

A Multipreliminary Approach to the Delineation of Groundwater Potential Zones: A Study of Ijero Ekiti and its Environs, Southwest-Nigeria

*¹Ologe, O., ²Ahmed, J. and ³Adegoke, A. O.

¹Department of Applied Geophysics, Federal University Birnin Kebbi, Nigeria

²Department of Chemical and Geological Sciences, Al-Hikmah University, Ilorin, Nigeria.

³Department of Physical Sciences (Geophysics Programme), Olusegun Agagu University of Science and Technology Okitipupa, Ondo State, Nigeria

ABSTRACT

This study employs multipreliminary approach, remote sensing (RS) and geographical information system (GIS) methods to determine groundwater potential zones in basement terrain of Ijero Ekiti and its environ of parts of SW-Nigeria. The thematic layers considered in this study are Lithology, Drainage, Soil, Lineament, Land use, slope and soils from remotely sensed data and other data sources. The soil and drainage maps were digitized from published maps. The thematic layers were finally integrated using ArcGIS 10.3 software to yield a groundwater potential zone map of the study area. On the basis of relative contribution of each of thematic layers towards groundwater potential, the weight of each thematic map was selected. The individual theme weight was multiplied by its respective class weight and all the raster thematic layers were aggregated in a linear combination equation. The result revealed that the study area can be categorized into three different groundwater potential zones: low, moderate and high. Areas with low potential account for 3.33% of the study area while moderate and high account for 58.7% and 38% respectively of the total study area. Consequently, the study area offers about 96% as moderate groundwater potential. The RS and GIS techniques have proved useful for the identification of groundwater potential zones. On a regional level, groundwater details at specific points can be found through the use of some other techniques such as surface geophysical methods.

Keywords: Groundwater, GIS, remote sensing, multi-criteria decision analysis, groundwater potential zones, crystalline basement terrains, weighted Index Overlay, ArcGIS.

INTRODUCTION

The study area lies between latitude $7^{\circ}49' 00''$ N and $7^{\circ} 50' 0''$ N, longitude $5^{\circ} 04' 02''$ E and $5^{\circ} 5'20''$ E. Groundwater refers to the water present beneath earth's surface in the soil pore spaces and in the fractures of rock formations, a unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable amount of water (Richard, 2006). The global importance of groundwater as a major source of freshwater for agricultural and domestic uses cannot be over-emphasized (Oladeji *et al.*, 2012). Groundwater is an important component in many industrial processes. It is a source of recharge for lakes, rivers, and wetlands (Hassan and Tanvir, 2008; Ayodele, 2006). The challenge of locating groundwater within the subsurface is that no one can see directly into the ground (Olutona *et al.*, 2019). Consequently, integration of remote sensing (RS) and geographic information system (GIS) has proven to be efficient, rapid and cost effective technique producing valuable data on geology, geomorphology, lineaments and slope as well as a systematic integration of these data for exploration and delineation of groundwater potentials zones (Prasad *et*

al., 2008; Fashae *et al.*, 2014; Oyeyemi *et al.*, 2020). Remote sensing is the collection and interpretation of information about an object without physical contact with the object (Chivasa, 1999; Ali, 2005). The technique give shallow earth information about plants, geologic materials and structures since water flows may be concentrated in fractures or other geologic structures that have surface expression, but are not readily discerned by walking over them. Fractures and faults are particularly easy to spots using side-scan radar (Srivastava and Bhattacharya, 2006; Ale *et al.*, 2014). Drilling is then directed into the fractures, ancient river channels, fault zones, or layers where water is either known or suspected to be moving (Abdelsalam *et al.*, 1994). Due to complex and erratic nature of groundwater occurrences in crystalline basement terrains, groundwater development in form of boreholes/wells without the necessary pre-drilling hydrogeological investigations usually results in failure. Therefore, this paper is an attempt to carry out a reconnaissance assessment of the groundwater potentials of Ijero Ekiti by collecting, interpreting and utilizing the

*Corresponding author. E-mail: oluwatoyin.ologe@fubk.edu.ng

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geomorphological and geological/hydrogeological and lineaments analyses approach.

Geological Settings of the Study Area

The study area is mainly underlain by crystalline rocks, collectively referred to as the Basement Complex of Nigeria and principally made up of mica Schist, pegmatites, granite and quartz schist (Figure 1). The major rock types are micaceous schist, quartz schist, medium-grained granite and pegmatite (Elueze, 1988). In particular, the pegmatites which occur as low-lying bodies, with a mineralogy dominated by pinkish-white microcline perthite, quartz, muscovite and plagioclase plus accessory constituents of garnet, beryl and tourmaline have been investigated for their distribution, physical, chemical and mineralogical characteristics in order to evaluate their industrial qualities. Geological features noticed within the rocks mapped include foliation, mineral lineation, veins, joints and faults all over the outcrops. Slightly jointed rocks and fractures were observed within the country rocks. The schist shows the mineral alignment and foliation in which strike and deep measurement were taken. The study area

is generally underlain by mica schist, granite and quartz schist, with pegmatite trending in the NNW-SSE direction occurring as near vertical intrusions into the older rocks. Pegmatite bodies of Nigeria, intrude generally discordantly, older lithologies of the schist belt, the gneiss migmatite complex and the Older Granite suites. These pegmatite bodies were hitherto thought to be restricted to a 400 km NE-SW trending belt from the southwestern part around Abeokuta to the north central parts around Jos (Oyawoye, 1970).

