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Analysis of Remote Sensing and GIS to Investigate Regional Groundwater Potential Zones in GU Volcanic Line, Plateau State, Central Nigeria

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Abstract: *This study is aimed at developing and modeling areas with various levels of groundwater prospecting and exploration potential in Gu Volcanic Line. Also, the study looked at mapping out suitable zones groundwater potential locations using Analytical Hierarchical Process (AHP) method of the volcanic province. It employed datasets for analyses such as satellite image, DEM, geology and point locations to volcanic peaks as important criteria for study. The AHP method helped in the combination of these datasets using their relative weights in order to derive a suitable potential map. Results showed that the area has more moderate potential of about 56.9% and 0.78% of the area has high groundwater potential. Other results indicated that Southern region of the landscape has low groundwater potential than Northern areas. The paper recommends that more advanced and accurate methods of obtaining data as well as analyses are required. Also, increased attention need to be paid to issues regarding water resources in the study area.*

Keywords: *AHP; Geology; Groundwater; Potential; Suitable Zones; Topography*

Introduction

Ground water accounts for about 30% of all fresh water on Earth, including surface water sources like lakes and rivers. Of this, rivers account for only the remaining 0.3% (Elkhrachy, 2015). There is a noticeable increase in demand for fresh water resources wherever there is population growth, particularly in the Northern region(Andualem & Demeke, 2019). Groundwater extraction has become a crucial feature of many water management systems especially in rural areas. The development of water resources is a challenge for planners and decision-makers in countries like Nigeria that is experiencing significant population growth and water scarcity(Adeyeye, Ikpokonte, & Arabi, 2019). The use of groundwater is a viable alternative since it is considerably less expensive to use it through hand-dug wells and boreholes than through conventional surface water programs that require the construction of impounding reservoirs. By taking steps to avoid contamination and controlling its usage responsibly, groundwater can continue to play a crucial role in ecosystems and human endeavors(Ahmadi, Mahdavirad, & Bakhtiari, 2017).

Using geospatial techniques and multi-criteria decision analysis, the study aimed to develop and model areas with various levels of groundwater prospecting and exploration potential as well as map out suitable zones for groundwater potential locations. The specific objectives include identifying contributing factors for determining groundwater potential sites, delineating suitable groundwater potential zones and demonstrating the effectiveness of GIS in groundwater potential exploration in Gu Volcanic Province. This study is focused on implementing and concentrating more on issues relating to the region's groundwater availability in order to contribute to successful water resource management.

Related Works

The definition of the groundwater potential zone can be done more accurately and with less bias when a variety of conventional approaches are combined with remote sensing (RS) and geographic information system (GIS) technologies. By evaluating thematic layers including geomorphology, geology, drainage pattern, lineament, soil, rainfall intensity, and slope, researchers have applied geospatial skills to groundwater studies. Savita et al., (2018) undertook a study to demarcate the groundwater potential zones in Kanakanala Reservoir Subwatershed, Karnataka by using RS and GIS approach. It was shown that most of the area had moderate potential zones, covering an area extent of 50%. Also, Duguma & Duguma(2022) delineated groundwater potential zones by combining remote sensing and geographical information system techniques in the Guder watersheds of the Upper Blue Nile Basin, with multi-influencing factors like geomorphology, land use/cover, lithology, soil type, soil texture, drainage density, slope, lineament, rainfall, and elevation. This indicate that there is no doubt that remote sensing and GIS techniques have been quite helpful in mapping and delineating groundwater potential zones in different regions.

Scope of Research

This research scope is majorly focused on areas within the Gu Volcanic Province located in central Plateau. The research is poised at deriving groundwater potential zone within a structurally-controlled areas within Plateau State. This covers the analysis that was derived within the study extent.

