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# DELINEATION OF GROUNDWATER POTENTIAL ZONES IN SOME SELECTED TOWNS WITHIN MINJIBIR LOCAL GOVERNMENT AREA OF KANO STATE

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***ABSTRACT***
*Sustainable management of groundwater resources requires precise quantitative assessment, which can be accomplished through scientific theories. This study used an integrated approach to assess the potential groundwater zones within selected towns in the Minjibir Local Government area of Kano State. The assessment was carried out using the Analytical Hierarchy Process (AHP) method. Seven thematic maps on the occurrence and movement of groundwater were generated. These maps included multiple factors such as slope, drainage density, geology, land use/land cover (LULC), precipitation, lineament density, and soil. The standardized weights were determined using a pairwise comparison matrix derived from the Analytic Hierarchy Process (AHP). This approach was utilized to produce, a map illustrating the groundwater potential zones within the study area. Therefore, this study can form the basis for further research in determining the percentage yield of groundwater potential zones for optimal groundwater management.*

***KEYWORDS;*** *Groundwater, land use/land cover, remote sensing, and Analytical Hierarchy Process.*

## 1 INTRODUCTION

### 1.1 Background

It is possible to streamline groundwater modeling into groundwater resource development and sustainable management by employing Analytical Hierarchy Processes (AHP) approaches and remote sensing for groundwater recharge estimation. All three of these sectors (Industries, Agricultural, and Domestic uses), rely on groundwater (Upwanshi et al., 2023). As a result of the vadose zone's filtration and protection, groundwater is preferable to surface water. Groundwater demand is increasing as a result of population growth, agricultural water needs, climate change, rapid urbanization, human consumption, and ecological restoration via base flow. In recent times, the vast majority of research works revealed that innovative strategies, such as simulating aquifer behavior and degradation owing to overexploitation, are essential for effective groundwater management. In addition, several experts from different parts of the world have studied the vulnerability of groundwater through the use of geographical information systems (GIS) and

Remote Sensing (Biswas et al.,2012), with a report that indicates that climate change and human activities are the major threats to water resources. However, this is because water is essential for the expansion of industry, agriculture, urbanization, and population, all of which humans engage in daily. Large-scale groundwater zone detection has been greatly aided by Geographical Information Systems (GIS) and Remote Sensing (RS).

The ongoing concern raised by the impact of water scarcity resulting from human activities is global, but not different in the challenges faced at most locations; urban or rural (Allafta et al.,2021). The scheme had been very difficult to sustain as the water sources like the Hadeja Jama'are River in Minjibir, Gabasawa, and Gezawa are all contaminated with effluent from the dyeing and bleaching industries, contributing to groundwater depletion (Abdulazeez, 2020). Public water is sourced from dams and rivers, while a huge population depends on water purification alternatives with its challenges. For over 20 years, efforts have been made by all tiers of Government to curb the menace, with support from global bodies like the United Nations International Children Emergency Fund (UNICEF), United Nations Development Program (UNDP), the European Union (EU), the Global Water Partnership, and Water Aid in the form of provision for private borehole drilling rigs, geophysical equipment, chemical laboratory kits, hand pumps, replacement of components, and direct support (Bashir & Eduvie, 2006). Meanwhile, domestic water suppliers (commonly known as Garuwa) have increased in numbers in both rural and urban areas of Kano over the past 20-30 years and scholars have raised concerns about the challenges and effects of the poor water management schemes available to the populace. (Abdulazeez, (2015) argues that public water systems are unavailable and cannot be maintained. Rural areas have poor river and dam management which has resulted in the proliferation of self-owned boreholes for the past 15–20 years (Adamu et al.,2013), while hand-dug wells have been in use for much longer.

In this regard, the main aim of this study was to assess and identify groundwater potential zones in the research area.

### 1.2 Description of the Study Area

Minjibir Local Government Area is located in Kano state, northwestern, Nigeria Figure 1 and is bounded by longitude 12° 6'0'N to 12° 19'0'N and latitude 8° 33'30'E to 8°45'0'E. The study area has an area of 416km2 and a population of 213,794 according to the 2006 census. The Minjibir Local Government area is also surrounded by about five Local Government Areas; Namely Danbatta to the North, Gabasawa to the East, Dawakin Tofa to the South-West, Ungongo to the South, and Gezawa to the South-East respectively.

