Delineation of Groundwater Potential Zones of Minna and its Environs, North Central Nigeria: an Integrated GIS and Remote Sensing Approach

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ABSTRACT

Due to the discontinuous nature of groundwater occurrences in the basement complex terrains and Nigeria in general, groundwater development without the necessary pre-drilling hydrogeological investigations may result in low success potential groundwater delineation. Thus, there is the need for adequate characterization of aquifers and delineation of groundwater potential zones in such basement setting. This research employed the integration of multi-criteria decision analysis (MCDA), remote sensing (RS) and geographical information system (GIS) techniques to delineate groundwater potential zones of Minna, North central-Nigeria. The study approach involved integration of nine different thematic layers (geology, rainfall, geomorphology, soil, lineament density, landuse, water proximity, drainage density and slope) based on weights assignment and normalization. The thematic maps were then integrated using ArcGIS 10.5 software to generate the overall groundwater potential map for the study area. The research revealed three groundwater potential zones (GPZ) as indicated on the final map, namely low, moderate and high zones. Areas with low PGZ covered about 747.64 km^2 (45.69%), Moderate GPZ covered about 885.78km^2 (54.13%) while areas with high GPZ covered about 2.83 km^2 (0.17%). The research highlights the efficacy and useful of modern approach for proper groundwater resources evaluation; providing quick prospective guides for groundwater exploration and exploitation in a basement complex.

Keywords: *Groundwater Potential zones; Geographical information systems; remote sensing; Basement complex, Minna*

1. INTRODUCTION

One of the major constraint is the Nigerian basement complex is the discontinuous nature of groundwater occurrences coupled with high rate of well/borehole failure in the absence of proper and adequate pre-drilling hydrogeological investigations. The occurrence and movement of groundwater in the basement complex terrain depends on the degree of weathering and extent of fracturing of the bedrock rocks, while identification of potential groundwater zones could help in proper development and utilization of groundwater resources for eliminating water scarcity (Rao 2006). Therefore, there is the need for adequate characterization of basement aquifers and delineation of groundwater potential zones (Olutoyin et al., 2013).

In the past years, several conventional methods such as geological, hydrogeological, geophysical and photogeological techniques were employed to delineate groundwater potential zones and still in use today (Meijerink 1996; Edet et al., 1998; Srivastava and Bhattacharya 2006). However, in the recent years, with the advent of powerful and high-speed computers, digital technique is used to integrate various conventional methods with satellite image/remote sensing (RS) techniques and geographical information systems (GIS) technology (Olutoyin et al.,2013.; Talabi and Tijani 2011).

Integration of Remote Sensing, GIS and AHP decision technique has gone a long way in enhancing potential Groundwater zones through overlaying all the thematic layers using weighted overlay tool in ARCGIS to generate a spatial groundwater distribution of an area. Many assessments of groundwater potential zones using remote sensing technology have been reported (Tesfaye, 2010; Khairul-Anam *et al.,* 2000; Shahid *et al.,* 2000.

Tesfaye (2010) uses integrated method in evaluating groundwater potential of Blilate river catchment south rift valley of Ethiopia through generation of thematic maps using GIS. The result was validated by selective ground truth verification and four groundwater potential zones were identified which are high, moderate, low and poor.

The demand for drinking water in Minna has increased over the years as a result of increase in population and subsequent urbanization. This has made access to potable water supply a challenge. Therefore, there is a need to apply a cost effective technique like remote sensing and GIS in the exploration for ground water to compliment the few surface waters. However, there is no previous study or report on the use of remote sensing and GIS as a tool in assessing groundwater resource potential in Minna area. Hence, the objective of this research is to characterize and delineate the zones with potential groundwater in the area.

2. STUDY AREA

2.1 Location and accessibility

The study area of the research is located between latitude 9°24′0″N to 9°45′0″N and between longitude 6°10′0″E to 6°40′ 0″E as shown in fig.1. Minna is bounded in the North by Rafi, Shiroro, Muya & in the South by Paiko, Gurara, Suleja. The study area is accessible through major roads from Kontagora-Minna, Suleja-Minna, Bida-Minna and can also be accessed through connected Railways (Jebba-Minna; Kaduna-Minna).

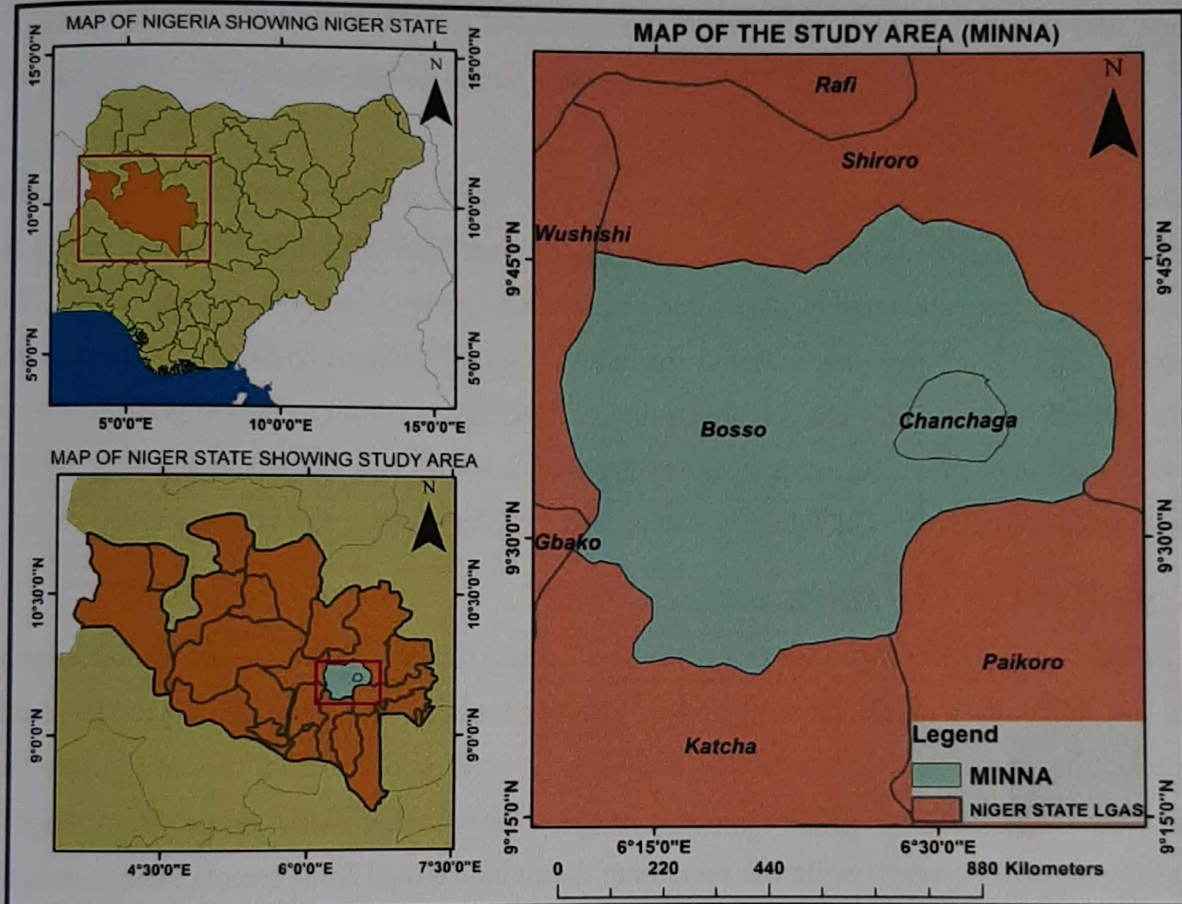

Figure 1: Location map of the study area

2.2 Physiography and Drainage

The area is marked by high relief to low hills as well as plain lands. The area is drained mostly by Shango River which also, extends into Chanchaga. There are few seasonal streams around Bosso area of Minna and pockets of ponds too.