Study Area

The Gu Volcanic Province is located between latitude 9°15'00"E to 9°24'00"E of the Greenwich Meridian and 9°8'00"N to 9°18'00"N of the Equator with an average elevation of 700m above sea level (Adeyeye *et al.,* 2019). It is located in Southern area of Pankshin and Mangu Local Government in Plateau State (Figure 1). The study area consists of villages such as Gu, Jibam, Jibilik, Jing, Grong, Kapil, Longkat and Chip. It has an area of about 300 km^2 and is home to three volcanic peaks (Figure 2). These peaks are located in close proximity to Gu, Jibilik and Jibam villages. The area is characterized by woodland savannah and large shrubs. The three volcanoes within the province have small trees and shrubs richly distributed at the top and base of the volcanic relics

The study area belongs to the Southern group of newer Basalts of the Jos plateau, North Central Nigeria(Onimisi, Obaje, & Daniel, 2013). It is bordered to the South, by the Panyam volcanic province which isan uplifted area with height of 1250m above sea level. It consists of five volcanic cones aligned in a NE-SW direction. These areJiblik, Kagu, Tokbyet and Katul volcanoes(Alaa, Alrajh, & Abdulaziz, 2021). The unique physical feature of the area is its high relief especially in the North due to its geological history. The high relief provides a hydrological center for many rivers in Northern Nigeria. Also, the drainage pattern of the Gu volcanic province is influence by its lineament pattern. While the drainage pattern around the volcanoes is radial, the province generally exhibits a dendritic drainage pattern. Most of the river flow towards the southern end of the plateau, forming the lower Shemankar River (Figure 2)

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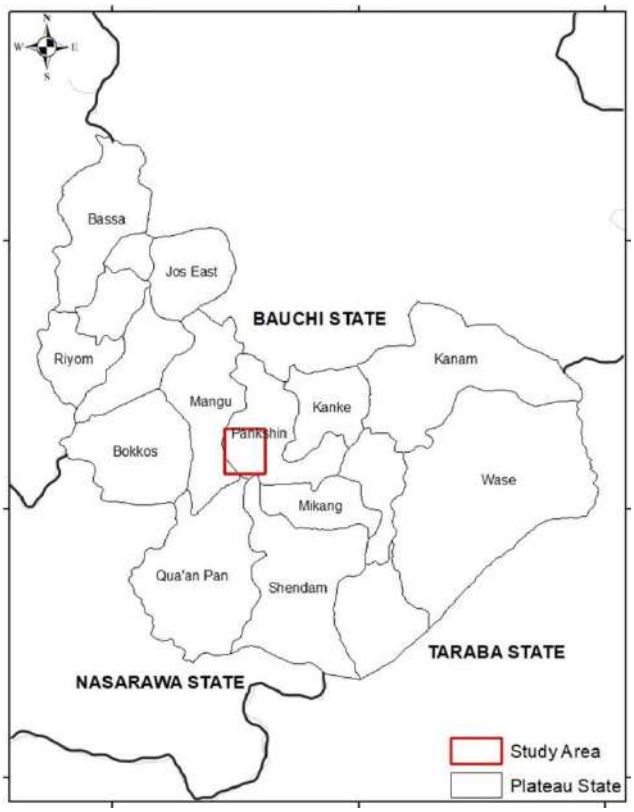