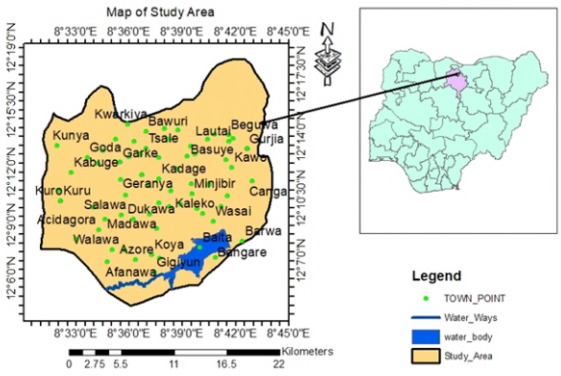


Figure 1: Map of the Study Area

## 2. MATERIALS AND METHODS

### 2.1 Data collecting and integrating into the GIS database

The core datasets described above are utilized in the creation of the seven thematic maps, which include slope, drainage density, line density, precipitation, soil type, geology, and land use/land cover. The GWPZ map was developed using the GIS software, which is a Geographic Information System (GIS) platform. The research areas about geology and soil mapping were obtained from the Nigerian Geological Survey Agency and the Soil Unit FAO/UNESCO Map of Nigeria. Thematic layer maps were subsequently created using the software. Nevertheless, the process of identifying lineaments within the research region was carried out by a manual approach, employing a lineament map acquired from the Nigeria Geological Survey Agency. The layer representing lineament density was created using the line density technique offered by the Spatial Analyst software.

### 2.2 Identification of Data Sets

The spatial distribution and hydrological movement of groundwater are influenced by various factors, such as geological features, precipitation patterns, slope gradients, drainage density, lineament density, land use/land cover patterns, and soil properties. These factors are primarily determined by employing digital image processing techniques on satellite imagery and integrating pre-existing data sources. In the early phases of geospatial database development, numerous companies provide analog maps with diverse scales. The process of digitizing the maps involved manual conversion using the GIS program, resulting in their transformation into a digital format. The aforementioned procedure ensures the safeguarding of vital information and its incorporation into the Geographic Information System (GIS) database.

### 2.3 Construction of the Research Geodatabase

The data generated, gathered, and digitized is structured according to geological factors such as line density and drainage density, as well as physiographic variables encompassing soil properties, elevation, slope, and land use/land cover. Consequently, each person is provided with a unique spatial representation format to effectively prepare them for analysis. After the research geodatabase was chosen, datasets were created to aid in the creation of future maps within the specified geographic region.

To demarcate the areas with potential for groundwater inside the designated study area, it was imperative to create a sequence of themed maps utilizing remote sensing techniques and topographic maps. The maps were created with a scale of 1:700,000, and each pixel on the map represents an area of 22 m. A drainage density map is generated by employing SRTM (Shuttle Radar Topography Mission) data and performing hydrological processing on a 30-m digital elevation model (DEM). The generation of the elevation map is achieved by the utilization of SRTM data and topographic sheets. Lineament density is determined through the utilization of the Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM). A slope map is produced by employing a digital elevation model (DEM), along with elevation, drainage density, and line density maps. The land-use/land-cover map for the Sentinel-10m image was produced through the implementation of supervised classification using GIS software. The process of generating a groundwater potential zone map entails the utilization of overlay analysis techniques. Following this, the data acquired from the

drilling process is utilized for validation purposes using the GIS software.

2.4 Data Analysis

During this phase, the satellite data is subjected to computer processing to extract essential information. The examination of groundwater resources within the specified research area entails the creation of thematic maps and their subsequent integration using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques. Saaty's Analytic Hierarchy Technique (AHP) is utilized to validate the weights assigned to each class and the scores assigned to each theme (Table 1). A nine-point key scale is utilized to produce a pairwise comparison matrix for each card. The resulting weight map comprises precise weights assigned to each input variable. The generation of the groundwater potential zone map entails a methodical refining of the weighted values derived from the ultimate map via a rational categorization procedure. This analysis offers a comprehensive understanding of the probable groundwater zones within the designated study areas.