MATERIALS AND METHODS

Software materials used to process and analyse the data are ILWIS 3.2 and ArcView3.1. These data include existing hydrogeological and relevant data on soils, geological/lithological units, structural features, geomorphologic and climatic conditions of the study area. The processes involved in this study for the laboratory analysis include data entry and data / image processing. The overall study concept involved integration of thematic layer maps of soil, drainage and lineament, land-use, and slope as well as remotely sensed data.

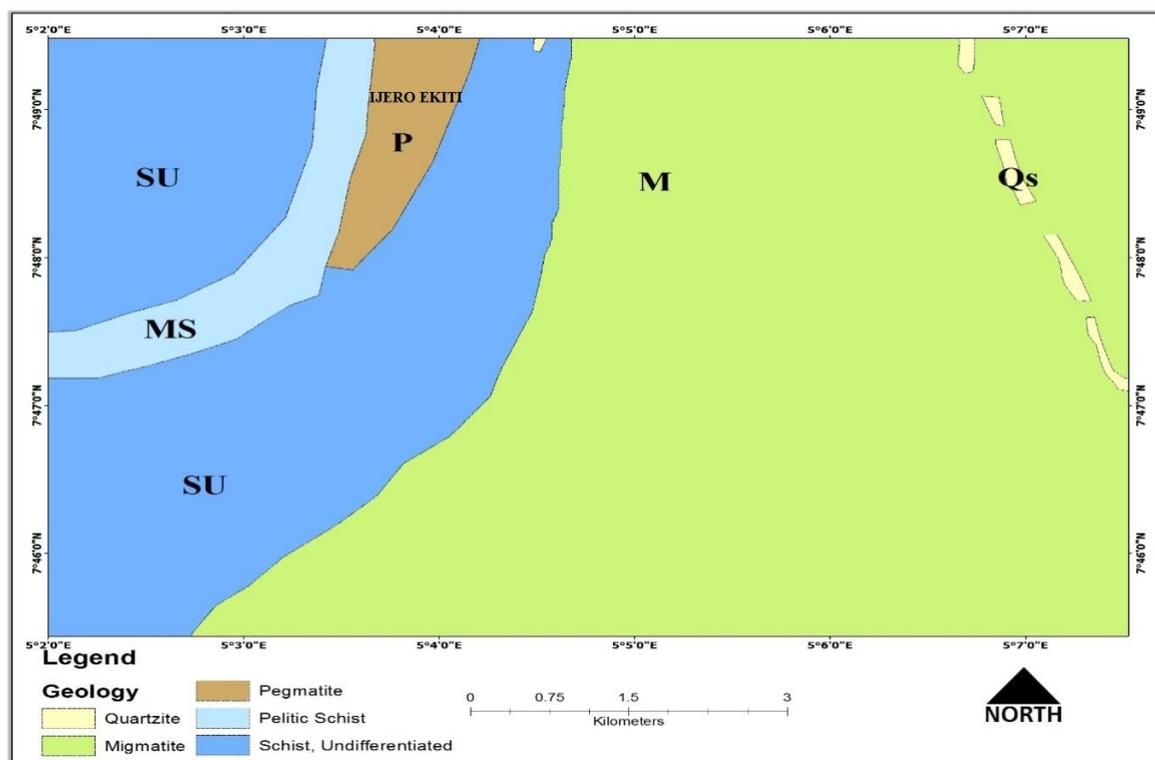


Figure 1: Geological Map of Study Area (modified after NGSA 2015)

Preparation of thematic layers and Integration

Weighted index overlay analysis was adopted as a simple mathematical model for a combined analysis of multi parameters. Each thematic map was assigned a weight (Table 1) depending on its influence on the movement and storage of groundwater (Nag, 2005; Champati, 2000); Relative ranking of each thematic unit in a theme were assigned as knowledge based hierarchy using Spatial Analyst tool of Arc GIS. The integration of various thematic maps describing favorable groundwater zones into a single groundwater potential map has been carried out through the application of GIS. It required mainly three steps of spatial database building, spatial data analysis and data integration.