Figure 1: Study area within Plateau State

Source: Fieldwork

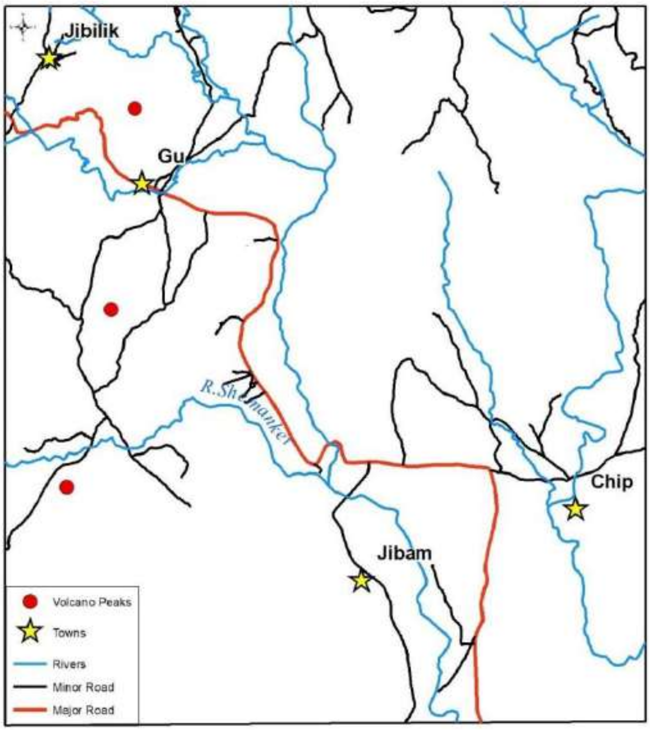


Figure 2: Gu Volcanic Province

Source: Fieldwork

Methodology and Discussion

Materials used for this study include Digital Elevation Model (DEM) as well as satellite image. Landsat image and SRTM DEM of 30m were acquired from Earth Explorer website of the United States Geological Survey Agency. In this study, the criteria used in determining groundwater potential sites included land use, lineament density, drainage density, slope, distance to volcanic peaks and geology(Andualem & Demeke, 2019; Atmaja, Putra & Setijadji, 2019; Abdalla, Moubark & Abdelkareem, 2020).

Slope and drainage density were derived from DEM using the Spatial Analyst Extension. While steep slope areas encourage fast runoff, which provides less residence time for rainwater and less infiltration, gentle slope areas allow modest surface runoff, providing more time for rainwater to percolate(Rohit Babu & Naidu, 2019; Savita et al., 2018). High drainage density reflects less infiltration and consequently do not favor much on the groundwater potential of the area. Low drainage density translates to high infiltration, which raises the groundwater potential more(Shimpi, Rokade, & Upasani, 2019).

Furthermore, lineaments are linear features evident at land surface that are an expression of the underlying geological structure (Hammouri, El-Naqa, & Barakat, 2012; Kumar, Moorthy, & Srinivas, 2017). Groundwater can be stored in significant quantities in well-developed fractures or lineaments that contact one another. Lineaments are hydro-geologically significant and provide channels for groundwater circulation. The intersections of the lineaments are regarded as excellent groundwater potential zones(Alaa *et al.,* 2021).

Volcanic regions are often prone to contamination of water through the varying volcanic processes and this is why it is important for potential groundwater sites to be far away from those locations. In the same way, geology goes a long way to determine potential sites in that porosity and permeability of rocks are considered. It is one of the most important factors which plays significant role in the distribution and occurrence of groundwater(Andi, Gumilar, & Pulung, 2017; Arulbalaji, Padmalal, & Sreelash, 2019; Atmaja et al., 2019). Figure 3 gives a summary of the workflow used in deriving potential sites for groundwater.