Table 1 Constant rating scale of Saaty's AHP (Saaty 1990) Dekongmen Benjamin Wullobayi 2021.

| Scale Intensity | Definition | Importance |
|---|---|---|
| 1 | Equal importance | Two elements contribute equally to the objective |
| 3 | Moderate importance | Experience and judgement slightly favor one element over another. |
| 5 | Strong importance | Experience and judgement strongly favor one element over another. |
| 7 | Very strong importance | One element is favored very strongly over another, it dominances is demonstrated in practice. |
| 9 | Extremely importance | The evidence favoring one element over another is of the highest possible order of affirmation. |
| 2,4,6,8 can be used to express intermediate values. | | |

## 3. RESULTS AND DISCUSSIONS

### 3.1 Drainage Density

Drainage density plays a right essential role in groundwater obtaining ability and adulteration. The drainage setup depends on lithology and it runs an important key of infiltration rate. Drainage density is an inverse function of permeability. Consequently, it is an imperative parameter in the demarcation of the groundwater potential zone. Drainage density is attained by dividing the total extent of all the rivers in a drainage basin by the total area of the drainage basin. High drainage density denotes less infiltration and henceforward does not favor considerably the groundwater potential of the area. Low drainage density signifies high infiltration and hence donates additional to the groundwater potential. The drainage density was reclassified and classified as Very low, Low, Moderate, High, and Very high (fig 2). For the groundwater potential zone, a high weight was given for low density, and a low weight was assigned for high density.

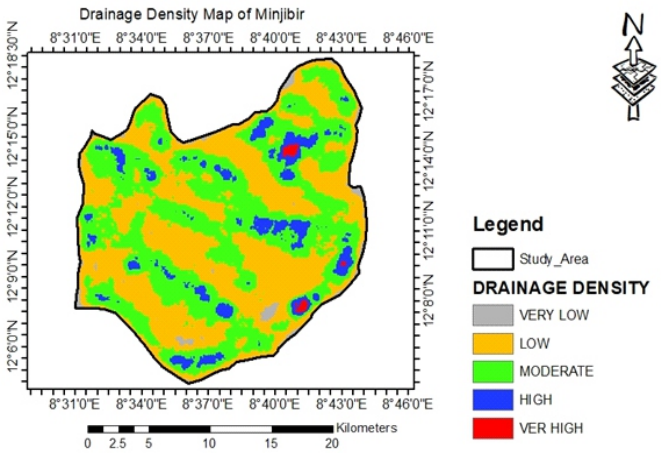


Figure 2 Drainage Density Map of the Study Area

### 3.2 Lineament Density

The lineament density map was then prepared using the line density tool in ArcGIS software and is represented in Figure.3 By judiciously investigating the values acquired, the data were reclassified into five categories viz: Very low, Low, Moderate, High, and Very high. The scales are agreed for lineament density based on the proximity of lineaments. It is shown that the concentration of groundwater potential drops with growing distance from the lineaments. High weight is allocated for high density and low weight for low-density classes.

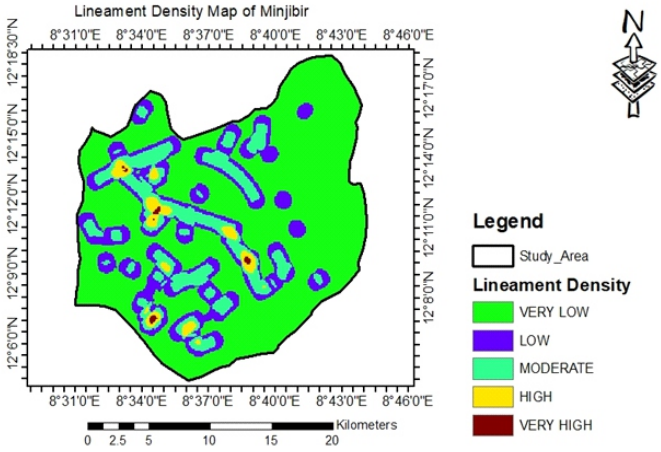


Figure 3 Lineament Density Map of the Study Area

### 3.3 Land use/Land cover (LULC)

The images captured by Sentinel-2a at a spatial resolution of 10 meters has been utilized to generate the ultimate land use and land cover (LULC) map for the study region in 2019. The images were subjected to atmospheric and radiometric correction using the WGS84 geodetic datum and the Universal Transverse Mercator map projection (UTM Zone 32N). In the domain of remote sensing, the notion of land use/land cover comprises a broad spectrum of land surface attributes that manifest as either natural, semi-natural, or man-made in origin. The aforementioned characteristics can be easily seen by directly observing satellite imagery. In contrast, land use is classified based on its utilization (fig 4). The notion being examined can be classified into several separate categories, such as residential, commercial, urban, rural, and agricultural, vegetation among others.

