granites) (Fitches *et al.*, 1985). Rocks of the Nigerian Basement Complex are intruded by Mesozoic ring complexes of Jos Plateau and overlain unconformably by Cretaceous to Quaternary sediments forming the sedimentary basins (Fitches *et al.*, 1985). The geological makeup of the study area is characterized granites (porphyritic granites, fine grained granites, biotite granites) and gneisses as major rocks while other minor lithologies are mylonite and pegmatites. Structural features such as joints, faults, foliations, dykes, and veins also constitute the lithologies.

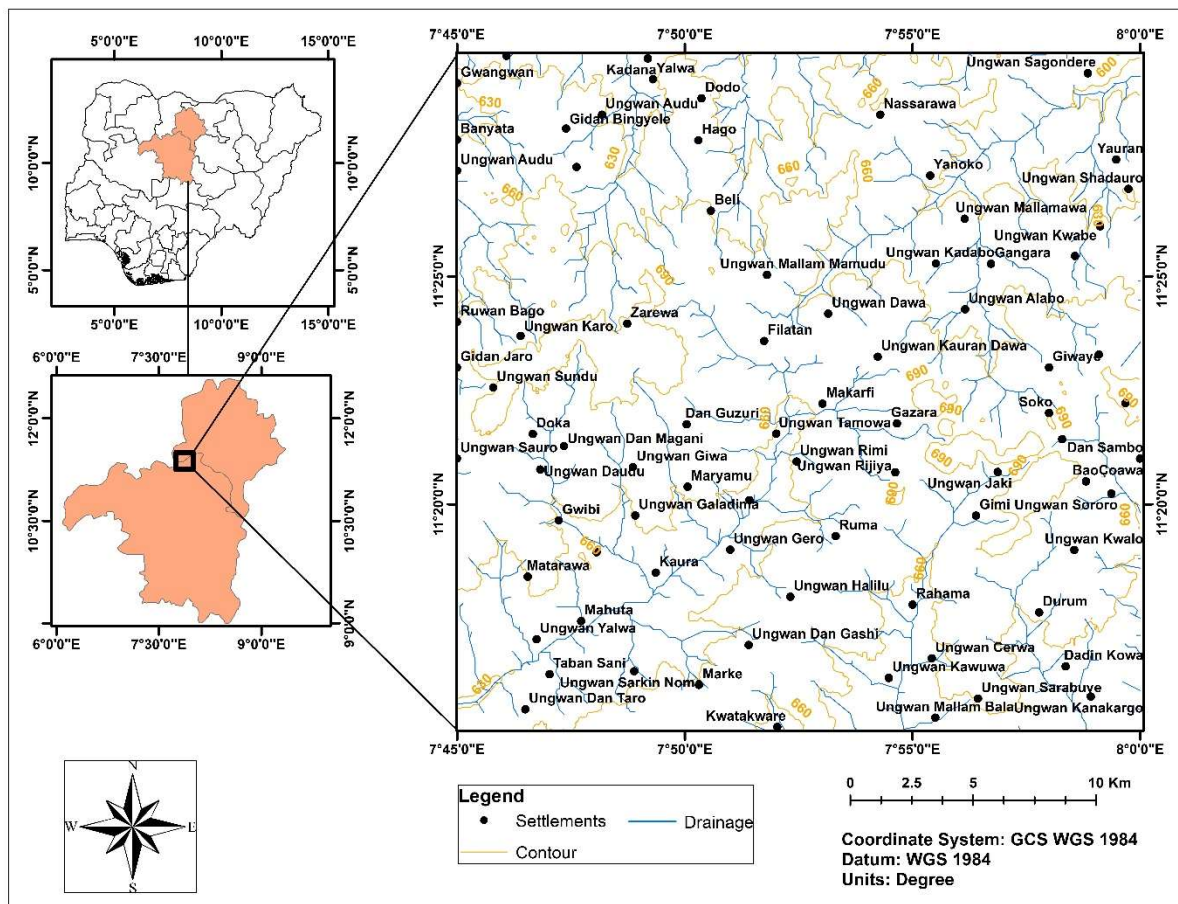


Figure 1: Location map of the study area

MATERIALS AND METHODS

The method employed in this study encompassed a comprehensive review of pertinent literature in the field of geology, hydrogeology, and groundwater potential modelling using GIS and remote sensing (RS) data. The desk studies played a crucial role in establishing the conceptual framework. Fieldwork activities included geological and hydrogeological mapping of the study area on a 1:50,000 scale. Vertical Electrical Sounding (VES) was conducted following standard procedures with the utilization of the PIOS resistivity meter. To assess groundwater potential, Analytic Hierarchy Procedure (AHP), a multi-criteria decision analysis technique developed by Saaty (1980, 1992), was employed. The AHP method involved

