Determination of Groundwater Potential Areas Using Remote Sensing (RS) and GIS Techniques in Mubi North Local Government Area, Adamawa State, North Eastern Nigeria.

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DOI: https://dx.doi.org/10.47772/IJRISS.2024.804113

Received: 28 March 2024; Accepted: 06 April 2024; Published: 13 May 2024

ABSTRACT

This study utilizes Remote Sensing (RS) and Geographic Information Systems (GIS) techniques to determine groundwater potential areas in Mubi North Local Government Area, Adamawa State, Nigeria. The research aim to provide insights for water resource management and sustainable development.Data collected includes Landsat imagery, Digital Elevation Model (DEM), soil data, and vector layers. Preprocessing involved data format conversion, spatial reference alignment, and resolution standardization for compatibility and consistency.Spatial analysis extracted topographic parameters from the DEM and supervised classified Landsat imagery for Land Use/Land Cover (LULC) maps. Six factors, Drainage density, Slope, Soil, Elevation, LULC, and Aspect, were reclassified into low, average, and high groundwater potential indexes.ArcGIS overlay analysis integrated the factors, prioritizing Drainage density, Slope, Soil, and Elevation, to create a composite groundwater potential index. The index was calibrated and classified into five categories: Very Low, Low, Average, Marginally High, and High potential areas.Results reveal diverse groundwater potentials. Very Low areas cover 17,168.23 hectares, Average areas cover 18,534.86 hectares, Marginally High areas cover 19,362.08 hectares, Low areas cover 13,838.41 hectares, and High areas cover 12,757.44 hectares.Spatial distribution shows High potential in settlements like Sabon Gari and Bukkaji, while Very Low potential is found in Wuro Alhaji and Venda. This study contributes to water resource management and sustainable development. Findings aid targeted strategies, benefiting socio-economic development. The research enhances knowledge and informs decision-making for water resource management, fostering development and improving livelihoods in Mubi North LGA.

Keyword: Remote Sensing, Drainage Density, Slope, Soil, Elevation, Land Use/Land Cover

INTRODUCTION

Access to clean and sustainable groundwater resources are essential for the socio-economic development and well-being of communities worldwide*(Ahirwar et al., 2020; Arunbose et al., 2021; Elisha, 2012; Shao et al., 2020)*. In regions facing water scarcity challenges, effective groundwater potential mapping plays a crucial role in guiding water resource management and supporting sustainable development initiatives(Ajibade et al., 2021). The application of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques has proven to be instrumental in mapping and analyzing groundwater potentials in various geographic settings(Ahmed et al., 2021; Chaminé et al., *2021*; Elisha, 2012).The integration of Remote Sensing (RS) and Geographic Information System (GIS) techniques has revolutionized groundwater potential mapping, enabling accurate and localized assessments in water-scarce regions (Kolawole et al., 2016; Martins et al., 2015; Shao et al., 2020). This approach combines spatial data, analytical tools, and geoscientific principles to enhance water resource management strategies (Ojoina Omali & Samuel Kolawole, 2019). A pivotal study by Martins et al. (2015) focuses on groundwater exploration zones within Mubi Local Government of Adamawa State. The researchers employ RS and GIS methods to delineate potential areas for groundwater exploitation. Their methodology entails data acquisition, preprocessing, and a weighted overlay analysis. Thematic maps encompassing Geology, Geomorphology, Slope, Drainage Density, Lineament Density, and Land Use/Land Cover are integrated to generate a composite groundwater potential zone map.

*Arunbose et al. (2021); Hairchi (2023); Owolabi (2020); Shao et al. (2020)*further extend the applicability of RS and GIS in groundwater potential mapping by incorporating analytical hierarchical process (AHP) techniques; the researchers achieve high-precision mapping of groundwater potential zones in their various study locations. Their multidimensional approach integrates surficial lithology, lineament density, drainage density, rainfall distribution, vegetation index, and topographic wetness index. Validation against borehole yield for example in Owolabi (2020) underscores the reliability of the model, exemplifying its suitability for semi-arid environments. In Lokoja Metropolis, Central Nigeria, Ojoina Omali & Samuel Kolawole (2019) demonstrate the utility of RS and GIS techniques in mapping groundwater potential zones. Through systematic analysis of geomorphic units, lineament features, and lithologies, the researchers categorize the region into distinct groundwater potential zones. The study showcases the significance of thematic maps derived from satellite data in delineating hydrogeomorphological aspects for groundwater exploration. This research sought to integrate high-resolution settlement data, to elevate the precision of groundwater potential mapping. This innovation refines our understanding of local dynamics, providing a localized perspective crucial for decision-making. By building upon the methodologies of previous studies and introducing new elements, this research contributes to a nuanced and contextually informed approach to groundwater potential mapping.