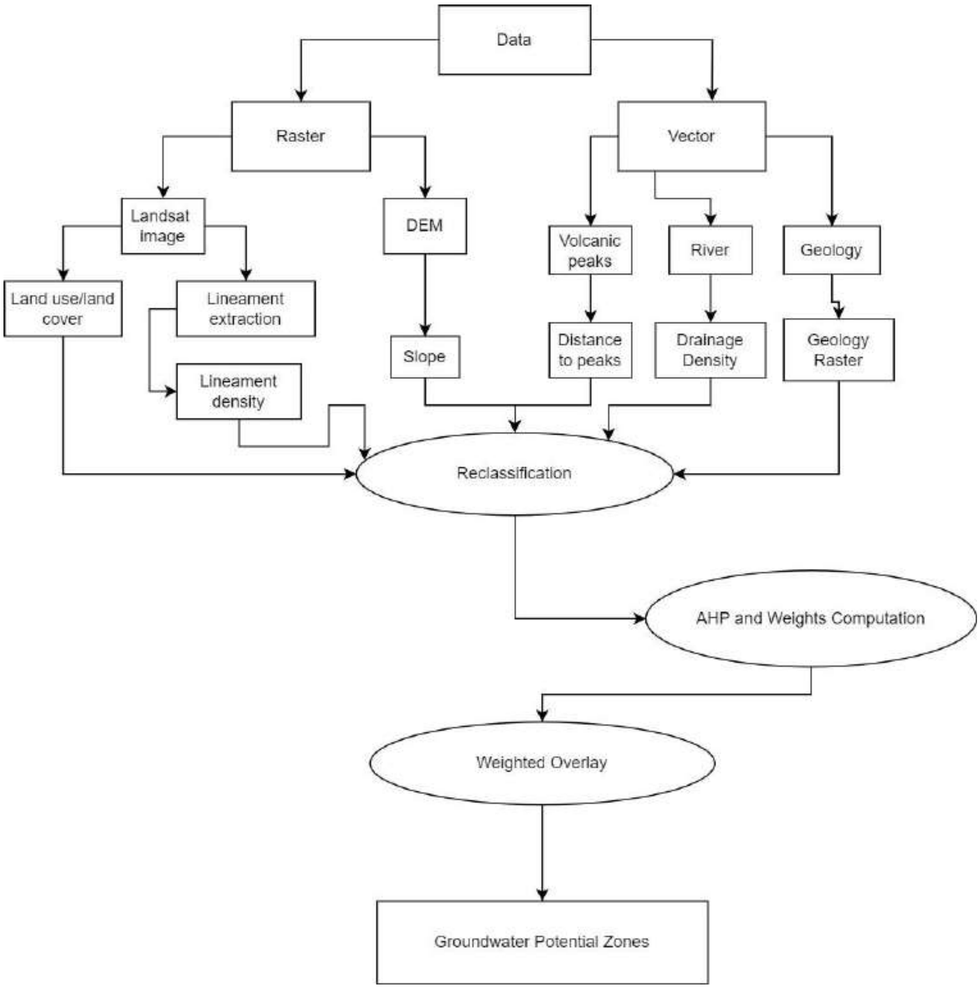


Figure 3: Methodology Workflow (Source: Fieldwork)

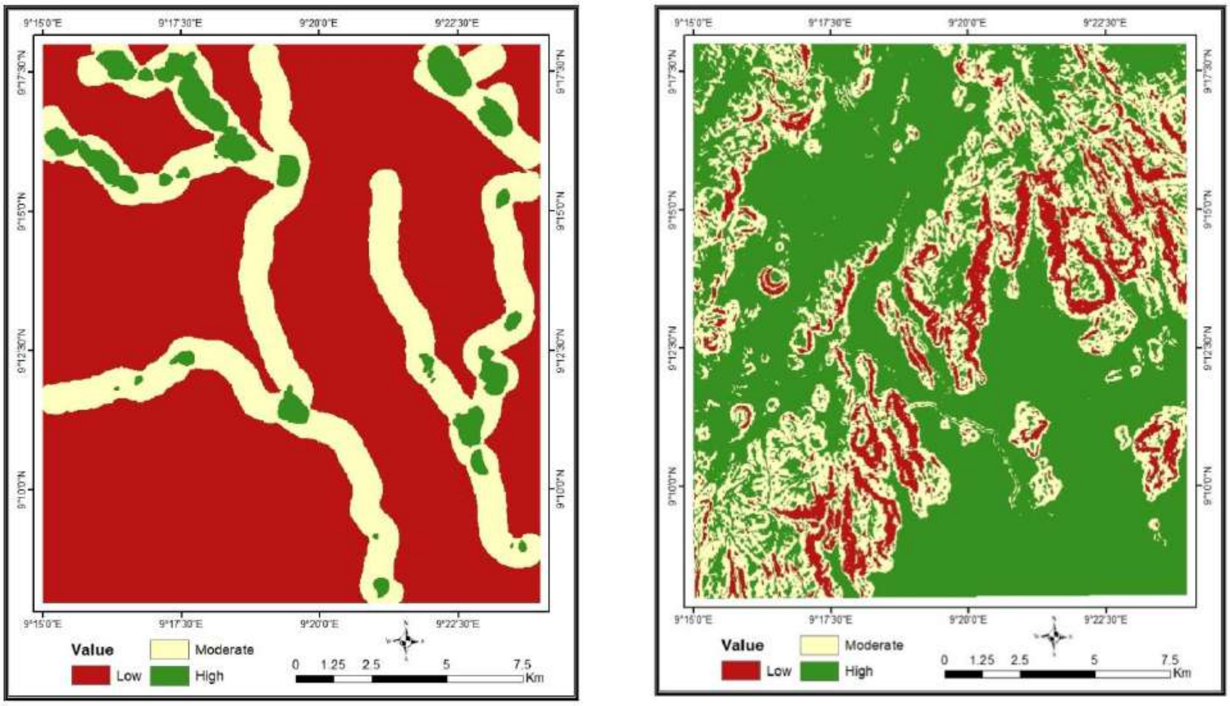
Analytical Hierarchical Process (AHP) is a multi-criteria decision-making method developed by Prof Thomas L. Saaty in 1980 that involves the comparison methods (Arulbalaji et al., 2019; Jhariya et al., 2021; Senthilkumar, Gnanasundar, & Arumugam, 2019). All the factors were paired with each other and following that, each factor was given an arithmetic value between 1 and 9. 1 represents equal importance between the two factors and a score of 9 indicates the extreme importance of one factor compared to the other one (Table 1). Using this scale, Pairwise Comparison Matrix was derived based on thematic layers and the weights were computed to determine the groundwater potential zone.