Spatial data analysis is an analytical technique associated with the study of locations of geographic phenomena together with their spatial dimension and their associated attributes (like table analysis, classification, polygon classification, and weight classification). All thematic maps were reclassified and assigned suitable weightage (Fischer, 1962; Fashae *et al.*, 2014). The raster maps of these parameters were assigned respective theme weight and their class weights. The individual theme weight was multiplied by its respective class weight and then all the raster thematic layers were aggregated in a linear combination equation in Arc Map GIS Raster Calculator module.

Table 1: Layers and their weightage factors (Adapted from Hajem *et al.* 2013)

Thematic layers	Features/Categories	Rank	Weightage
Geology	Schist, Undifferentiated	3	25
	Pegmatite	1	
	Quartzite	4	
	Pelitic schist	3	
	Migmatite	1	
Slope	0-5%	5	20
	5-10%	4	
	10-15%	3	
	15-20%	2	
	20-40%	1	
	40-65%	1	
Soil	Ferric Lixisols	4	10
	Ferric Alisols	2	
Land use/ Land cover	Built up	1	15
	Bare surface	3	
	Vegetation	5	
	Wasteland	3	
	Wetland	5	
Lineament density	0-80.34	5	10
	80.34-160.698	4	
	160.698-241.047	3	
	241.047-321.397	2	
	321.397-401.746	1	
Drainage density	0-151.94	5	5
	151.94-303.88	4	
	303.88-455.83	3	
	455.83-607.77	2	
	607.77-759.72	1	
Elevation (Meters)	376-425	5	15
	426-454	4	
	455-485	3	
	486-517	2	
	518-599	1	

RESULTS AND DISCUSSION

The Geological map of the study area is shown in Figure 1. The following attribute maps extracted from the

digital elevation model were used to categorize the areas into its hydrogeologic potential. They include slope map, land use map, drainage density map, lineament

map and soil map are presented in Figures 2-6. The groundwater potential map showing the spatial distribution of the various zones of groundwater potential obtained from the model is presented in Figure 7. The thematic layers were placed into one of the following categories: Good, Moderate and Poor depending on their level of groundwater potential.

Geology

Geology is one of the major factors which plays an important role in the distribution and occurrence of ground water. The geology of the study area is dominated by the Precambrian basement rocks consisting of igneous and metamorphic rock units, i.e. migmatite gneiss, pegmatite, schist and quartzite. An understanding of the local geology was developed based on existing maps as pegmatite, schist and pelitic schist have little influence on groundwater availability based on their poor infiltration capacity while quartzite has a moderate influence on groundwater potential. A weightage of 25% was assigned to the geology (Table 1) based on the high influence of geology to groundwater.

Slope

Slope as an aspect of geomorphologic features relates to the local and regional relief which gives an idea about the general direction of groundwater flow and its influence on groundwater recharge. Slope of an area represents steepness or inclination of an area determined from two points on a line. Slope plays a vital role in determining soil erosion in hilly terrain. A steep slope will cause more runoff and will enhance the soil erosion in absence of vegetation cover leading to land degradation (Fashae *et al.*, 2014). The slope angle is considered as an important input as it has considerable influence in the study area for the identification of groundwater potential zones. The slope of the study area was classified into six classes, such as less than 5% slope angle (plain area), slope zones 5-10%, 10-15%, 15-20%, 20-40% and above 40% while weightages of 5, 4, 3, 2, 1 and 1 were respectively assigned to them based on their groundwater prospects. In this case, higher weightage was given to shallow slopes and gradually lesser and lesser weightages were assigned steeper and steeper slopes because runoff is directly proportional to slope (Table 2 and Figure 2). The slope percentage map (Figure 2) of the area was generated from the digital elevation model.

Table 2: Classification of the entire catchment based on slope percentage

Slope	Slope category	Area	Perc_area	Rank	Weightage
0-5%	Gentle	28.17212	28.308	5	20
5-10%	Moderate	40.16533	40.35906	4	
10-15%	Moderately Steep	19.29678	19.38985	3	
15-20%	Steep	7.19802	7.232737	2	
20-40%	Very Steep	4.488066	4.509712	1	
40-65%	Escape Steep	0.199681	0.200644	1	

Based on the percentage of slope the entire catchment was classified into six categories as shown in Table 2. Twenty eight percent (28%) of the study area is under gentle slope (0-5%) category, 40.4% under moderate slope category. A cumulative of about 31.3% of the study area is under various categories of steep slope. Gentle slope (0-5%) indicates the presence of high groundwater potential zones, high slope (>10%) shows the presence of poor groundwater potential zones as water runs rapidly off the surface (Figure 2).