To assess groundwater potential, a combination of datasets was collected, including Landsat imagery, Digital Elevation Model (DEM), soil data, and vector layers; data preprocessing involved converting all datasets to a common format compatible with ArcGIS and standardizing spatial references and resolutions. Subsequently, topographic parameters such as slope, elevation, and aspect were extracted from the DEM, and supervised classification was employed to create Land Use/Land Cover (LULC) maps from Landsat imagery.

The study utilized six factors, namely, Drainage density, Slope, Soil, Elevation, LULC, and Aspect, to characterize groundwater potential. Each factor map was reclassified into three indexes representing low, average, and high potential areas. By overlaying these factor maps, a composite groundwater potential index was generated, prioritizing Drainage density, Slope, Soil, and Elevation. The resulting index was then calibrated and classified into five categories: Very Low, Low, Average, Marginally High, and High groundwater potential areas.The significance of this research lies in its contribution to sustainable water resource management and development planning in Mubi North LGA. By identifying areas with varying groundwater potentials, decision-makers can formulate targeted water supply strategies, allocate resources effectively, and promote community growth and prosperity. The spatial distribution of groundwater potential areas offers valuable insights into areas where water resources are abundant or limited, aiding the implementation of sustainable development projects and the improvement of water security for the local population.

STUDY AREA AND DATA COLLECTION

Mubi North Local Government Area is situated in the northern senatorial zone of Adamawa State, located in

the northeastern region of Nigeria. The study area is bounded by significant geographical features, with the Cameroun Republic to the east, Michika Local Government Area to the north, Mubi South Local Government Area to the south, and Hong Local Government Area to the west. Additionally, the northwest axis of Mubi North shares boundaries with Borno State. Geographically, Mubi North Local Government Area lies between the coordinates of 13°11'5.903"E longitude and 13°31'45.755"E longitude, and 10°11'6.988"N latitude and 10°31'27.418"N latitude. It is characterized by diverse topography, encompassing lowland areas and higher elevations, which significantly influence the hydrogeological conditions and groundwater flow patterns in the region. The geology of the study area is predominantly represented by the Pan - African Older Granitoids formation, spanning from Pre - Cambrian to Cambrian periods. Notably, lithological facies such as Porphyritic Granite Coarse porphyritic biotite and biotite hornblende granite contribute to the geological composition.

The local climate is influenced by distinct wet and dry seasons, with an annual rainfall range of 700 to 869.4 millimeters(Adebayo & Zemba, 2012; Martins et al., 2015). Rainfall plays a crucial role in groundwater recharge and availability, shaping the overall hydrological conditions in Mubi North Local Government Area. Soil characteristics within the study area consist primarily of silty sands, clayey sand, and loamy sand(A. A. et al., 2019; Adebayo & Zemba, 2012; I. D. et al., 2021). Additionally, rock outcrops are observed along the Mandara mountain range, adding to the geological complexity and influencing groundwater storage and movement. Administratively, the study area is under the jurisdiction of Mubi North Local Government Area, providing a defined and cohesive geographical unit for the investigation. The data collection process for this groundwater potential mapping study involved gathering various geospatial datasets from different sources. Each dataset plays a crucial role in understanding the hydrogeological factors that influence groundwater potential in Mubi North Local Government Area. The following subsections describe the data collected, their sources, and their relevance to the study.

Landsat Imagery

Landsat satellite images were acquired from the United States Geological Survey (USGS) spatial portal, EarthExplorer. Specifically, Landsat Bands 2, 3, and 4 were obtained for the year 2023. These multispectral images provide essential information on land cover and land use patterns in the study area(Abdulwahab & Bello, 2019; Ahirwar et al., 2020; Ahmed et al., 2021; Ajibade et al., 2021; Arunbose et al., 2021; Hairchi, 2023; Kolawole et al., 2016; Martins et al., 2015; Ojoina Omali & Samuel Kolawole, 2019; Owolabi, 2020; Senthilkumar et al., 2019). The composite image created from stacking these bands allows for a detailed classification of different land cover types, enabling the identification of areas with vegetation, water bodies, built-up areas, and other land cover categories relevant to groundwater potential assessment.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