pairwise comparisons of thematic features such as Geology, Soil, Lineament, Drainage, Slope, and Elevation, assigning values on a scale from 1 to 9 (Saaty, 1980, 1992). This process results in the creation of a matrix that compares the thematic data's significance in relation to groundwater potential. The integration of these six thematic maps was executed to create the Groundwater Potential Model (GWPM) for the study area. This integration was achieved using the raster calculator feature within the ArcMap software and implemented through Weighted Linear Combination (WLC) methodology, as proposed by Prasad *et al.* (2008). The flow chart for the methodology is presented in Figure 2.

$$GWP = \sum W_i X_{i_{cf}}$$

where GWP = Groundwater potential;

W_i = Weight for each map score; and

X_i = Individual map.

Table 1: Saaty's Scale for Assignment and its Interpretation Showing Pair-Wise Comparison Process (Saaty, 1980, 1992)

Less important				Equal	More important			
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

2, 4, 6 and 8 are intermediate values

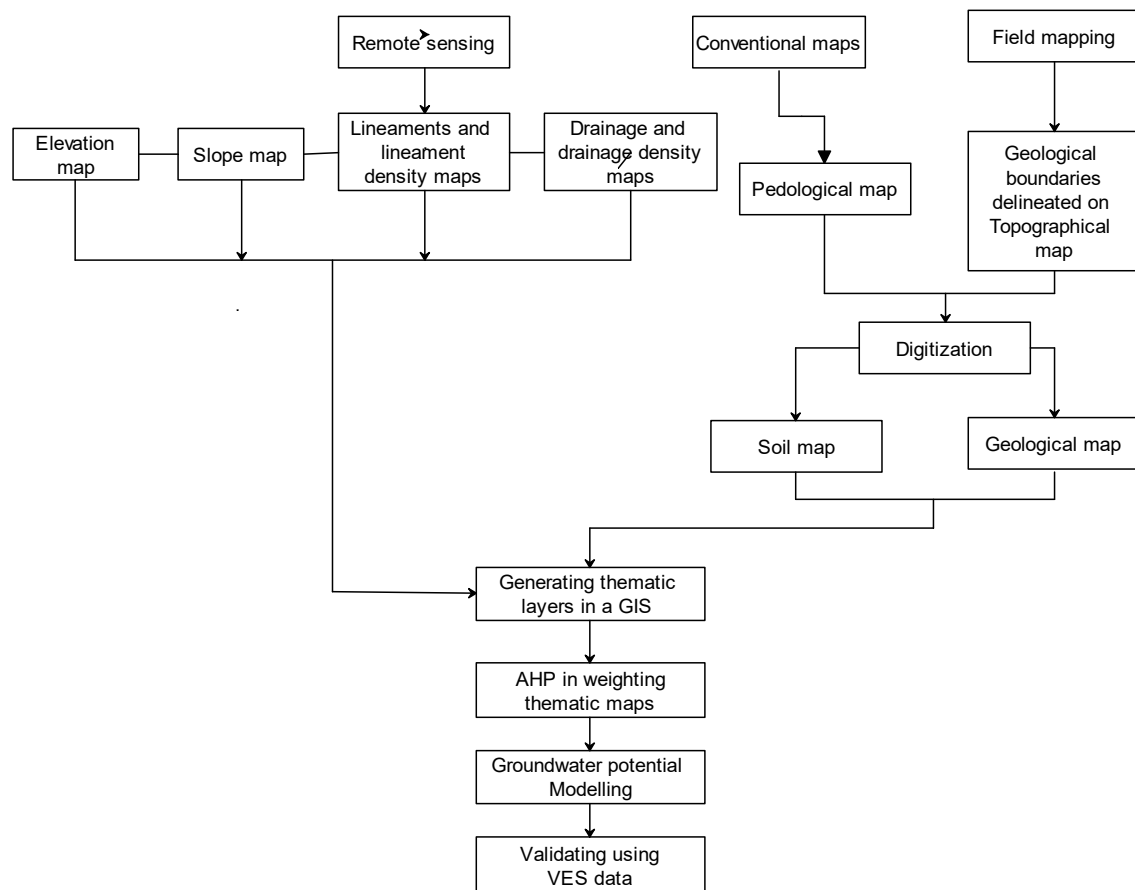


Figure 2a: Flow chart for the methodology used in this study

RESULT AND DISCUSSIONS

The production of the Groundwater Potential Map (GWPM) involved the utilization of six thematic maps, each representing distinct factors: geology, soil, drainage density, lineament density, slope, and elevation. Each of these factors underwent a series of steps, including data acquisition, processing, and analysis, resulting in the creation of individual thematic maps. The thematic maps were then reclassified and assigned weighted values through the implementation of the Analytic Hierarchy Process (AHP) technique. The integration of these weighted thematic maps took place within the ArcGIS environment, employing a weighted overlay approach. The outcome of this integration was the generation of the Groundwater Potential Map (GWPM) for the study area, offering valuable insights into the distribution of groundwater potential across the region.

Elevation

Groundwater recharge is less favourable in high elevations compared to low elevations. We classified elevations into four distinct categories based on their influence on groundwater potential, namely, "Very High," "High," "Low," and "Very Low" elevated areas, as illustrated in the figure. Each category was assigned a corresponding weight to reflect its impact.

Slope

The nature of the slope has a direct impact on infiltration rates. Steeper slopes tend to result in reduced recharge because water quickly runs downhill during rainfall events, leaving insufficient time for surface infiltration and the replenishment of the saturated zone. This terrain characteristic can be effectively illustrated through the