The study area lies within the sub-humid tropical zone, and has a mean annual rainfall that Range between 1100 to 1320mm (Olutoyin et al., 2013). It experiences two main alternating seasons: dry and wet seasons. Rainfall lasts from April/May to September/October, characterised by moisture laden South Westerly winds blowing from the Atlantic Ocean, while the dry season lasts in-between with predominantly North-East trade winds.The vegetation pattern of the study area is basically moist savannah, characterized by mixtures of trees, shrubs, grasses, and herbs.

Farming and small scale Gold mining/quarry is the main occupation of the area. Crops grown in the area include maize, guinea corn yam.

2.3 Geology of Minna area

The study area consists of four main rock types. These include Granites, Gneiss, schist, migmatite around the Rafin Yashin area, and the granites .The schist has b een intruded by the granites and form sharp contacts at some places while inferred contacts in other places. The granite occurs extensively as batholith spanning from the Maikunle to Maitumbi areas. Some are generally low-lying, light coloured with characteristic medium to coarse grained texture. Mineral components of the rock consist of quartz, feldspar and mica. The schist is slightly weathered and foliated. The foliation is manifested by displacement of schistocity the rock..

3. MATERIALS AND METHODS

The methodology employed for this research consists of data generated from remote sensing & GIS (secondary data) and validated by structural map. To achieve the objective of this research as stated in the introduction included the integration of nine thematic layers viz: geology, soil, drainage and lineament maps, rainfall data was gotten from Nigeria Meteorological Agency, while the remaining data was derived from remote sensed data for example, the land-use, slope and geomorphology using ArcGIS 10.5. Geomatica, Rockwork, SAGA GIS and Envi software was used in the generation of lineament of the study area. All the parameters were compared against each other in a pair–wise comparison matrix using AHP approach then they were later normalized to determine the parameter that is most important to groundwater.

3.3 METHODOLOGY

The methodology flow chart (Figure: 2) summarizes all processing and analysis that have been carried out in order to fulfil the objective of this research.

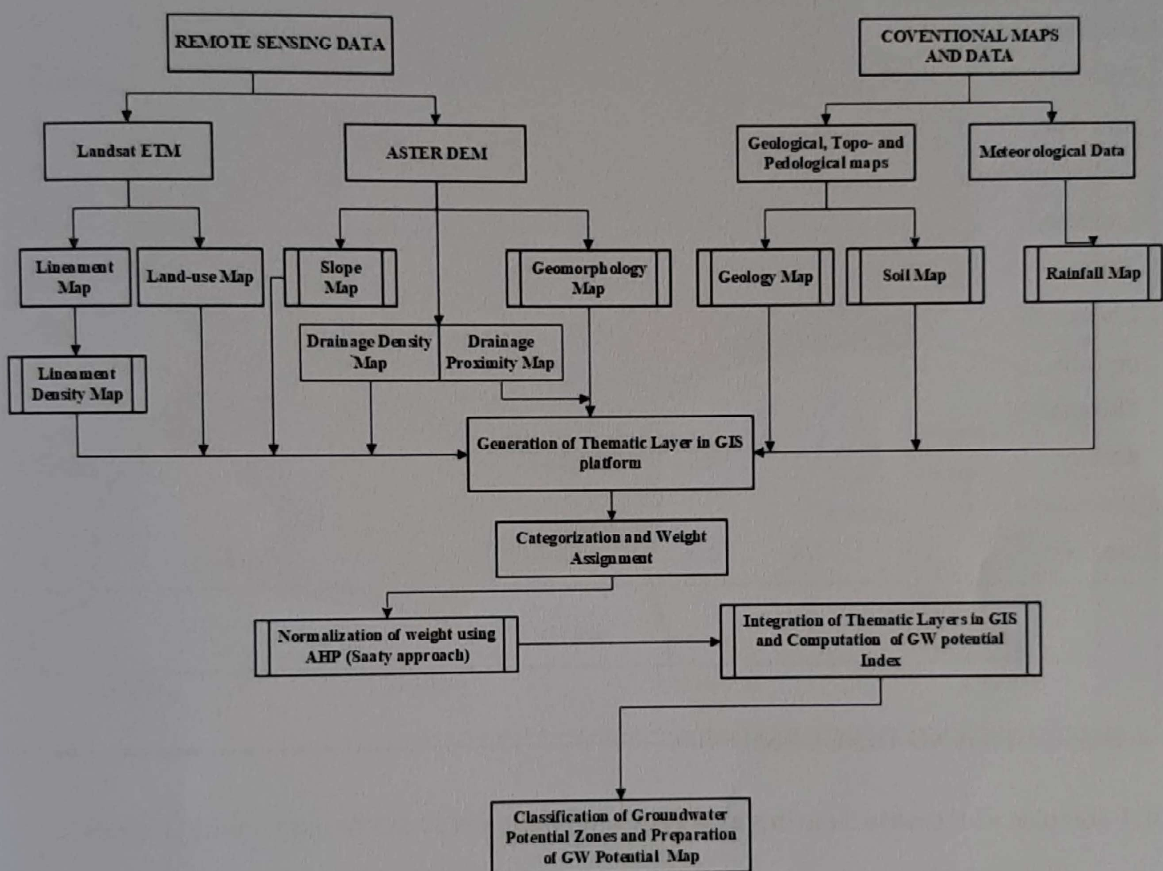

Figure 2: Flowchart showing Methodology

Table.1 the pair-wise comparison matrices table of the different themes

	Pairwise comparison								
	GG	RF	ST	GM	LU	SL	LD	DD	DP
Geology	1	1	1	1	1	2	3	4	9
Rainfall	1	1	1	1	1	2	3	5	8
Soil type	1	1	1	1	1	1	2	2	7
Geomorphology	1	1	1	1	1	1	1	2	6
Landuse	1	1	1	1	1	1	1	4	4
Slope	½	1/2	1	1	1	1	1	2	3
Lineament density	1/3	1/3	½	1	1	1	1	0.2	3
Drainage density	¼	1/5	½	½	¼	½	5	1	2
Drainage proximity	1/9	1/8	1/7	1/6	1/5	¼	1/3	½	1

4. RESULTS AND DISCUSSION

4.1 Results of Remote Sensing and GIS analyses

4.1.1 Slope map

Slope is one of the factors controlling the infiltration and recharge of groundwater system and can give indication of groundwater prospect of an area. Hence, in low slope there is more time for infiltration of rainwater while the surface runoff is low. However, high slope area enhances high runoff with short time for water to infiltrate. In this study, the slope thematic map as presented in Fig.3 revealed slopes ranging from less than 7.03% to more than 21.11%. About 630.176626km^2 is covered by less than 7.03% slope, which signifies nearly flat surfaces to very gentle slopes and constitutes about 38.06 % of the study area while about 622km^2 7.04 - 12.79% slope (gentle to slight slopes) making up of 37.59%. Area with 12.8 - 21.1 (slightly steep) and greater than 21.11 % slope (steep slopes) cover area of 332.86 and 70.01km^2, respectively, both of which constitute 24 % of the total area. By implication, the southern part of the study area has nearly flat surfaces to very gentle slopes.