Table 1: Pairwise Comparison and weights derived from the factors

Criterion	Land use	Slope	Drainage density	Distance to Volcanic peaks	Geology	Lineament density	Weights (%)
Land use	1	0.333	0.333	1	0.333	0.333	7
Slope	3	1	0.5	1	1	0.5	14
Drainage density	3	2	1	3	1	1	24
Distance to volcanic peaks	1	1	0.333	1	0.333	0.25	8
Geology	3	1	1	3	1	0.5	19
Lineament density	3	2	1	4	2	1	28

Source: Fieldwork

Steep slope areas was located within the Central, North East and South West while gentle slopes were seen more in the North West and South East. In general, about 61% of the area has high potential with respect to slope while 11% has low potential due to steepness (Figure4). Moderate potential accounts for 28% of the area. In terms of potential, about 5% of the area has high potential for groundwater delineation while over 70% of the area has low potential. This indicated that the area has mostly low drainage density because some areas have no little or no access to the drainage system resistant or permeable subsurface material.

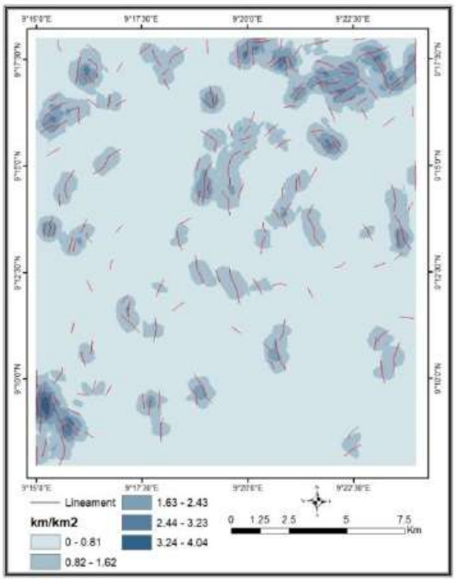


(a) (b)

Figures 4a & b: Drainage Density and Slope potential for groundwater occurrence

Source: Fieldwork

As there is a high possibility for faults and discontinuities of different complexities to occur on the rock surface, it represents a high potential for groundwater occurrence. According to the lineament density parameters, high-density areas have a higher rate of infiltration whereas low-density areas have a higher rate of runoff (Figure 5). The total length of lineament derived from the geologic surface using lineament extraction technique from satellite image is 135.3 kilometers and the lineaments are distributed evenly across the area but there are some areas with none of the features like the extreme southern aspect (Figure 5). About 59% of the area has low potential due to less lineament or fault zones occurring on the rock surfaces; moderate potential comprises 30% while high potential zone in terms of lineament comprise 11%. It is important to note that the areas within the crystalline rock terrains that have high groundwater potential are often influenced by lineament and drainage proximity. This influences the location of boreholes and well yields in most cases.