horizontal spacing of contours on a topographic map. Areas with gentle slopes generally experience lower runoff and greater infiltration compared to areas with steep slopes. Consequently, we can anticipate higher groundwater potential in regions characterized by gentle slopes (Waikar and Nilawar, 2014; Ndatuwong and Yadav, 2014). In the context of our study area, the slope data was classified into four categories: "Very Steep," "Steep," "Moderate," and "Gentle."

Lineament and Lineament Density

Lineament density is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials, as the presence of lineaments usually denotes a permeable zone. Thus, areas with higher lineament density are regarded as favourable for groundwater development. Accordingly, we assigned a higher weight to regions characterized by high lineament density and a lower weight to areas with limited lineament density using a pairwise comparison method.

Drainage and Drainage Density

The drainage system of the study area was observed to be structurally influenced by the directions of lineaments. The presence of lineaments which serve as conduit and storage in parts of the study area indicated the dendritic and parallel pattern of the drainages. The two major rivers are draining in opposite directions i.e. NE and SW and the other ones been either northward or southward. Drainage density is an inverse function of permeability, and therefore it is an important parameter in evaluating groundwater potential zones (Agarwal et al, 2013). Area of high drainage density indicates less infiltration which

favours runoff and hence acts as poor groundwater prospect because major part of the rainwater over the area is lost as surface runoff with little infiltration for recharging the groundwater reservoir. On the other hand, low drainage density areas permit more infiltration and recharge to the groundwater reservoir, hence can be described as a good potential zone for groundwater prospect (Ndatuwong and Yadav, 2014). Pair-wise comparison of the drainage densities after classification into four was carried out. Each class was assigned weight according to perceived influence on ground water as shown in table below.

Soil

The accumulation of groundwater through infiltration is a consequence of the soil's permeability. In the study area, we

conducted a pairwise comparison of soil types, considering their specific properties and their influence on subsurface infiltration. We identified three primary soil classes that span the study region: clay loam, sandy clay, and sandy loam.

Geology

The area is underlain by crystalline basement rock and showed four major rock types namely: gneiss, porphyritic granite, medium grained granite, and fine-grained granite. In terms of groundwater potential, geology determines the aquifer where groundwater is stored. When prospecting for groundwater in crystalline terrain secondary porosity and permeability are common indicators (Gupta 2003) and also fracturing can increased ability of the terrain to serve as good aquifer.