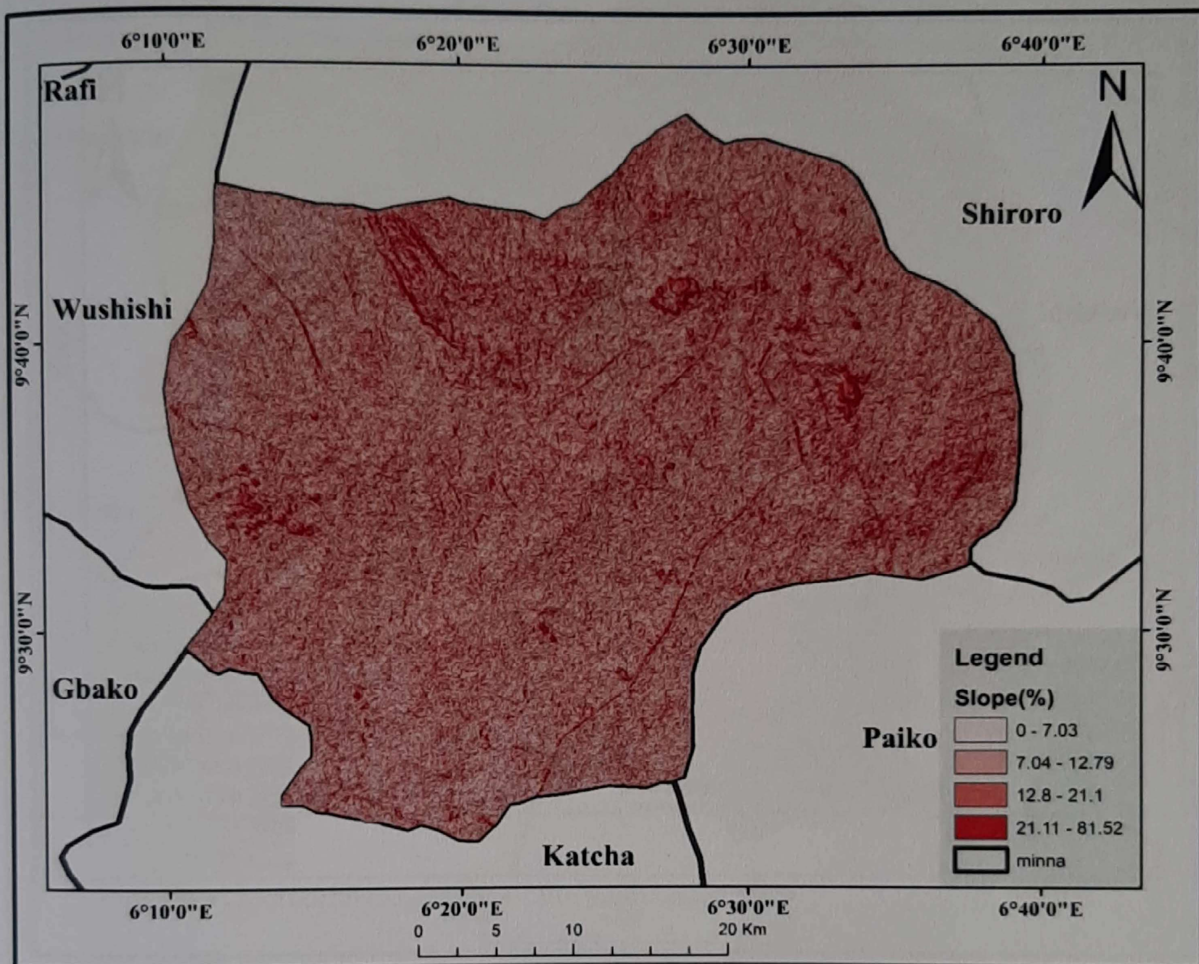

Figure 3: Slope map of the study area

4.1.2 Lineament density map

Lineaments are structure features in rocks of basement complex with openings which serves as a passage and conduit of fluid from the surface to the subsurface. Also a passage via which recharge is made to aquifer at subsurface from the surface.

For the study area, the lineament density ranges from less than 0.38 km/km^2 to greater than 1.2 km/km^2 (Fig. 4) About 594.969572 km^2 is covered by less than 0.38 km/km^2 which signifies low lineament density and constitutes about 35.96% of the study area. About 20.387701km^2 is covered by more than 1.2 km/km^2 which signifies high lineament density and constitutes about 1.23%. With area underlain by Amphibole schist having high lineament density while area underlain by Medium to coarse grained biotite granite having low lineament density. Hence, areas with higher lineament density are regarded as good for groundwater potential because they serve as conduit for groundwater recharge and occurrence