Land use

Land use is clearly constrained by environmental factors such as soil characteristics, climate, topography, and vegetation (Fashae *et al.*, 2014). Land use also reflects the importance of land as a key and finite resource for

most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchments and storage. The land use/land cover map (LULC) of the study area (Figure 3) provides important indications of the extent of groundwater requirement and utilization (Narendra *et al.*, 2013). The LULC is generated from the Landsat OLI/TIRS 2015 satellite imagery. The major land use/land cover classes such as built up land (6.20%), Vegetation (42.67%), Bare Surfaces (1.18%), Wetlands (3.81%), and wastelands (45.28%) were identified in the study area. From the point of view of land use, wetlands and vegetation are excellent sites for groundwater exploration.

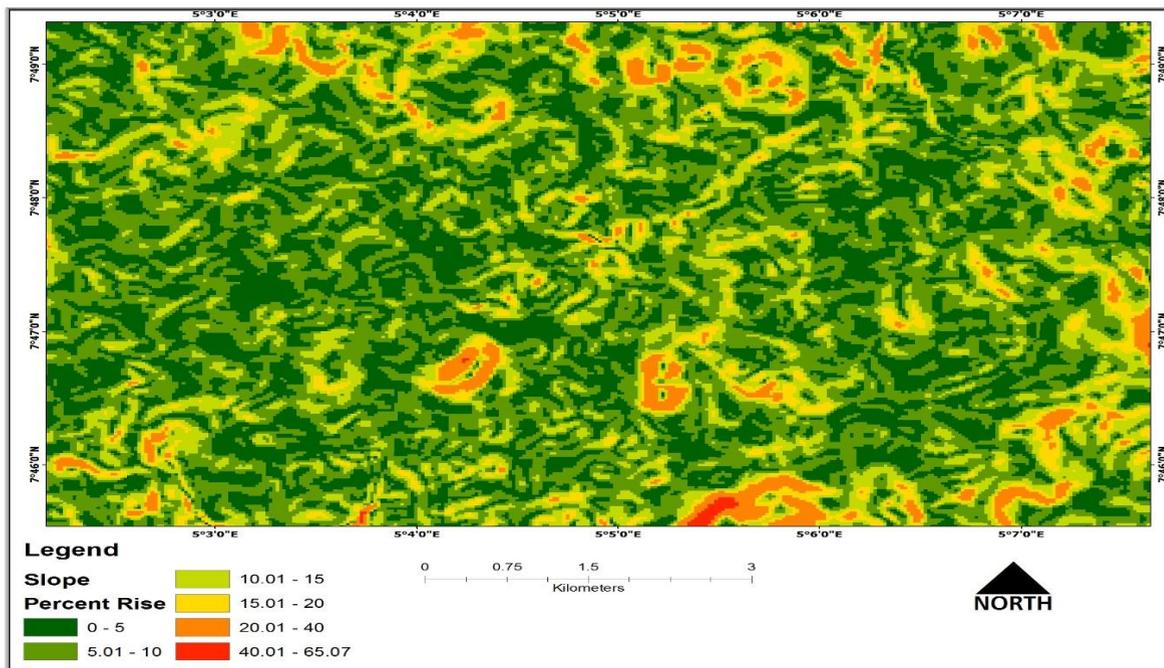


Figure 2: Slope Map of the study area

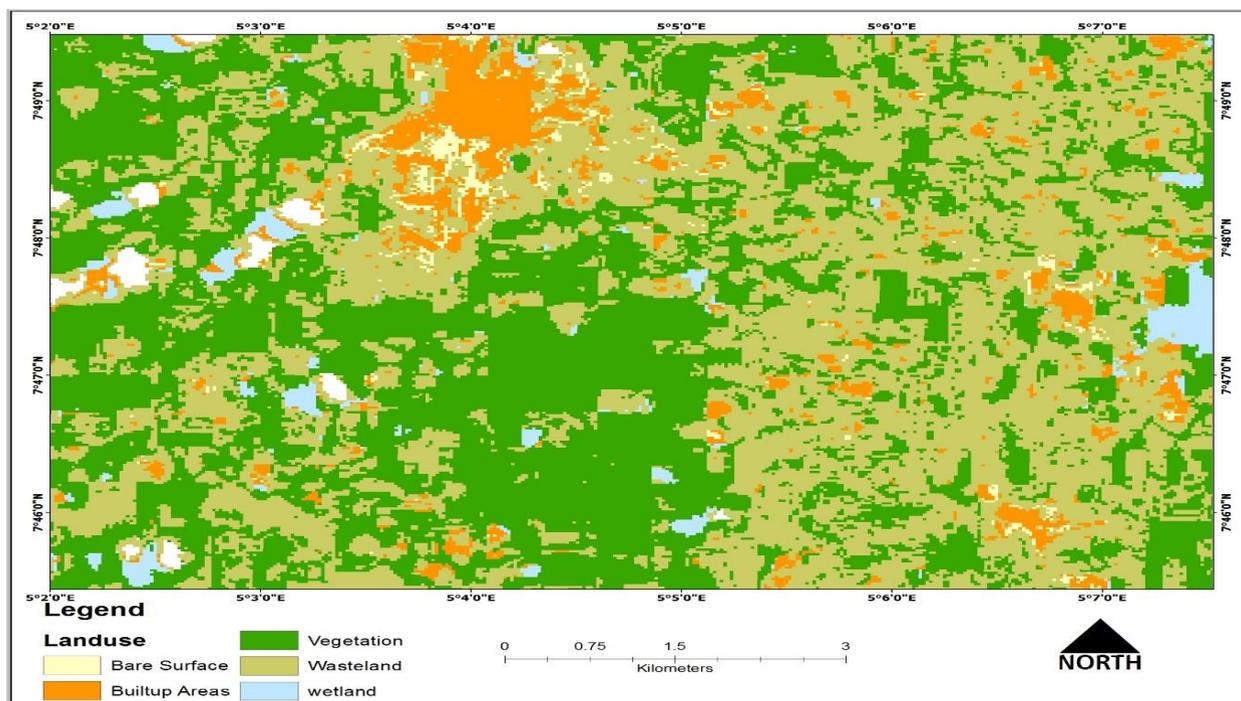


Figure 3: Land Use Map of the study area

About 46.48% of the catchment area, covered by vegetation and wetlands are highly favourable for groundwater potential while 46.42% comprising of wastelands and bare surface are mildly favourable.

Table 3 details the land use classes, their percentage distribution as well as assigned weights based on their groundwater prospect zones.

Table 3: Land Use/Cover Classes

Landuse	AREA	PERC_AREA	Rank	Weightage
Built-up areas	6.17	6.20	1	15
Vegetation	42.47	42.67	5	
Bare surface	1.17	1.18	3	
Wasteland	45.06	45.28	3	
Wetland	3.79	3.81	5	
	99.52	100.00		

Drainage

The drainage is one of the factors which play the important role in groundwater occurrence. A drainage map of the area (Figure 4) gives an idea about the permeability of rocks and also gives an indication of the yield of the basin (Wisler and Brater, 1959). The area of very high drainage density represents more closeness of drainage channels and vice versa; hence, the higher the drainage density, the greater the runoff while the lesser the drainage density, the lower the run-off and the

higher the probability of recharge or potential groundwater zone. Evaluation of the drainage map reveals that the catchment is consequent in nature mainly due to the original slope of the land surface. The flow of the direction of tributaries joining the main stream is controlled by structural features. Majority of the lower order streams are found to be in sequence in nature joining the higher order main stream at higher angles and lacking structural and geological controls.