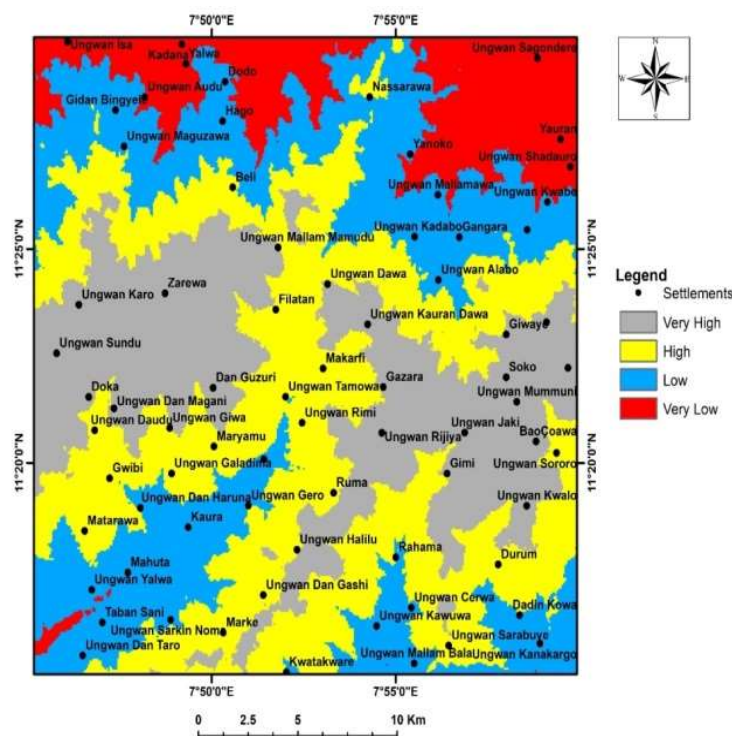


Figure 3a: Classified elevation map of the study area

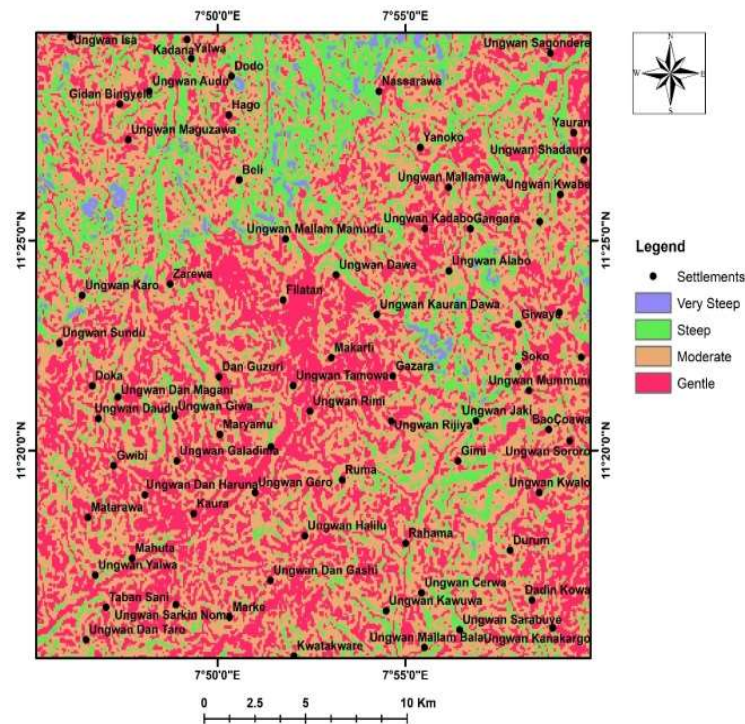


Figure 3b: Classified slope map of the study area

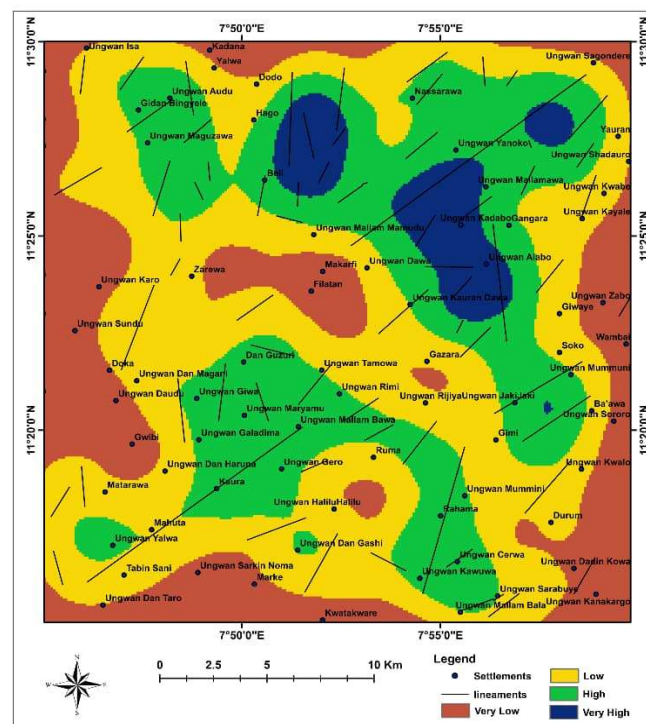


Figure 3c: Classified Lineament Density Map

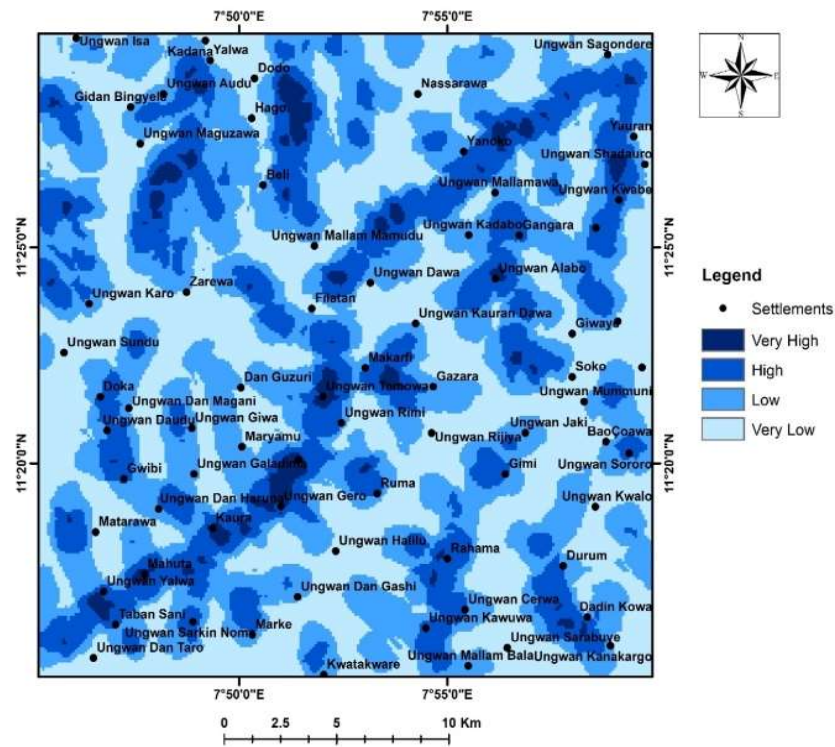


Figure 3d: Classified Drainage Density map of the area

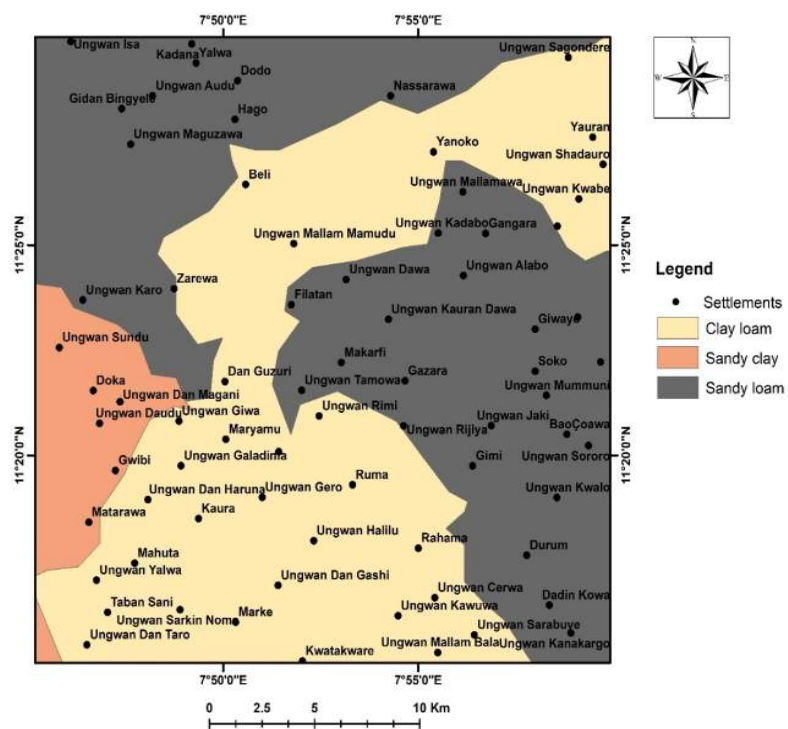


Figure 3e: Soil Map of the Study Area



The thematic layers comprised of slope, elevation, lineament density, drainage density, soil, and geology. After normalized weighting, were integrated in a GIS environment to produce the groundwater potential map of the study area (Figure 4). The groundwater potential map revealed four areas; poor, low, moderate, and high groundwater as well as the distribution