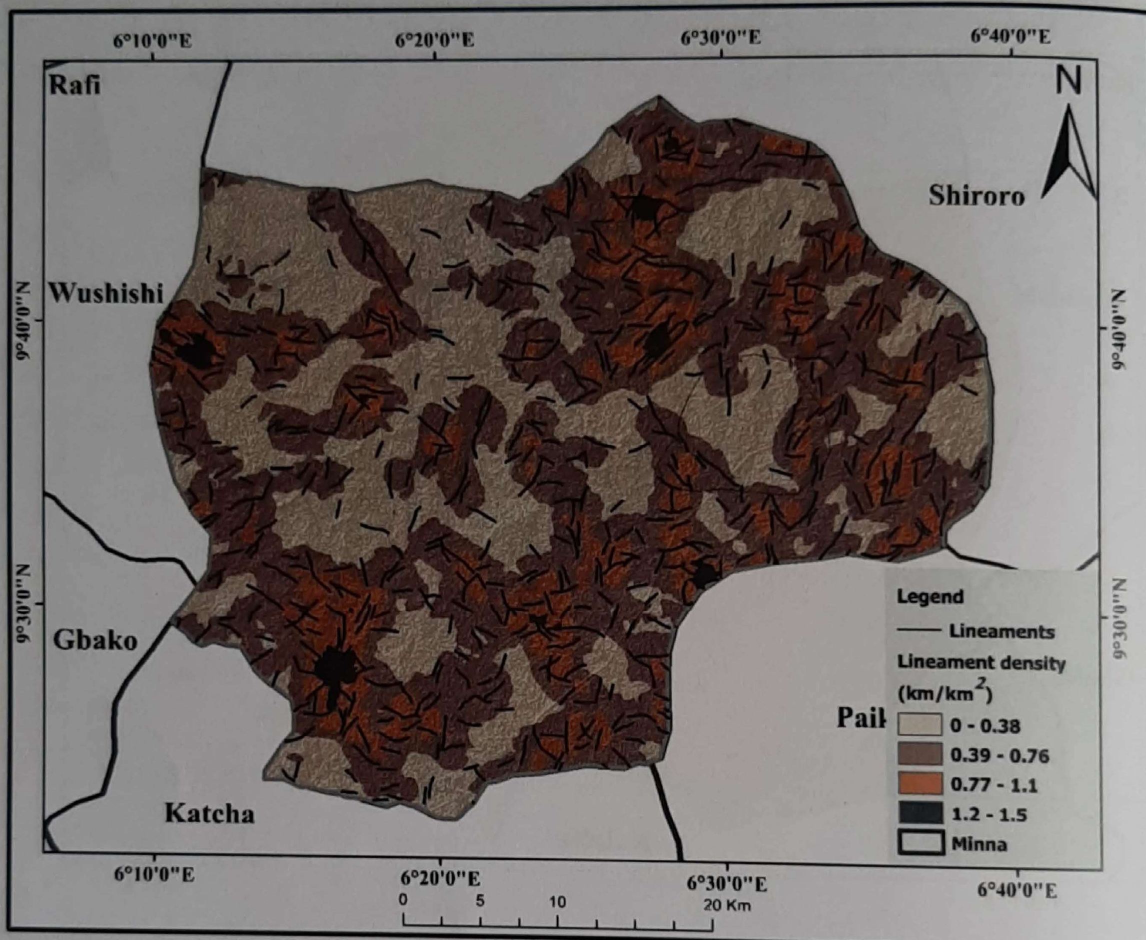

Figure 4: Lineament density map of the study area

4.1.3 Geomorphology

In this study, four different geomorphological features were identified based on changes in elevation generated from detailed study of the area DEM (Fig.5). Areas with lowland and plains which signifies low elevation occupy about 432.03 km^2 (26.09%) and 475.58 km^2 (28.72%) respectively.

Plains are area of lowland either level or undulating, hence it represents area suitable for groundwater recharge while inselberg is area of highland having steep sides, round top and composed of granite which tend to increase amount of run and not suitable for groundwater recharge.

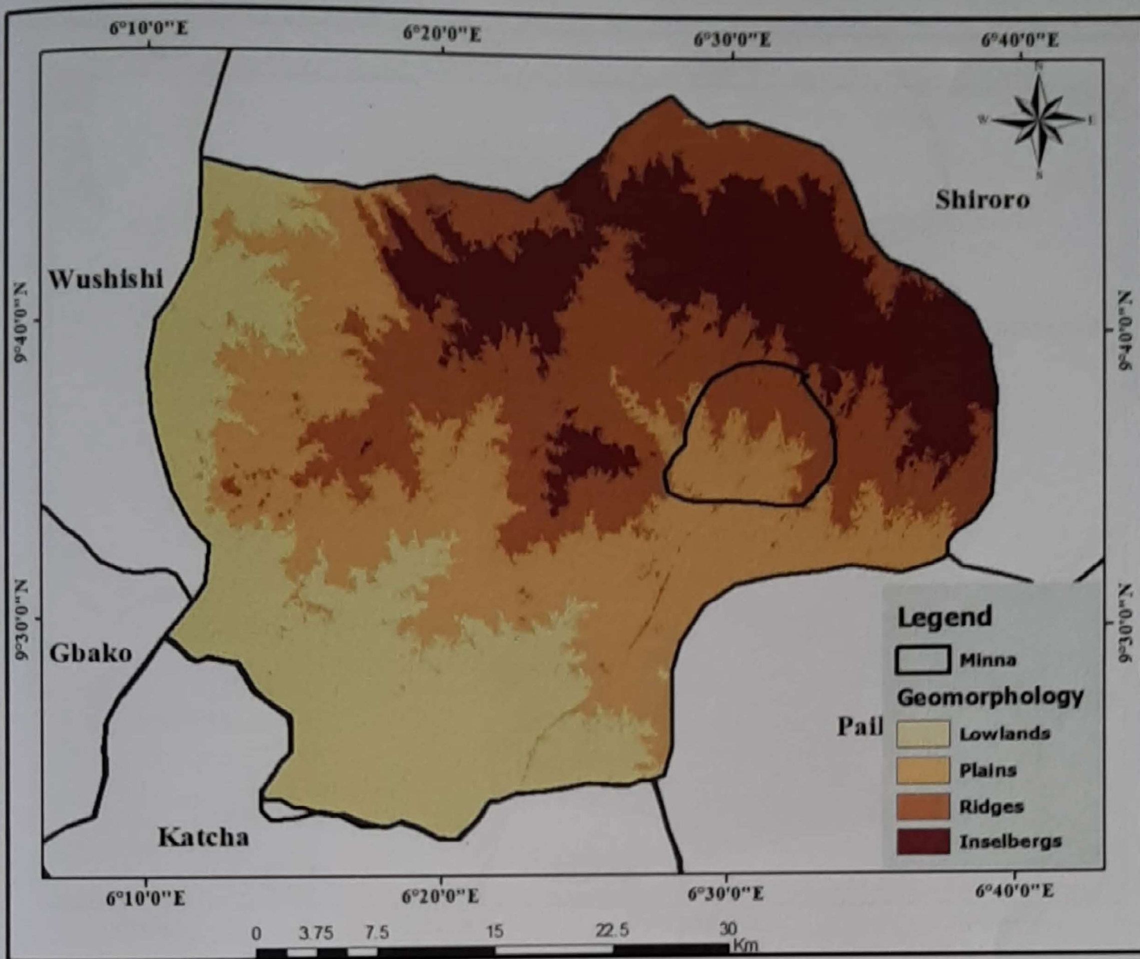

Figure 5: Geomorphology map of the study area

4.1.4 Drainage density

It has been suggested that a measure for permeability is drainage density (i.e. total length of drainage channels per unit area), in the sense that permeable conditions are associated with low drainage density and vice versa (Meijerink 2007). Fig.6 shows the drainage density pattern of the study area ranging from < 3 to > 7 covering about 606.71km^2 (36.65%), 682.55km^2 (41.23%), and 365.83km^2 (22.10%) respectively.