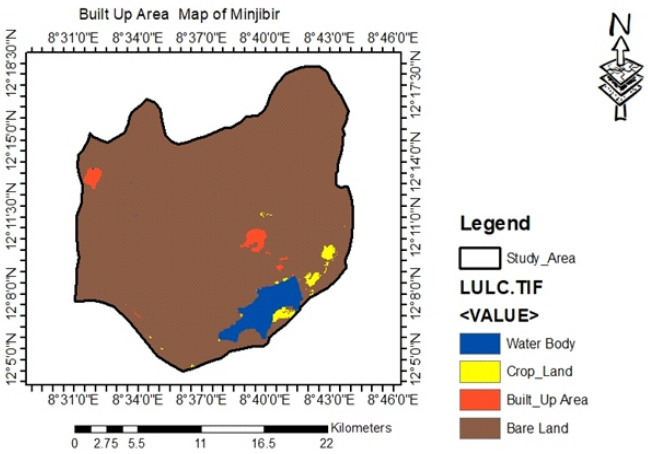


Figure 4 Land use Land cover Map of the Study Area

### 3.4 Rainfall map

Rainfall is the major water source in the hydrological cycle and the most dominant influencing factor in the groundwater of an area. For the present study, the rainfall data of 2021 was used. The annual rainfall ranges from mm to mm. The spatial distribution map of rainfall was prepared using the IDW interpolation method. Based on the maximum and minimum values, the rainfall has been reclassified into five categories Very Low, Low, Moderate, High, and Very High rainfall (figure 5). Infiltration depends on the intensity and duration of rainfall. High-intensity and short-duration rain influence less infiltration and more surface runoff; Low-intensity and long-duration rain influence higher infiltration than run-off. High weights are assigned for high rainfall and vice versa. The figure depicts the rainfall spatial interpolation map of Minjibir.

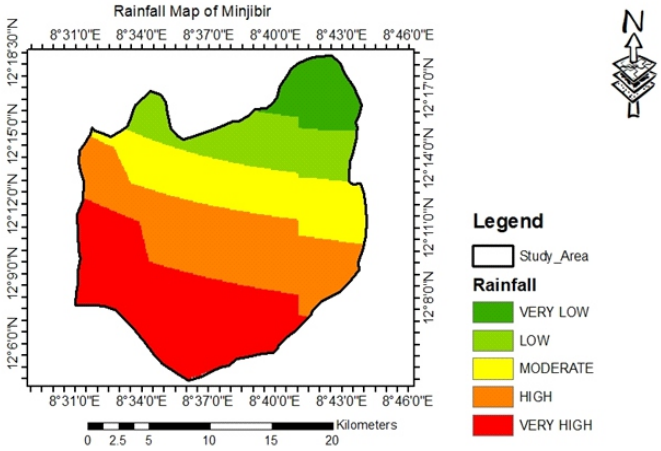


Figure 5 Rainfall Map of the Study Area

### 3.5 Slope Map

The slope is a significant terrain characteristic that expresses the steepness of the ground surface. The slope gives essential information on the nature of the geologic and geodynamic processes operating at a regional scale. Surface run-off and rate of infiltration are influenced essentially by the slope of the surface. Larger slopes produce smaller recharge because the water received from precipitation flows rapidly down a steep slope during rainfall. Therefore, it does not have sufficient residence time to infiltrate and recharge the saturated zone. The figure depicts the slope map of the Toro and its environment. The slope values were reclassified and categorized into five classes such as Very

low, low, moderate, high, and very high. The high weight is assigned for fat and gentle slopes. The low weight is assigned for steep and very steep slopes.

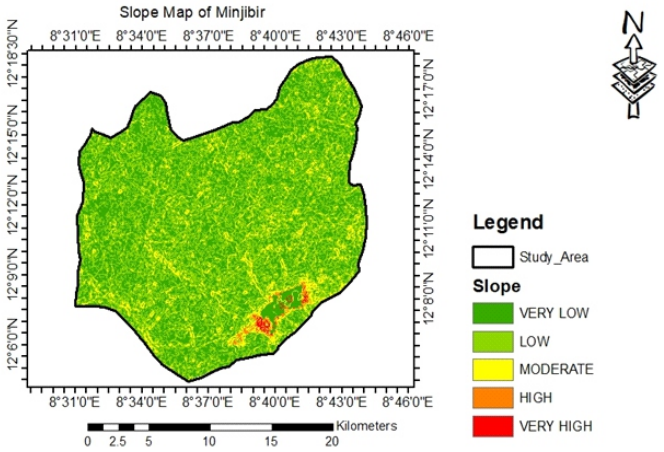


Figure 6 Slope Map of the Study Area

Table 2 Classification of slope based on its groundwater influence. Anthony & Doreen (1977).