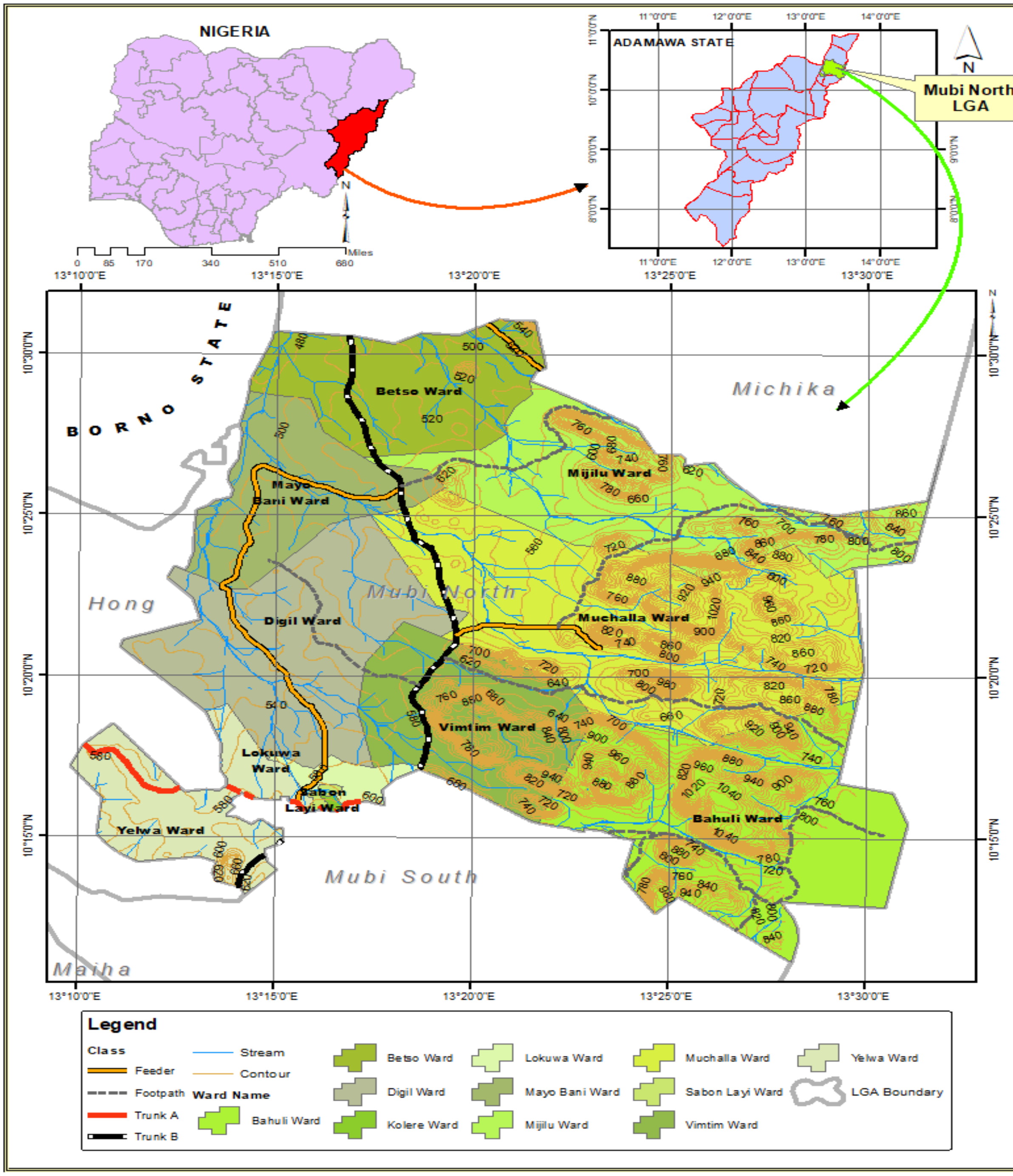


Figure 1.Locational Map of Mubi North Local Government Area

Digital Elevation Model (DEM) Data

The Digital Elevation Model (DEM) (see figure 2c) data was also sourced from the USGS spatial portal, Earth Explorer. The DEM provides crucial topographic information, including elevation, slope (see figure 2f), and aspect (figure 2d)(Ahirwar et al., 2020; Ajibade et al., 2021; Arunbose et al., 2021; Elisha, 2012; Kolawole et al., 2016; Martins et al., 2015; Ojoina Omali & Samuel Kolawole, 2019; Owolabi, 2020; Senthilkumar et al., 2019). These parameters significantly influence groundwater flow patterns, with elevation determining the groundwater potential gradient and slope influencing the direction of groundwater movement(Anbarasu et al., 2019; Kolawole et al., 2016; Ojoina Omali & Samuel Kolawole, 2019).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