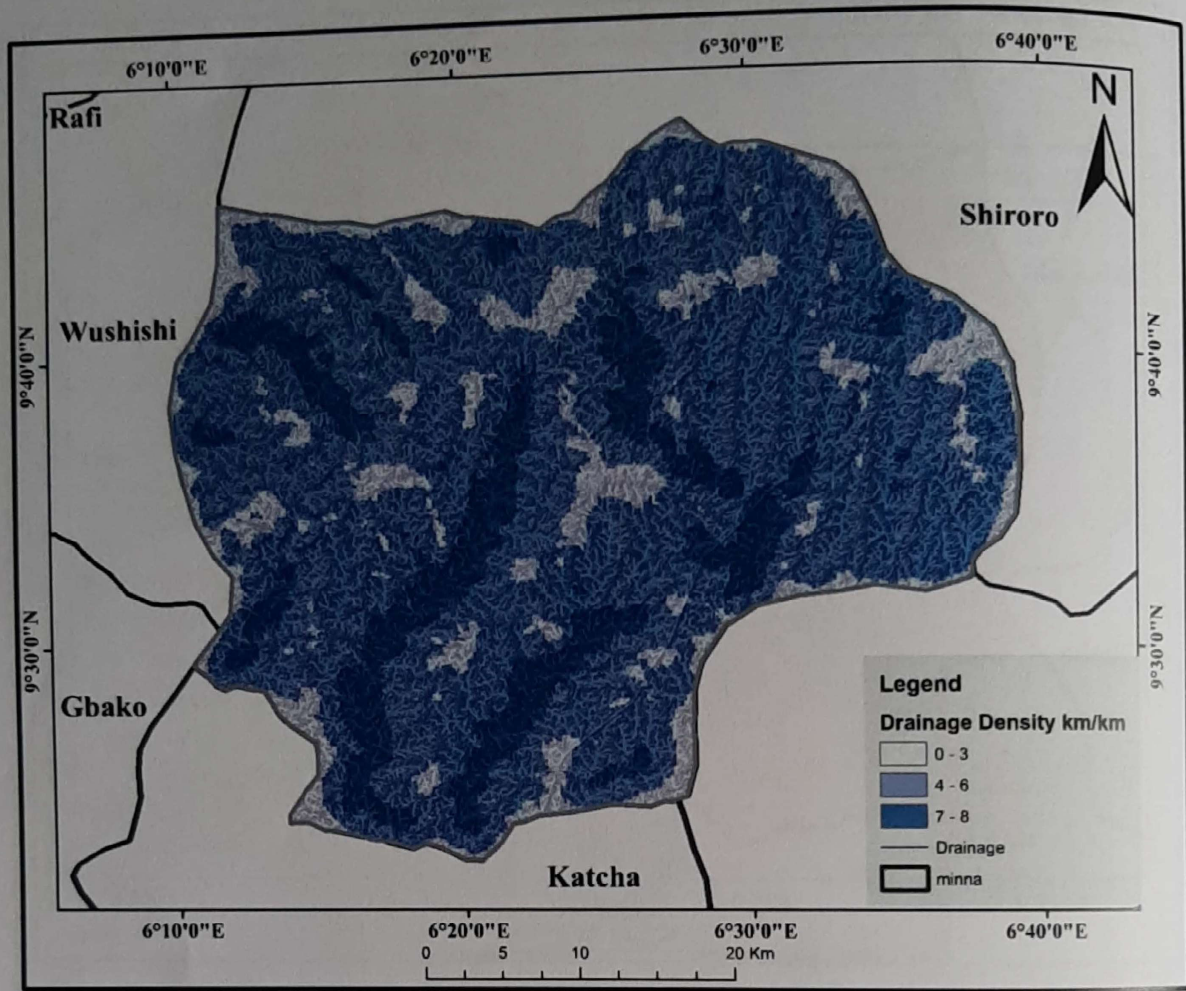

Figure 6: Drainage density map of the study area

4.1.5 Water Proximity

Eculidean distance in Arctool box was used to generate the water proximity pattern of the study area and was divided into three zones. The zones include < 254, 255-509 and >509 meters with a total area of 1520.47km^2 (91.89%), 133.49km^2 (8.06%) and 0.59km^2 (0.03%) respectively (Fig.7). The 254-m buffered area around the surface water bodies was considered as a more suitable zone for groundwater occurrence than other areas. This is based on the knowledge that zones closer to water bodies have a very low infiltration ratio compared to those far away.

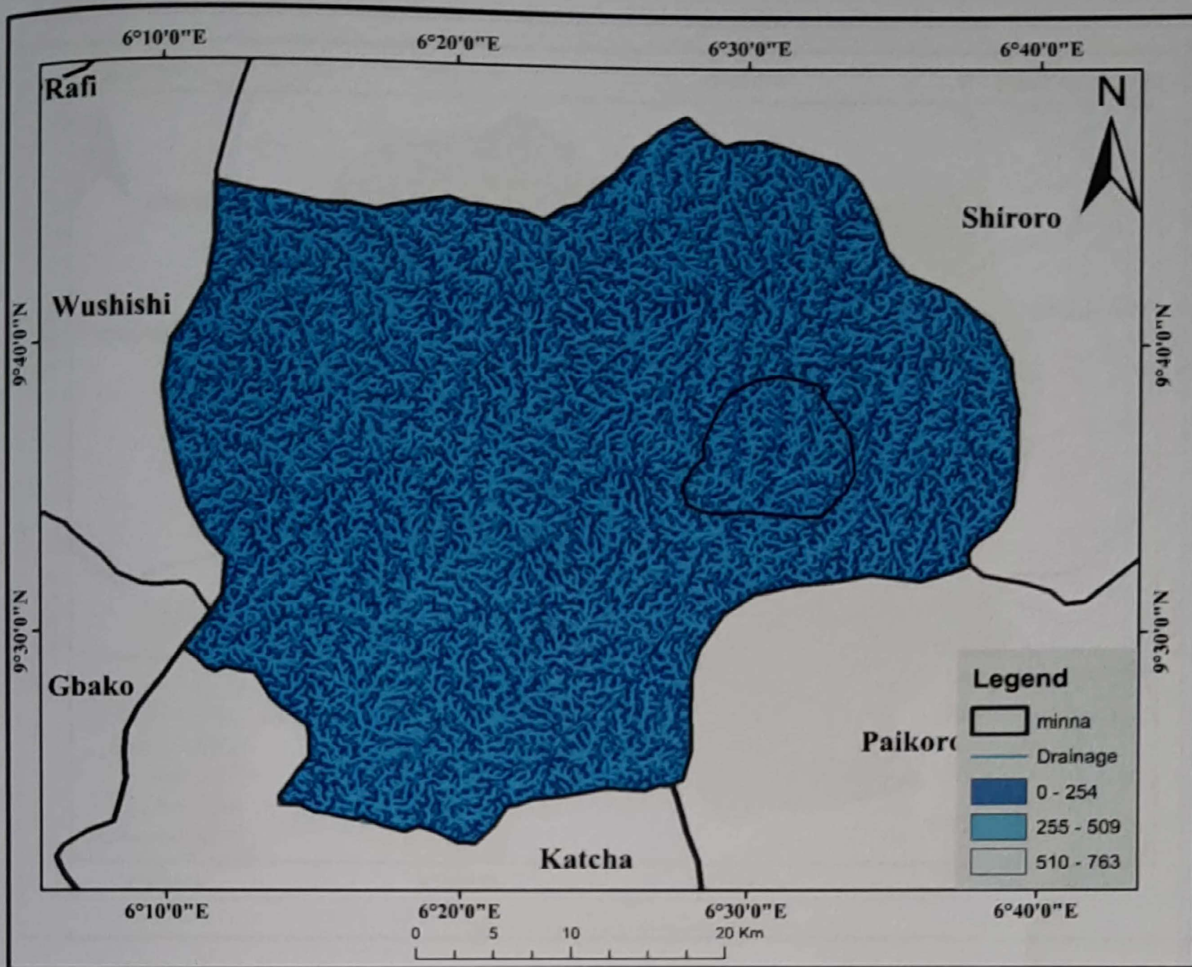

Figure 7: Water proximity map of the study area

4.1.6 Land Use and Land Cover

This also plays an important role in the movement of surface water to the subsurface. Five different kinds of Land use and Land cover were observed in the study area namely; Water bodies, vegetation, Rock, built-up as well as bare surface (fig.8). Rock bodies as the dominant land cover types covered an area of about 711.39km^2 (42.97%), followed by bare surface covering about 516.63km^2 (31.21%). Vegetated area covers about 401.70km^2 (24.26%). Built up area constitute about 24.26km^2 (1.53%) while water bodies covers about 0.20km^2 (0.012%) only.