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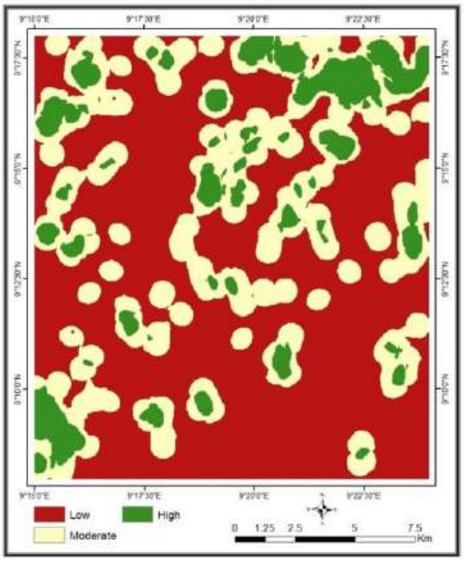


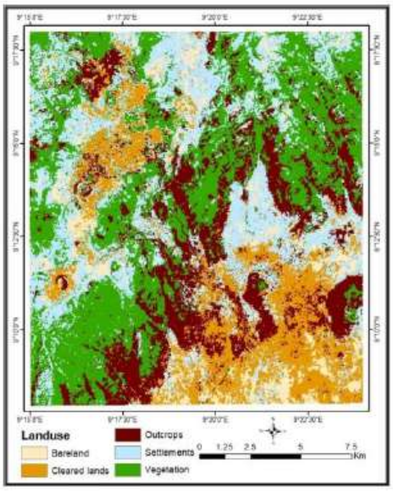
(b)

Figure 5a & b: Lineament density and its groundwater potential.

Source: Fieldwork

Furthermore, proximity to volcanic peaks has the tendency to impact groundwater flows because volcanic ashes can reduce the pH of water and increase the tendency for pollution. Areas of low potential due to distance to volcanic consist of 39% as they are closer to the volcanic peaks. High potential zone due to distance comprise 29% and is located mostly in the north east and south east. In addition to providing soil information such soil moisture content, groundwater and surface water, and an indicator suggesting groundwater potential prospects, land use and land cover play a key impact in the capacity of any watershed or sub basin for runoff, infiltration, and groundwater recharge (Duguma & Duguma, 2022).

With respect to land use (Figure 6), the presence of vegetation, bare land, cleared areas and outcrops with settlements also influences groundwater potential. For instance, land use classes like forest and agriculture land hold substantially high proportion of water than the built-up land, barren land and rocky surface. This is why about 31% of the area has high tendency to host groundwater and they are mostly vegetation. Outcrops, settlement and cleared lands comprise 62% but have low potential.



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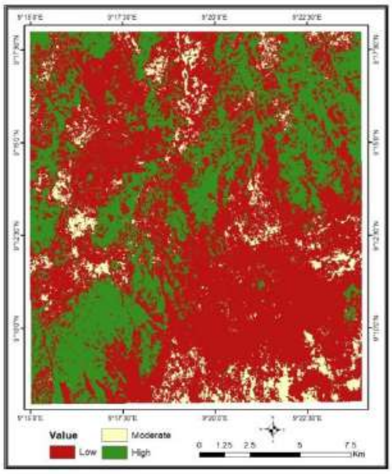


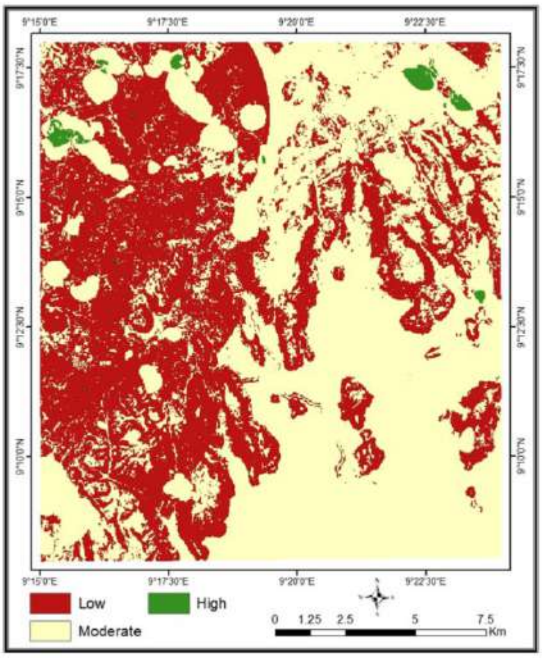
(b)