and area of coverage (Table 4). The groundwater potential map (Figure 4) shows that the excellent groundwater potential zones are concentrated in the extreme north-eastern and north-western region. According to Schoneich and Garba (2010), the zone with higher groundwater potential is better recharge because streams

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Table 2: Pair-Wise Comparison of Parameters

Factors	Slope	Elevation	Lineament Density	Drainage Density	Soil	Geology	Weight	Weight percent (%)
Slope	1	3	2	2	5	3	0.25	25
Elevation	1/3	1	1/2	2	3	2	0.33	33
Lineament Density	1/2	2	1	3	4	3	0.12	12
Drainage Density	1/2	1/2	1/3	1	3	2	0.17	17
Soil	1/5	1/3	1/4	1/3	1	1/2	0.08	8
Geology	1/3	1/2	1/3	1/2	2	1	0.05	5

Table 3: Parameters Weight, Rank, and Influence Levels

Parameters	Classes	Attribute	Weight	Rank	Influence (%)
Slope	46 ⁰ -2 ⁰	Very Steep	5	4	25
	24 ⁰ -46 ⁰	Steep	9	3	
	13 ⁰ -24 ⁰	Moderate	27	2	
	27 ⁰ -13 ⁰	Gentle	59	1	
Elevation	673-708	Very High	5	4	33
	654-673	High	10	3	
	632-654	Low	27	2	
	588-632	Very Low	58	1	
Lineament Density (Km/Km ²)	88.25-117.45	Very High	59	1	12
	59.05-88.25	High	23	2	
	29.85-59.05	Low	13	3	
	0.65-29.85	Very Low	5	4	
Drainage Density (Km/Km ²)	184.43-245.91	Very High	5	4	17
	122.95-184.43	High	11	3	
	61.47-122.95	Low	26	2	
	0-61.47	Very Low	58	1	
Soil	Clay Loam	Moderate	7	3	8
	Sandy Clay	Good	32	2	
	Sandy Loam	Excellent	61	1	
Geology	Fine Grained Granite			1	5
	Biotite Granite			2	
	Porphyritic Granite			4	
	Gneiss			3	

Table 4: Groundwater Potential Zones Distribution and Extents

GWP	Area (Km²)	Area (%)
Poor	1.22	0.16
Low	289.65	37.62
Moderate	449.70	58.40
High	29.43	3.82