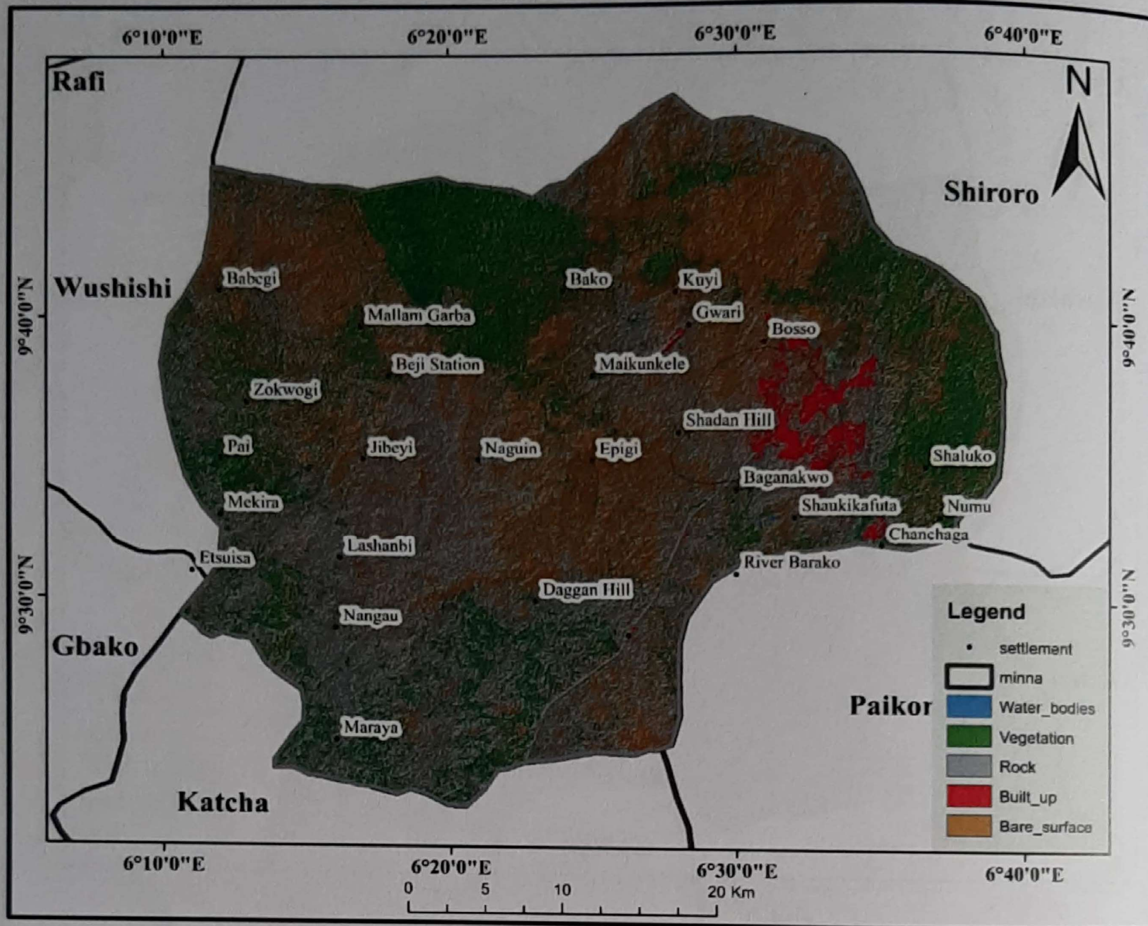

Figure 8: Landuse/landcover map of the study area (generated from Landat imagery)

4.2 Result gotten from Secondary data

4.2.1 Rainfall

Rainfall is one of the major source of supply for groundwater recharge. For the study area the rainfall distribution ranges from 80.33mm to > 89.31mm (Fig 4.2.1 shows the rainfall distribution pattern of the study area). From the map created, it can be depicted that area along the north western part have relatively low rainfall (< 83.32mm) while the southern part of the area have higher rainfall (> 89.31mm).

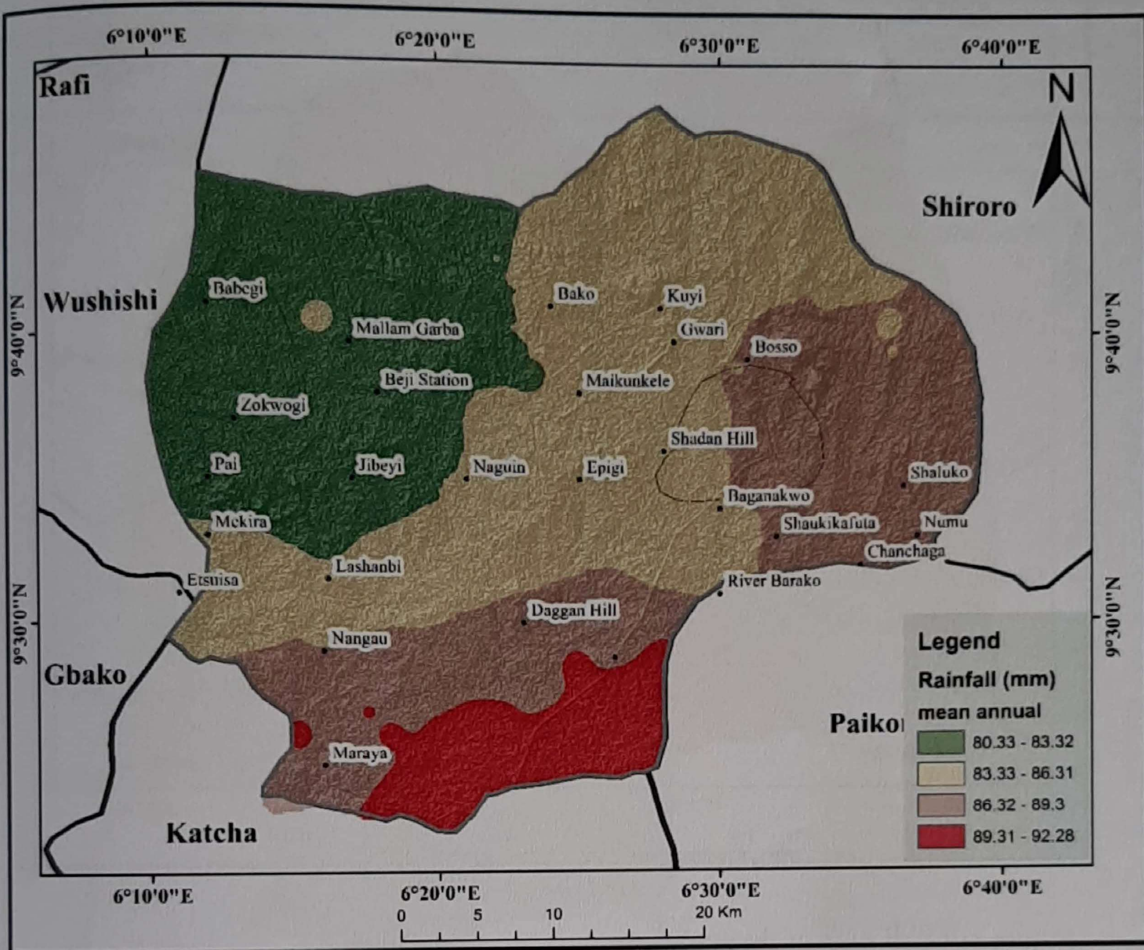

Figure 9: Rainfall map of the study area

4.2.2. Soil

Soil is a principal factor that governs the movement of water from the surface to the subsurface owing to grain sizes. Coarse grained soil is highly porous and permeable than fine- grained soil thereby making water to infiltrate easily to the subsurface. Three different type of soil type were identified within the study area namely; Loamy sand, Sandy-loam and Sandy clay-Loam occupying 123.62km (7.445%), 1522.47km (91.69%) and 14.30km (0.86%) respectively as shown in Fig.10