Additionally, aspect data aids in understanding the orientation of landforms, which can impact water infiltration and groundwater recharge.

Soil Data

The soil data used in this study was obtained from the Nigerian soil map of 2006. The soil map provides information on the spatial distribution of soil types in the study area, such as silt sands, clayey sand, and loamy sand. Understanding the soil characteristics is vital in assessing the potential for water retention, percolation rates, and groundwater storage capacity(Ajibade et al., 2021; Arunbose et al., 2021), all of which influence groundwater potential (see figure 2a).

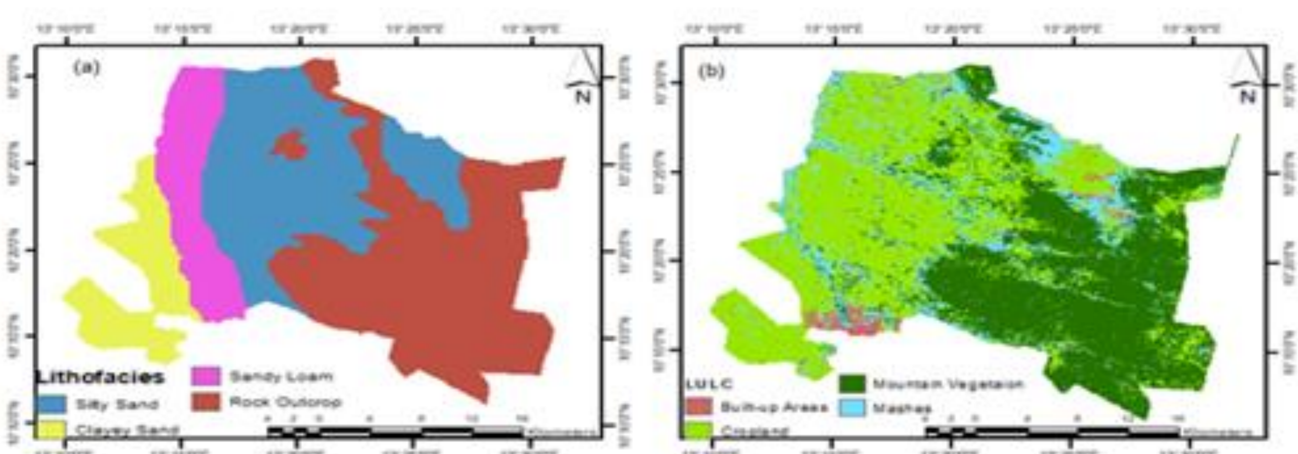
Stream Network and Drainage Density Data

The stream network and drainage density data were derived from hydrological analysis of the DEM. These datasets identify the spatial distribution of streams and rivers in the study area and indicate areas of high and low drainage density (see figure 2e). The presence of perennial or intermittent streams influences groundwater recharge(Ajibade et al., 2021; Senthilkumar et al., 2019), as areas with higher drainage density are more likely to contribute to groundwater resources.

Local Government Boundary, Settlement, and Road Data

Local government boundary maps, settlement data, and road data (see figure 1) were sourced from GRID-3 of e-health Africa. These datasets provide essential administrative and societal context for the study area. The settlement data, which includes local names with corresponding groundwater potential categories (High, Marginally High, Average, Low, and Very Low); offers valuable insights into local perceptions of groundwater availability. Integrating local knowledge enhances the understanding of how communities interact with their water resources. The collected geospatial data are highly relevant to the groundwater potential mapping study.

The Landsat imagery and DEM provide essential information on land cover (see figure 2b), elevation in figure (2c), and terrain characteristics, influencing groundwater availability and movement. The soil data contributes to assessing groundwater retention and storage capacity, while the stream network and drainage density data aid in identifying potential groundwater recharge zones. Additionally, the local government boundary, settlement, and road data provide valuable societal and administrative context for the study area, enriching the overall assessment of groundwater potential.



ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

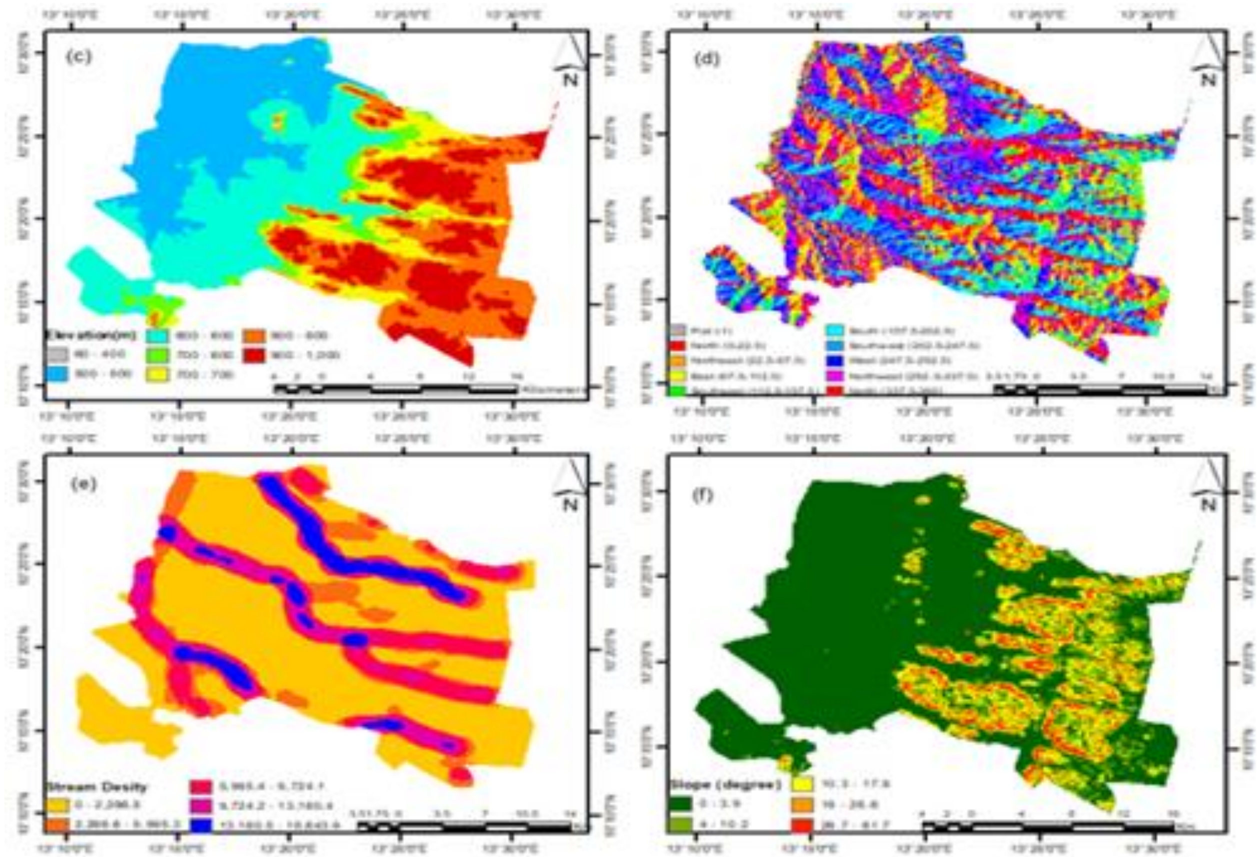


Figure 2. Ground Potential Parameters of the Study Area: (a) Soil Map, (b)LULC Map, (c)Elevation Map, (d)Aspect Map, and (e) Density Map, (f) Slope Map

METHODOLOGY

Groundwater potential mapping in Mubi North Local Government Area (LGA) involved the integration of Remote Sensing (RS) and Geographic Information System (GIS) techniques to assess and identify areas with varying groundwater potential. Remote Sensing techniques involve the use of satellite or airborne sensors to capture and acquire information about the Earth's surface(Abdulwahab & Bello, 2019; Ahirwar et al., 2020; Arunbose et al., 2021; Chaminé et al., 2021; Martins et al., 2015; Ojoina Omali & Samuel Kolawole, 2019). In Mubi North LGA groundwater potential mapping, RS techniques were utilized to derive valuable data related to land cover, land use, and surface characteristics. Landsat satellite images are a valuable data source for assessing land cover and land use patterns in the study area. Multispectral bands, such as Bands 2, 3, and 4, provided information on vegetation, water bodies, built-up areas, and other land cover classes, which are critical in determining areas suitable for groundwater recharge and storage. Georectification was performed to ensure that the Landsat imagery aligns accurately with the study area's spatial reference. Ground control points (GCPs) were used to accurately position the imagery in the correct coordinate system, enabling subsequent analysis.