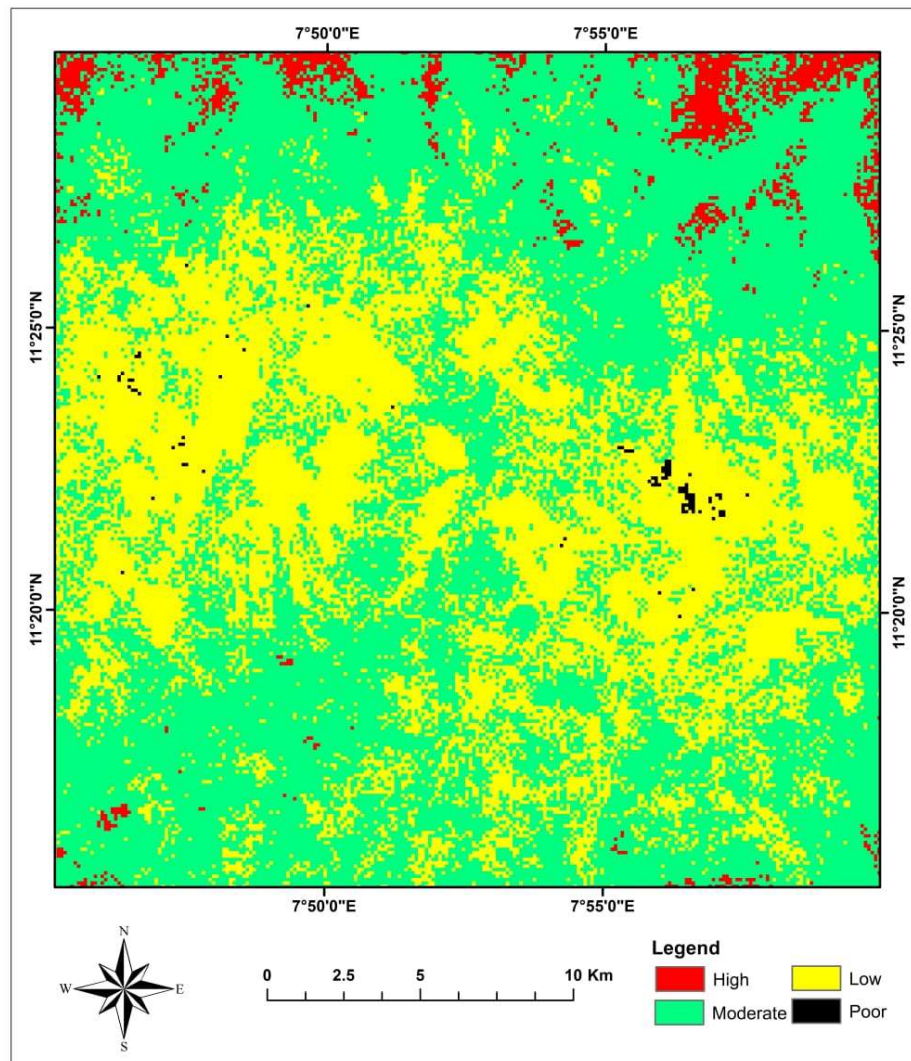


Figure 4: Groundwater Potential map of the Study Area showing four zones of groundwater coverage.

Model Validation

Observed thickness and nature of the weathered layer are important parameters in the groundwater potential evaluation of a basement complex terrain (Clerk, 1985; Bala & Ike, 2001). Two VES profiles were

taken in order to validate the groundwater potential model. The first traverse was carried out across the zone of low groundwater potential, while the other profile was run in the zone of moderates through the low to the moderate

groundwater potential (Figure 4). All the zones of groundwater potential lie on the crystalline geological terrain. Profile 1, three – four layers were delineated namely: topsoil, weathered overburden, fractured basement and fresh basement respectively. VES 1,2,3, and 4 has probable resistivity value and aquiferous thickness of 70 Ω m, 100 Ω m, 80 Ω m, 60 Ω m and 7m, 12m, 6.8m, 6m respectively (Figure 6a). The second profile was taken within the area of moderate to high groundwater potential. Three - four layers were also encountered in this zone namely: topsoil, weathered overburden, fractured basement and fresh basement respectively. While VES 5, 6, 7, and 8 has probable resistivity value and aquiferous thickness of 120 Ω m, 100 Ω m,

100 Ω m, 150 Ω m and 13m, 7m, 12m, 16m respectively (Figure 6b).

The two VES curves on (figure 5), the first curve on the left has about 10m overburden layer which likely implies the aquifer is shallow and may not yield good water potential. However, the second curve on the right aquifer thickness and overburden is thicker and could help more water retention hence may yield water throughout the seasonal variation. In terms of the geology, we tend to have more water in the older rock because it's weaker and may have more weathered and fractured zone than the younger one which might be still fresh i.e. curve 8 falls on older rock the gneiss and curve 4 on younger rock the granite.