Owing to high porosity and permeability areas with Sand-Loam was observed to contribute massive infiltration of water to the subsurface.

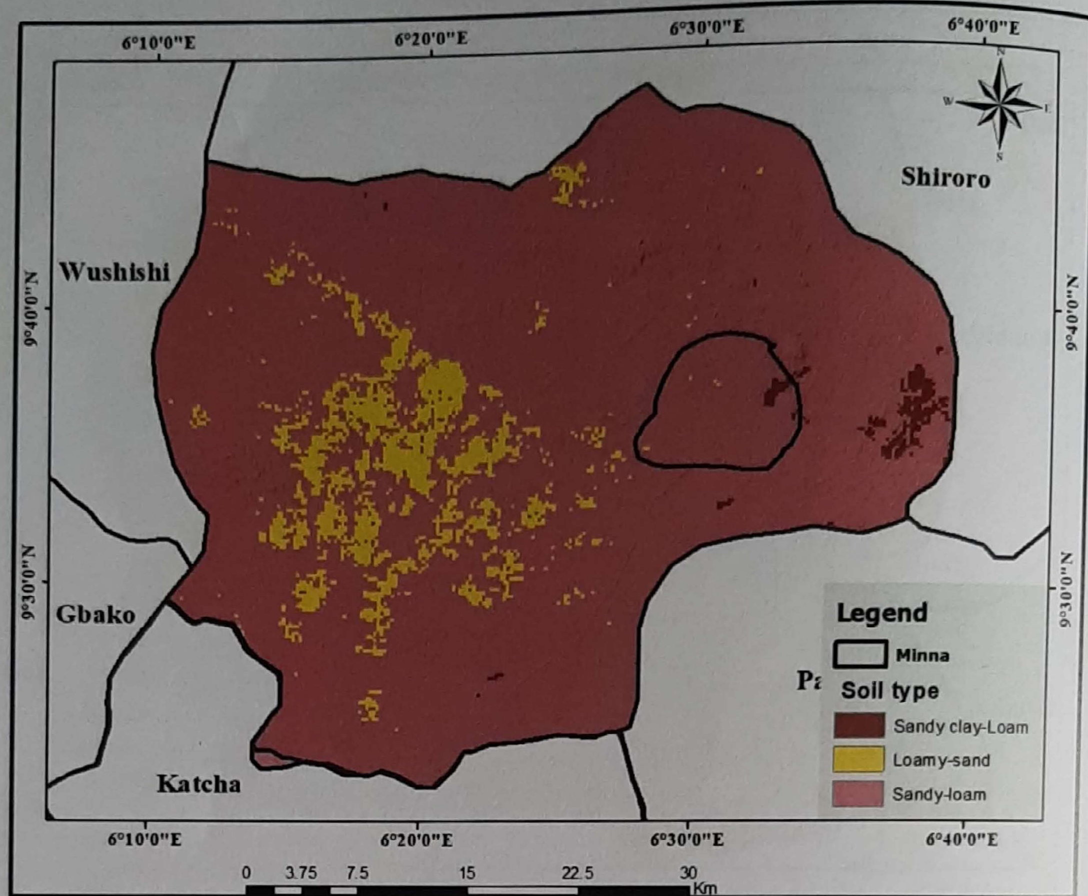

Figure 10: Soil map of the study area

4.2.3 Geology

The geology formation of an area also plays a significant factor in the delineating of groundwater. In fact, owing to its importance it was ranked second among the parameters associated with groundwater occurrence. The study area is underlain by basement complex rocks which comprises of igneous and metamorphic rock (amphibole schist, fine grained biotite granite, migmatitic gneiss, mylonite, schist, silicified sheared rock, undifferentiated granite, medium to coarse grained biotite granite and meta-sediment) *Fig.11*. The dominant rock in the study area include Medium to coarse grained biotite granite and Migmatitic Gneiss covering about 396.94km^2 (23.81%) and 356.38 km^2 (21.38%) respectively. While schist, Fine grained biotite granite, Undifferentiated granite, Amphibole schist, Mylonite, Feldspathic sandstone and siltstone, Silicified sheared rock and Meta volcanic, meta-sediment cover about 289.66km^2 (17.37%), 276.97 km^2 (16.61%), 141.88km^2 (8.51%), 91.90 km^2 (5.51%), 72.67 km^2 (4.36%), 14.11 km^2 (0.84%), 13.41 km^2 (0.80%), and 12.90 (0.77%) respectively. Areas with schist was noted to contribute massively to the occurrence of subsurface water while areas with migmatitic gneiss was ranked the least.