GIS Techniques

Geographic Information System (GIS) techniques were used in the manipulation, analysis, and visualization of geospatial data layers. In groundwater potential mapping, GIS is used to integrate various datasets and perform spatial analyses to identify potential areas. The first step in the data processing involved preparing and preprocessing the acquired datasets to ensure compatibility and consistency. All datasets, including Landsat imagery, DEM, soil data, and vector layers, were converted to a common data format compatible

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

with ArcGIS, such as GeoTIFF for raster data and shapefile for vector data. The spatial reference of each dataset was checked and aligned to a standard coordinate system (UTM Zone 33N) suitable for the study area. Datasets with different resolutions or cell sizes were resampled to a uniform resolution to ensure consistency during subsequent analysis. This step avoids any mismatch or misalignment issues when integrating data layers. NoData values were standardized and filled to avoid gaps or inconsistencies in the datasets during spatial analysis. GIS allows for the integration of various datasets, including Landsat imagery, Digital Elevation Model (DEM), soil data, stream network, and settlement points. These data layers were combined to form a comprehensive understanding of the factors influencing groundwater potential. For georectification of Landsat imagery and clipping of vector and raster layers to the study area boundary, Landsat imagery acquired from EarthExplorer was georectified using ground control points (GCPs) collected from reliable reference sources, such as high-precision GPS points or existing georeferenced datasets. The georectification process involved matching and aligning the Landsat imagery to a known coordinate system using the GCPs. The study area boundary, represented as a vector layer, was used to clip the georectified Landsat imagery to the exact extent of Mubi North Local Government Area. This clipping process ensured that the analysis focused solely on the study area, reducing processing time and unnecessary data handling. Other relevant vector and raster datasets, such as soil data, stream network, and drainage density, were also clipped to the study area boundary using the same procedure to align them with the study area's extent. Topographic parameters (slope, elevation, and aspect) were derived from the Digital Elevation Model (DEM) using ArcGIS Spatial Analyst tools. The slope of the terrain was calculated from the DEM, representing the steepness of the land surface at each location. This was done using the slope tool, and the results were expressed in degrees. The elevation values from the DEM were directly used to represent the terrain height at each raster cell. These values were crucial for analyzing groundwater potential based on elevation differences. The aspect, representing the direction of the slope, was computed from the DEM. It provided information on the orientation of the terrain, which influences the movement of groundwater and surface water flow.

The raster variable maps (Drainage density, Slope, Soil, Elevation, LULC, and Aspect) were reclassified into three indexes each to represent low potential, average potential, and high potential groundwater areas (see figure 2 a-f). In reclassification process, each variable map was reclassified based on domain-specific knowledge and hydrogeological expertise. Appropriate threshold values were assigned to separate the three potential classes for each variable. For each variable, the low potential areas were assigned an index value of 1, the average potential areas were assigned 2, and the high potential areas were assigned 3. This ensured that all factor maps had a consistent scale for further integration. The overlay tool in ArcGIS Spatial Analyst was used to integrate the reclassified factor maps into a composite groundwater potential index. By assigning different priorities to each factor, the overlay analysis generates a comprehensive map that represents the combined influence of multiple factors on groundwater potential.After the overlay analysis, the groundwater potential index is calibrated to adjust the results based on local knowledge and hydrogeological understanding. The calibrated index was then classified into distinct categories, such as High, Marginally High, Average, Low, and Very Low, using the geometrical interval classifier.