| S/N | Slope | Explanation | Relationship with Groundwater. |
|---|---|---|---|
| 1 | $0^0$-$2^0$ | Level or almost level. | Not much runoff, water percolates into the ground. |
| 2 | $2^0$-$3^0$ | Gentle | Runoff increases and percolation reduces. |
| 3 | $3^0$-$5^0$ | Moderate | Much runoff and low percolation in groundwater. |
| 4 | $5^0$-$18^0$ | Moderately steep | Very much runoff and little percolation into the ground. |
| 5 | >$18^0$ | Very Steep | Total runoff and no infiltration. |

3.6 Soil Map

Soil is one of the most important factors that determine the permeability and infiltration rate of groundwater recharge (Selvam et al., 2014). The coarse soil texture denotes the higher infiltration rate and the infiltration rate decreases towards the fine soil texture. The score of soil types has been allocated according to the characteristics of the infiltration rate. So, the higher weights were given to the coarse-textured soil, and lower weights were given to the fine-textured soil. There is one type of soil that has been found in the study area i.e. Eutric Regosol Figure 7 presents the soil map of the study area.

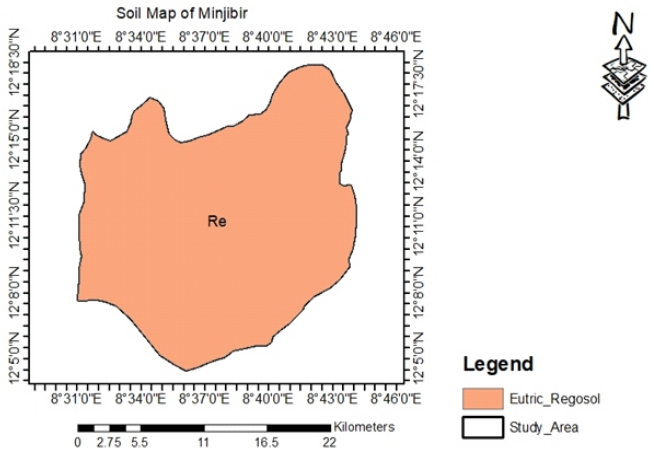


Figure 7 Soil Map of the Study Area

### 3.7 geology of the area

Geologic setting plays a vital role in the occurrence and distribution of groundwater in any terrain. Geological formations, structures, and characteristics influence groundwater recharge directly or indirectly and have an impact on a region's groundwater status (Acharya and Nag, 2013; Kurdistan et al., 2019). The most essential factor in groundwater recharge is the exposed rock formation (Bhattacharya et al., 2021; Kumar et al., 2016). The score has been assigned to several geological parameters based on their possible impact on the groundwater recharge. The published geological map of the Geological Survey of Africa was used for delineating different geological units of rocks in African terrain and therefore the study area geology units geo-lithological structure of the Minjibir is composed of one distinct geological unit or formations such as Precambrian i.e. comprises of gneiss, granite, basalt, and gabbro. etc.

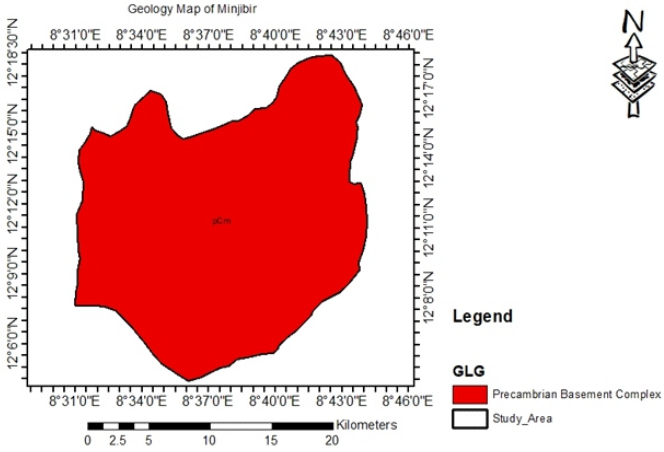


Figure 8 Geology Map of the Study Area

### 3.8 Groundwater Potential Zone Map

To assess the different groundwater potential zones, crucial parameters were considered, and the maps were arranged for each layer. These maps were transformed into raster data sets having the same pixel size (22m) and diverse weight was allocated as per their groundwater potential governing capability within the study area and reclassification of each map was done based on the weight values created. Consequently, the value 5 was given for very high regulatory units, 4 for high, 3 for moderately regulatory units, 2 for low controlling units, and 1 for very low controlling reclassified units. Finally, the maps were incorporated using GIS software with the purpose proposed to demarcate the groundwater potential areas for the study area. All the weighted thematic maps were integrated and defined criteria weight using the ArcGIS software analysis was done using the Analytical Hierarchy Principal (AHP) tool and groundwater prospect zones were created.