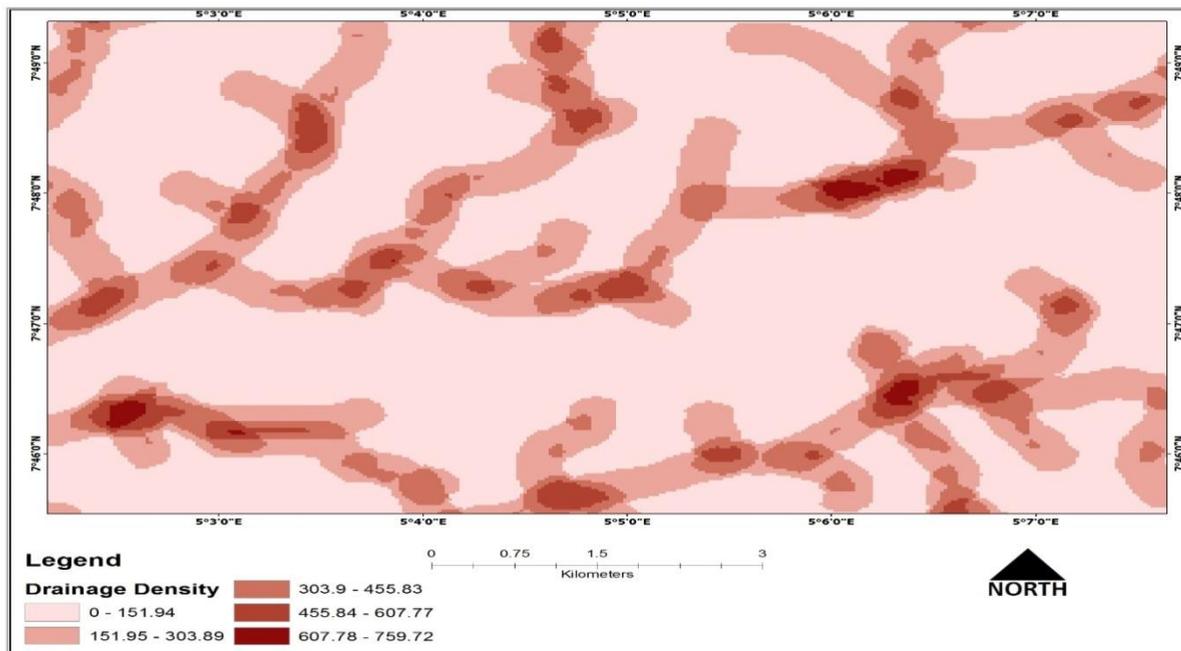


Figure 4: Drainage Map of the Study Area

The tributaries have spread irregularly in all directions and join the main stream at all angles. This suggested the dendritic and sub-dendritic drainage reflecting the homogenous character of the subsurface materials in the study area. Drainage density is the ratio of the total length of the stream to the area of the drainage basin. The drainage density map was generated from drainage network of the basin using GIS software. High drainage density is an unfavourable site for groundwater existence, moderate drainage density has moderate groundwater potential and less/no drainage density is high groundwater potential zone (Fashae *et al.*, 2014). Drainage density map of the study area is shown in Figure 4.

Lineaments

Lineaments like joints, fractures and faults are hydrogeologically very important and may provide the

pathways for groundwater movement (Sankar, 2002). Lineament density map 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 (Ali, 2005). The lineament map (Figure 5) is generated from the satellite imagery by identifying the fault lines in the imagery using the ArcGIS. The density of the lineament is generated using the lineament map. The study area is criss-crossed with lineaments consequent to a number of tectonic activities in the past. The prominent directions identified are SE-NE trends. Areas with higher lineament density are regarded as good for groundwater development (Azlikamil *et al.*; 1994). The weights have been given by setting more threat levels to higher lineament density which is groundwater prone (Figure 7).

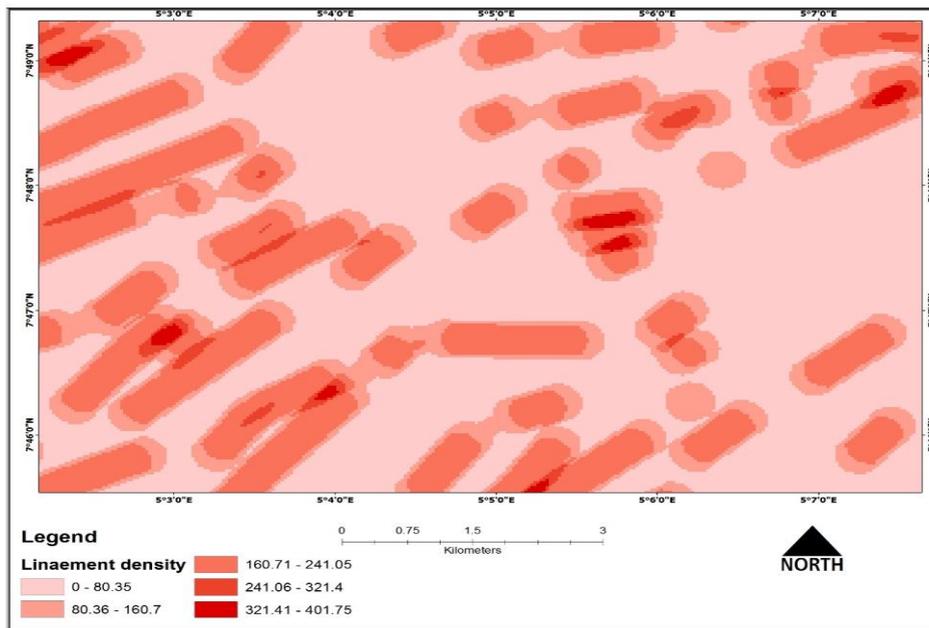


Figure 5: Lineament map of the study area

Soils

Fine-grained soils limit infiltration due to apparently low permeability unlike coarse-grained soil materials where water can infiltrate easily because of high permeability. In this study, two main soil units were identified: Ferric Lixisols and Ferric Alisols as shown in Figure 6. Given the relationship between the sand content/coarse grained materials and permeability, higher weightage was assigned soils with relatively higher permeability; thus Lixisols are assigned a weightage rank of 4 compared with that of Alisols with a rank of 2 indicating lower groundwater potentials.