Figure 6a, b: Land use and its potential for groundwater

Source: Fieldwork

Groundwater Potential Sites in Gu Volcanic Province

The groundwater potential map consists of three major classes including low to high potentiality. The produced groundwater potentiality map points to the promising localities for groundwater accumulations which are always located in areas of increased vegetation, high drainage and lineament densities, areas of increased soil permeability, and low-slope areas. Figure 7 show that parts in the north-west and north-east regions have spots of high potential. Distribution of groundwater in the region can also rely on maintenance of sources. Only 0.78% of the area has high suitability and is dispersed in different location. Presence of groundwater is not only a prerequisite for water provision as it also involves its quality and accessibility to people in the region.The result produced indicated that southern region of the landscape has low groundwater potential than northern areas. This was due to flat terrain with a very high tendency to infiltrate more water and nature of lineaments. The northern parts of the landscape mostly showed with very poor to moderate groundwater exposure. The influence of topography on the final groundwater potential map is evident as most of the areas with low groundwater potential are located on high areas while areas with medium to high potential are located on topographic lows. In general, areas of low potential consist of 42.2% of the area while moderate areas have about 59% of the study area.



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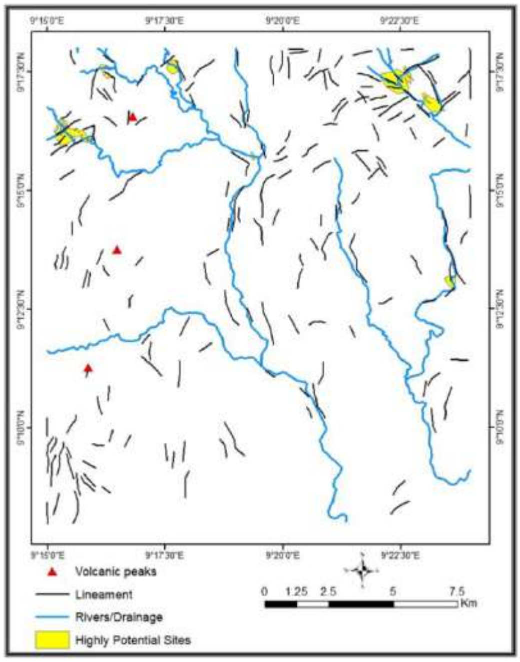

(b)

Figure 7a, b: Ground water potential and highly potential sites in Gu Volcanic Province

Source: Fieldwork

From the result above, it can be implied that groundwater potential occurrence is possible in the area, despite the geologic conditions that is present in the area. It is also important to understand that the potential is mostly high in the north more than the south. This can indicate that people in the south have a large probability to be at a disadvantage because of low accessibility to the proposed water resources. Most of the site falls on mostly bare land and vegetation, which according to Kumar *et al.,* (2017) are some of the best locations for groundwater potential (figure 8). Also, some of the sites are closer to river which aids a much higher potential for artificial recharge.

(a) (b)

Figure 8a, b: Potential sites shown in satellite images

Source: Google Earth

Conclusion

This study generally demonstrates that GIS and Remote sensing techniques could be used for the assessments of ground water potential zones in an area majorly dominated by igneous rocks and undulating topography. It can be considered as a time and cost-effective tool for delineations and identification of high ground water potential zones. The combination of satellite and existing secondary data in groundwater potential mapping is a powerful tool in revealing, studying and exploring groundwater. This research has substantially improved the understanding and analyses of groundwater in the study area. However, more advanced and accurate methods in obtaining data as well as analysis are required. For instance, addition of existing groundwater depths, well locations and water table would make the model more robust. Since geology, lineament, geomorphology, slope, and land cover remain factors affecting the occurrence, flow and distribution of groundwater in an area, low-resolution or moderate resolution data should be supplemented with high-resolution satellite data such as Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) or commercial imageries such as SPOT or Quick Bird.

Also, it is recommended that groundwater prospects mapping using GIS and RS be adapted in helping the field geologists to quickly identify the prospective groundwater zones for conducting site specific investigations and reasonably thus, significantly scaling down scope of search. Again, the need for borehole drillers including government agencies to keep data such as pumping test is also suggested as it will aid in giving empirical evidence of the groundwater potential of an area. Efforts should also be made to derive and analyze the quality of groundwater in the area such as pH, nitrate, and total dissolved solids to name a few, to ensure effective monitoring of water resources in the area.

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