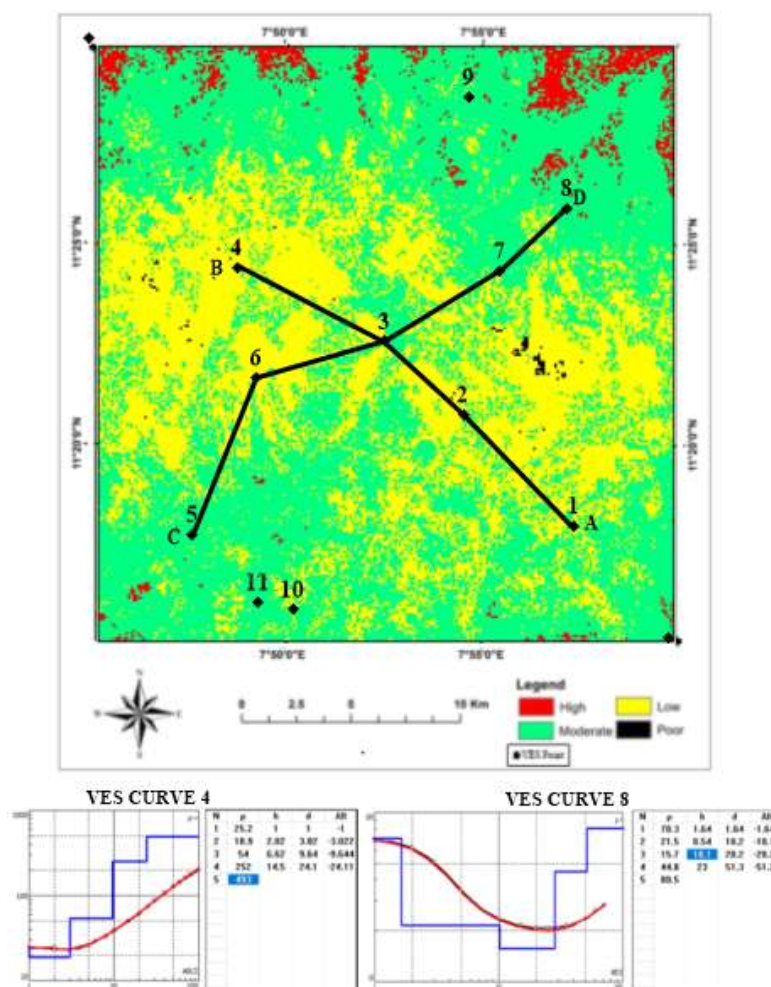


Figure 5: Two VES Profiles A-B and C-D on Groundwater Potential Map of the Study Area

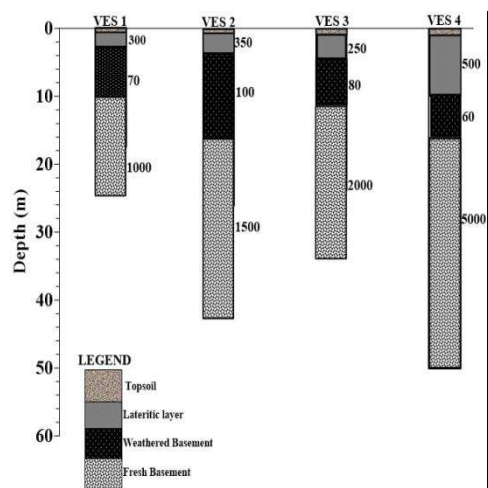


Figure 6a: Geoelectric Profile A-B from figure 5a

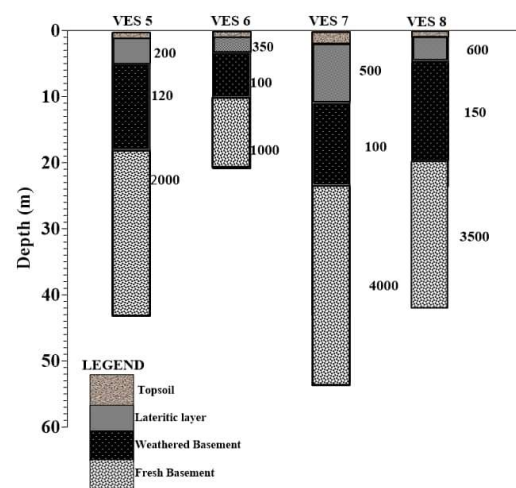


Figure 6b: Geoelectric Profile C-D from figure 5a

CONCLUSION AND RECOMMENDATION

A total of six thematic maps were digitized to generate the groundwater potential map (GWPM) based on their influence on the occurrence of groundwater in the study area. These include geology, soil, drainage density, lineament density, slope, and elevation respectively. The groundwater potential modelling of the area revealed four zones of groundwater potential namely; low, poor moderate and high potential zones cover 1.22Km²(0.16 %), 289.65 Km²(37.62%), 449.70Km²(58.40%), and 29.43Km²(3.82%) respectively. The study area is underlain by gneiss, porphyritic granite, medium grained granite, and fine-grained granite. These lithologies were severally cut by veins and pegmatites and the geological structures show prominent structural trend of NNW-SSE, and a less dominant NW-SE direction.

It is recommended that groundwater prospects mapping using GIS and RS should be implemented to assist field hydrogeologists in swiftly identifying potential groundwater zones for performing site-specific investigations, thereby greatly

reducing the scope of search. It is also recommended that borehole drillers, including government entities, retain data such as pumping tests and lithologs for research and other water resources assessment needs.

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