Rainfall

The rainfall distribution in the study area ranges from 1,300 to 1,350 mm suggesting a humid tropical terrain with the entire study area receiving more than 1,000 mm of rainfall annually (Nimet, 2015). Areas with higher amount of rainfall signify very good groundwater potential while areas with the low amount of rainfall suggest poor groundwater. The rainfall of 1350 mean total annual rainfall suggests an area with good groundwater potential

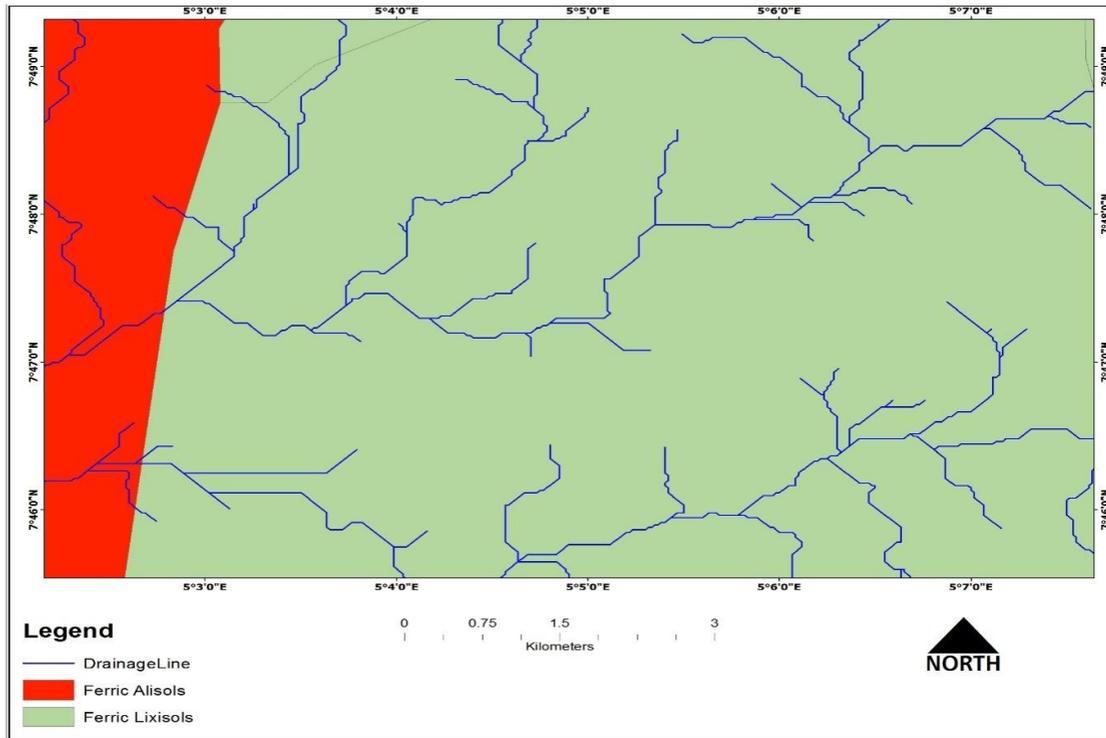


Figure 6: Soil map of the study area

Identification of Groundwater Potential zones

The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 10.3. During the weighted overlay analysis, the ranking has been given for each individual parameter of each thematic map and the weightages were assigned according to the influence of the different parameters and as presented in Table 4. These weightage have been taken considering the works carried out by researchers such as Krishnamurthy *et al.* (1996), Saraf and Choudhary (1998) and Srinivasa and Jugran (2003). All the thematic maps were converted into grid (raster format) and superimposed by weighted overlay method (rank and weightage wise thematic maps and integrated with one another through GIS (Arc / Info grid environment). In this study, the total weights of the final integrated grids were derived as sum of the weights assigned to the different layers based on suitability (ESRI, 1997). The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies

(Krishnamurthy *et al.*, 1996). In models derived through integration of various thematic maps using a GIS approach, several parameters are commonly involved to assess groundwater potential in the study area (Fig.4). The modelling involves delineation of zones of varying groundwater potential based on integration of six thematic maps in a raster based GIS. The six parameters considered are: Soil, Geology, Land use/ Land Cover, Lineament and Drainage and elevation. Every class in the thematic layers was placed into one of the following categories viz. (i) Good (iii) Moderate (iv) Poor, depending on their level of groundwater potential. Considering their behavior with respect to groundwater control, the different classes were given suitable values, according to their importance relative to other classes in the same thematic layer. From the analysis carried out, results of the weighted overlay shows that there are no areas of acutely high or low groundwater potential. The spatial distribution of the various zones of groundwater potential obtained from the model generally shows regional patterns related to soils, drainage and geology, lineament and Land use patterns. The good zonal categories are along major lineaments and drainage

channels with and without structural control, highlighting the importance of lineaments, geological and soil units for groundwater investigations (Bello *et al.*, 2019; Oyeyemi *et al.*, 2020). Areas with moderate groundwater potential are attributed to combinations of lithology and landform. The poor categories of groundwater potential are distributed mainly along hills, ridges and pediments and to some extent along lineaments in the low to poor slope classes. Areas with moderately low potential account for 3.33% of the study

area while areas with moderate and moderately high account for 58.7% and 38% respectively. This indicates that the study area with about 96% of the area has moderate groundwater potential. Areas with moderately low potential account for 3.33% of the study area while areas with moderate and moderately high account for 58.7% and 38% respectively. This indicates that the study area with about 96% of the zone has moderate groundwater potential.