Analytic Hierarchy Process (AHP) The rainfall map, slope map, geology map, lineament density, drainage density, land use land cover map, and soil map were compiled in raster format for input in overlay analysis. The weight of each layer is computed using an analytical hierarchy process. The analytic hierarchy process (AHP) introduced by Thomas Saaty (1980) is one of a family of methods known as multi-criterion analysis for decision-making when the attributes and decision variables are interconnected and cannot be quantified through measurement (Department for Communities 2009). By reducing complex decisions to a series of pair-wise comparisons, and then synthesizing the results, the AHP captures both subjective and objective aspects of a decision. The weights for the thematic layers adopted from AHP are shown in Table 3 below:

Table 3 Weights calculated from AHP for overlay Analysis

| S.No | Thematic layers | Weight % |
|---|---|---|
| 1 | Rain Fall RF | 23.3 |
| 2 | Slope SL | 19.2 |
| 3 | Lineament Density LD | 18.4 |
| 4 | Drainage Density DD | 11.3 |
| 5 | Land Use land Cover LULC | 9.1 |
| 6 | Soil S | 7.2 |
| 7 | Geology G | 11.5 |

3.9 Groundwater Potential Map

The groundwater potential map is developed in ArcGIS's spatial analyst weighted overlay analysis tool using Eq.(1).

$$GWP = 0.233RF + 0.192SL + 0.184LD + 0.113DD + 0.091LULC + 0.072S + 0.115G \quad (1)$$

The resulting maps are reclassified into five categories very high, high, moderate, low, and very low, figure.9.

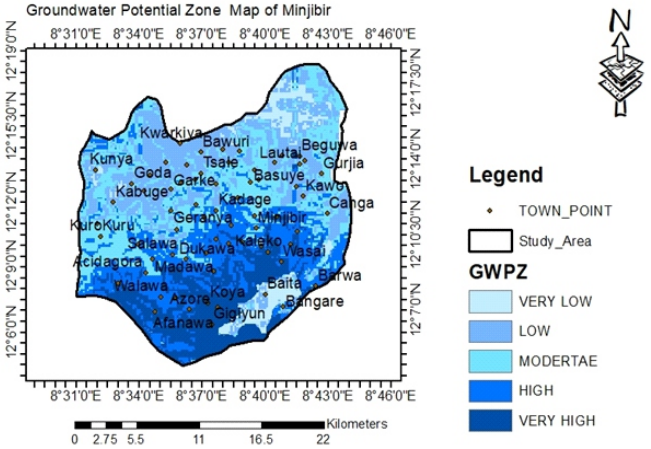


Figure 9 Groundwater potential zone map of the study area.

## 4. Conclusion and Recommendation

This study presents a comprehensive investigation of the assessment of the potential groundwater areas utilizing contemporary and advanced techniques such as Remote Sensing, Field Survey, AHP, and GIS in the three local government areas (Minjibir) situated in the northeastern part of Kano State. Despite the observed decline in the water table, the results suggest that future undertakings in regions with varying degrees of sensitivity, ranging from very high to moderate, should be treated cautiously. When devising methods to protect this vulnerable resource, professionals in the fields of urban planning, groundwater management, and policy-making can employ the maps produced in this study as a comprehensive tool for evaluating vulnerability. The investigation of the potential groundwater region was carried out using Geographic Information System (GIS) technology and remote sensing methodologies.

### Recommendations

- For further investigation of the groundwater potential zone of this study area, vertical electrical sounding with resistivity method (VES) and magnetic method should be used to get more primary data for research, because for this research purpose, I use secondary data, which are existing borehole data coordinates and their yields (l/m) within the study areas to determine groundwater

potential zone in these study areas.

- To achieve the development of a sustainable water supply in the specified research area, it is recommended to utilize the method of borehole drilling within the aquifer, ensuring a depth above 70 m.
- There should be a continuous collection of data on groundwater systems in these study areas to regularly check the map of groundwater potential zones for their potentiality.

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