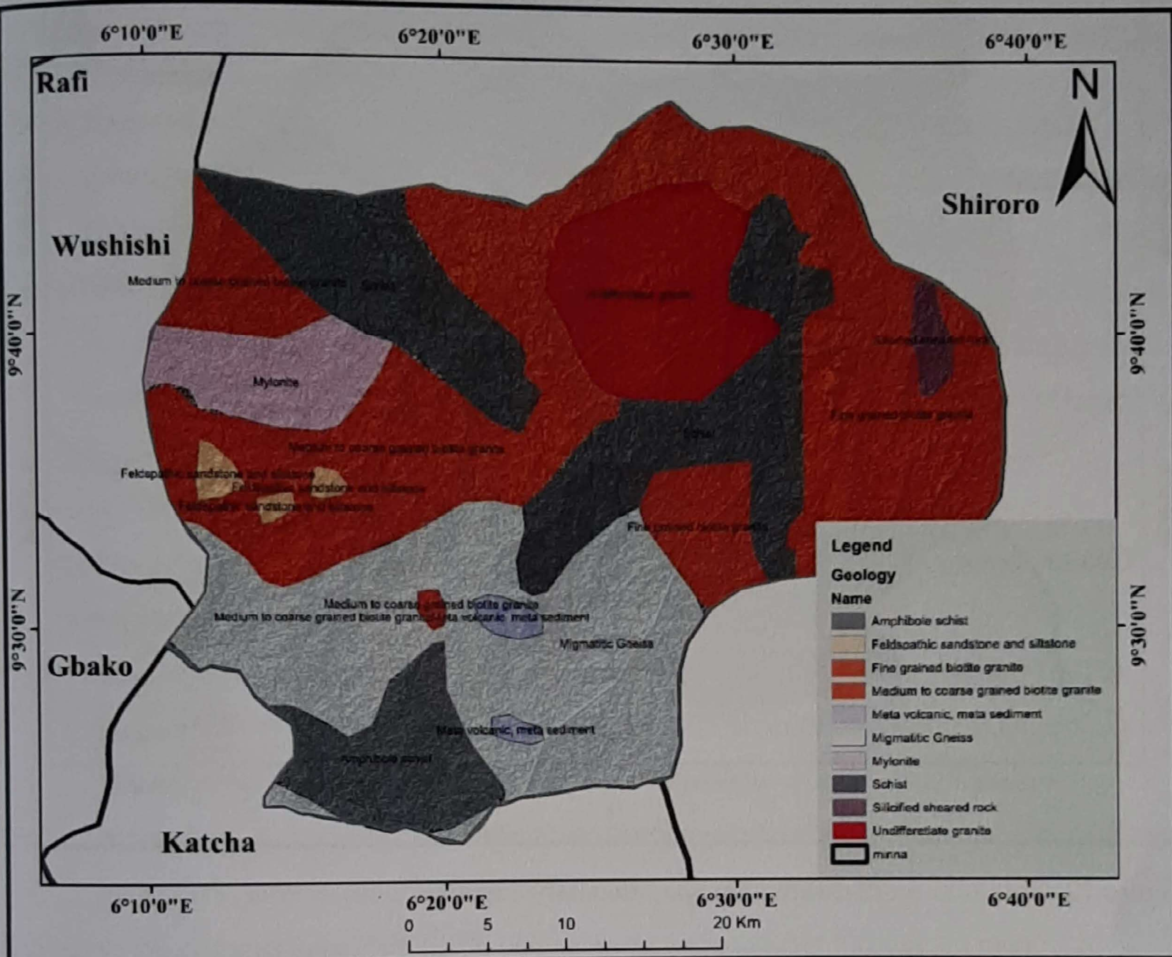

Figure 11: Geology map of the study area

4.3 Classification of groundwater potential zones

The potential groundwater zones (PGZ) of the study area revealed three distinct zones, namely low, moderate and high zones whose distribution varies over the study area. Areas with low PGZ covered about 747.64 km^2 (45.69%), Moderate PGZ covered about 885.78km^2 (54.13%) while areas with high PGZ covered about 2.83 km^2 (0.17%) only. These areas are around Tunga, part of Bosso, kpakugun, Part of Maikunkele, Chanchaga, part of Maitumbi and its environ A close observation on the PGZ shows that groundwater occurrence in the study area is majorly controlled by the Rainfall, Geology and soil type as they play their individual role in the conduit of water from the surface to the subsurface.

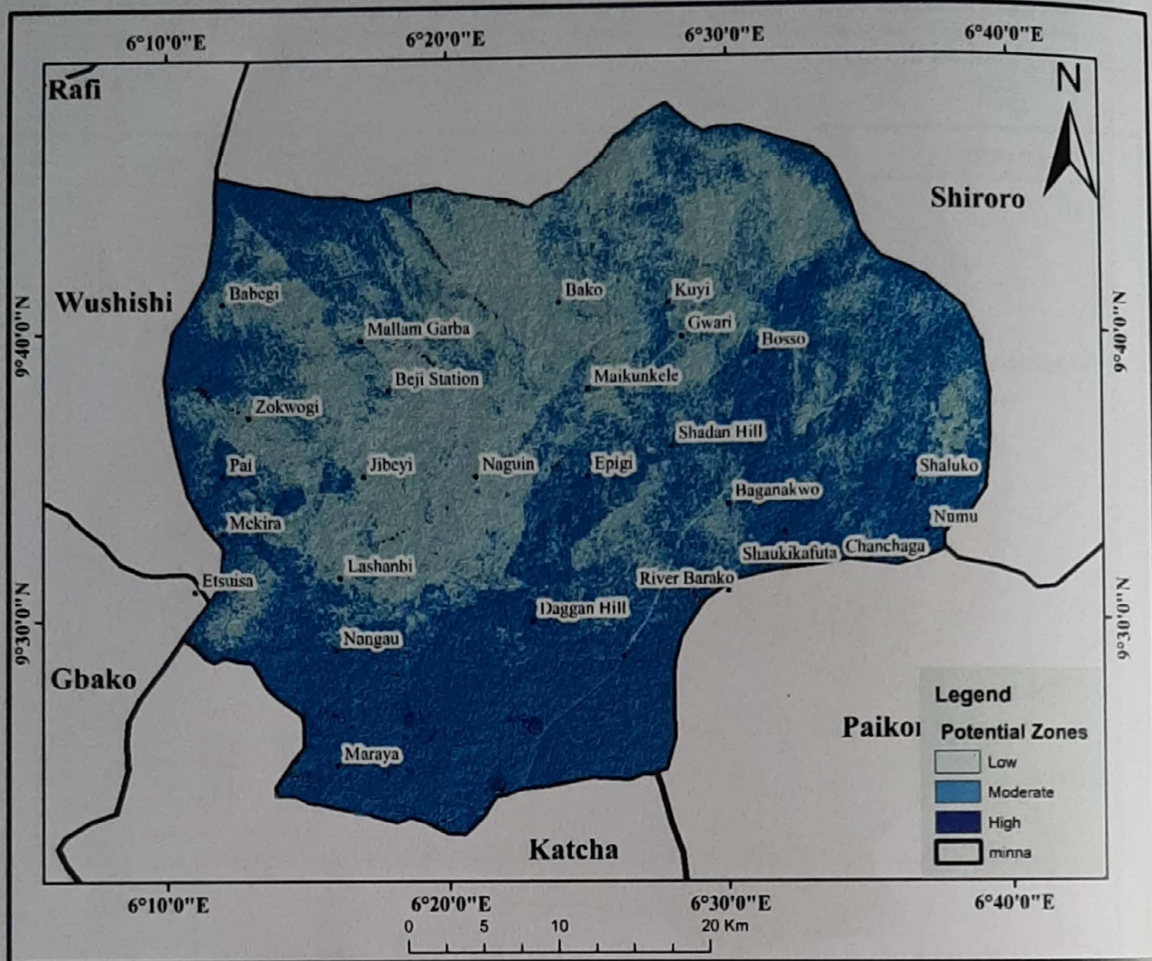

Figure 12: Potential groundwater zones of the study area

5. CONCLUSIONS

The results of the study shows how importance and easy the integration of remote sensing data, GIS, muti-criteria can be used in the delineation of groundwater . The result generated also served as reconnaissance investigation technique as it shows the overall grounwater disturbution of the area. Base on the different thermatics map used for this study, the groundwater potential of Minna area were characterized into three main different categories which are areas of low, moderate and high groundwater potential. The areas with high groundwater potentials were validated by high lineament density, low slope, low drainage density, high rainfall as compared to the low groundwater potential were it has low lineament density, high slope, low rainfall.

Nevertheless, the result presented here can be applied only for large scale studies for the purpose of groundwater development, as itwill assists policy makers to have an overall guides for groundwater exploration and exploitation while individual site investigation for groundwater development to take into consideration other site-specific conventional ground-truthing methods such as geophysical survey.

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