Table 4: Classification of the groundwater potential zones

Groundwater Potential	AREA	Perc_area
Low	3.318294	3.334299
Moderate	58.37133	58.65286
High	37.83038	38.01284
	99.52	100

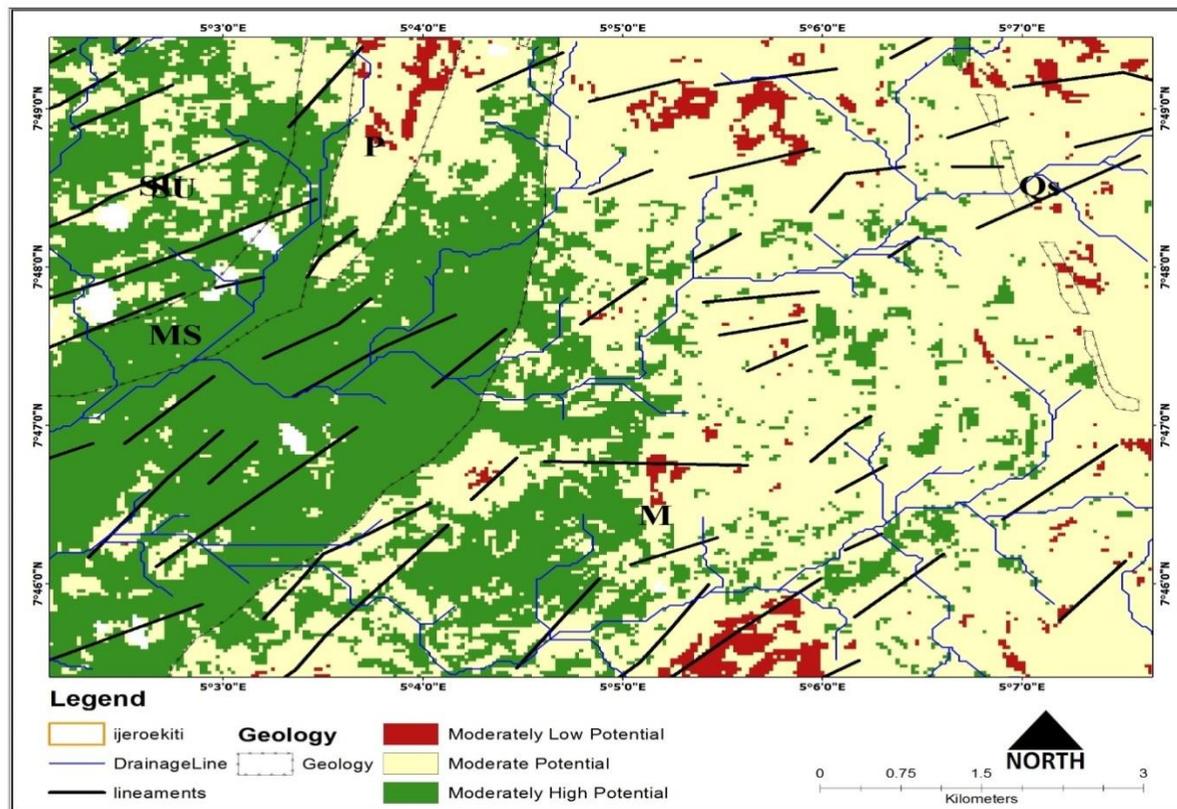


Figure 7: Groundwater Potential Map of the study area

Conclusions

Multipreliminary approaches (Remote Sensing and GIS) have been used to integrate various geological and hydrogeomorphological thematic maps, which play major role in occurrence and movement of groundwater. The integrated groundwater potential map has been categorized on the basis of normalized cumulative weightage assigned to different features of thematic maps. The groundwater potential map suggests the dominant influence of geology and geomorphological features in the delineation of the groundwater zone; the areas underlain by medium-porphyritic granite, biotite-hornblende granite and granite gneiss bedrock settings have moderate groundwater potentials compared to high potentials in the areas characterized by weathered/fractured quartzite, quartz-schist, amphibolite schist and phyllite bedrock settings. The overall integration of the thematic layers revealed that the study area can be categorized into three different groundwater potential zones: low, moderate and high. Areas with moderately low potential account for 3.33% of the study area while those with moderate and moderately high account for 58.7% and 38% respectively. The general indication is that the study area is 96% of it classified as moderate in groundwater potentials. The validation clearly highlights the efficacy of the integrated multi-criteria decision analysis methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation presented here can be applied only for regional studies for the purpose of groundwater development, providing quick prospective guides for groundwater exploration and exploitation in such crystalline basement settings, while individual site selection for groundwater development should take into consideration other site-specific conventional ground truthing methods, like surface geophysical methods.

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