RESULTS

The assessment of groundwater potential in Mubi North Local Government Area was conducted using a combination of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques. Various datasets were collected, including Landsat imagery, DEM, soil data, LULC data, settlement data, and road data, all of which were processed and integrated to create a composite groundwater potential index.The spatial distribution of groundwater potential areas in Mubi North LGA revealed distinct patterns across the region. The study area, which lies within the northern senatorial zone of Adamawa State, is situated on the geologic formation of Pan - African Older Granitoids. The topography varies, with elevations ranging from 60 meters to 1000 meters. Annual rainfall in the area fluctuates between 700 to 869.4 mm, influencing the

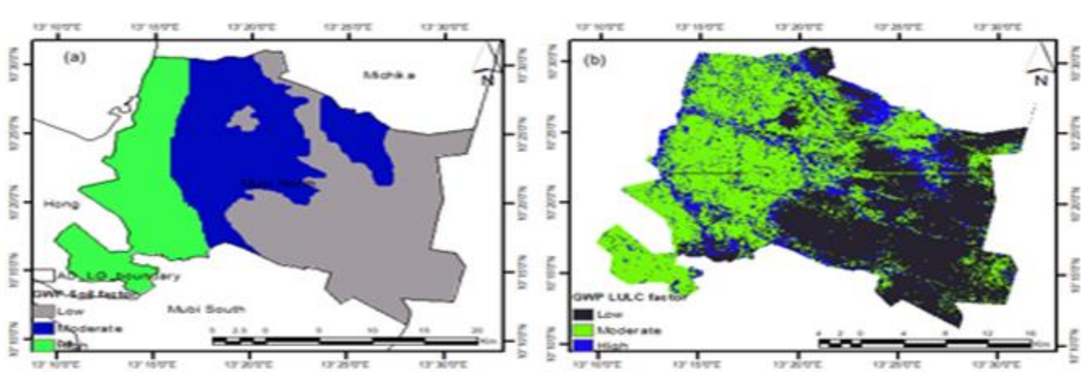
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

groundwater potential distribution.The composite groundwater potential index was derived from the overlay analysis of six variables: Drainage density, Slope, Soil, Elevation, LULC, and Aspect. Each variable was reclassified into three categories: 1 for low potential, 2 for average potential, and 3 for high potential groundwater.

GIS enabled the reclassification of datasets to assign different groundwater potential classes based on specific criteria. Each variable map, such as Drainage density, Slope, Soil, Elevation, Land Use/Land Cover (LULC), and Aspect, was reclassified into three indexes representing low, average, and high groundwater potential. In the groundwater potential mapping of Mubi North Local Government Area, the reclassification process was undertaken for each variable data used in the study. The variable datasets included Drainage density, Slope, Soil, Elevation, Land Use/Land Cover (LULC), and Aspect. The drainage density representing the density of stream networks in the study area was reclassified into three categories: low potential, average potential, and high potential groundwater areas.

Areas with low drainage density indicating limited surface water flow were assigned the value 1; areas with moderate drainage density, indicating moderate surface water flow, were assigned the value 2, while areas with high drainage density, indicating frequent surface water flow and potential groundwater recharge, were assigned the value 3; this resulted to the production of drainage density factor map for further use in overlay analysis (see figure 3e). The Slope data, representing the steepness of the terrain, was reclassified into three categories based on its influence on groundwater potential; areas with gentle slopes suitable for groundwater recharge were assigned the value 3, areas with moderate slopes that may still allow for groundwater recharge were assigned the value 2, while areas with steep slopes not conducive to groundwater recharge were assigned the value 1. Thus, producing a factor map of slope to groundwater potentials in the study area (see figure 3f). The Soil data, representing different soil types, was reclassified into three categories based on their water-holding capacity and permeability; areas with soils that have poor water-holding capacity and low permeability were assigned the value 1, areas with soils that have moderate water-holding capacity and permeability were assigned the value 2, areas with soils that have good water-holding capacity and high permeability were assigned the value 3 (see figure 3f). The Elevation data, representing the height above sea level, was reclassified into three categories to assess its influence on groundwater potential - Areas with low elevations that may indicate potential groundwater accumulation were assigned the value 1, areas with moderate elevations that may influence groundwater recharge were assigned the value 2, areas with high elevations that may indicate potential groundwater discharge were assigned the value 3 (see figure 3c).

The LULC data, representing different land cover classes, was reclassified into three categories based on their potential impact on groundwater; areas with urban/built-up land cover that hinders groundwater recharge were assigned the value 1, areas with vegetation cover that may facilitate groundwater recharge were assigned the value 2, while areas with water bodies (rivers, lakes) that may indicate potential groundwater recharge zones were assigned the value 3 (see figure 3b).



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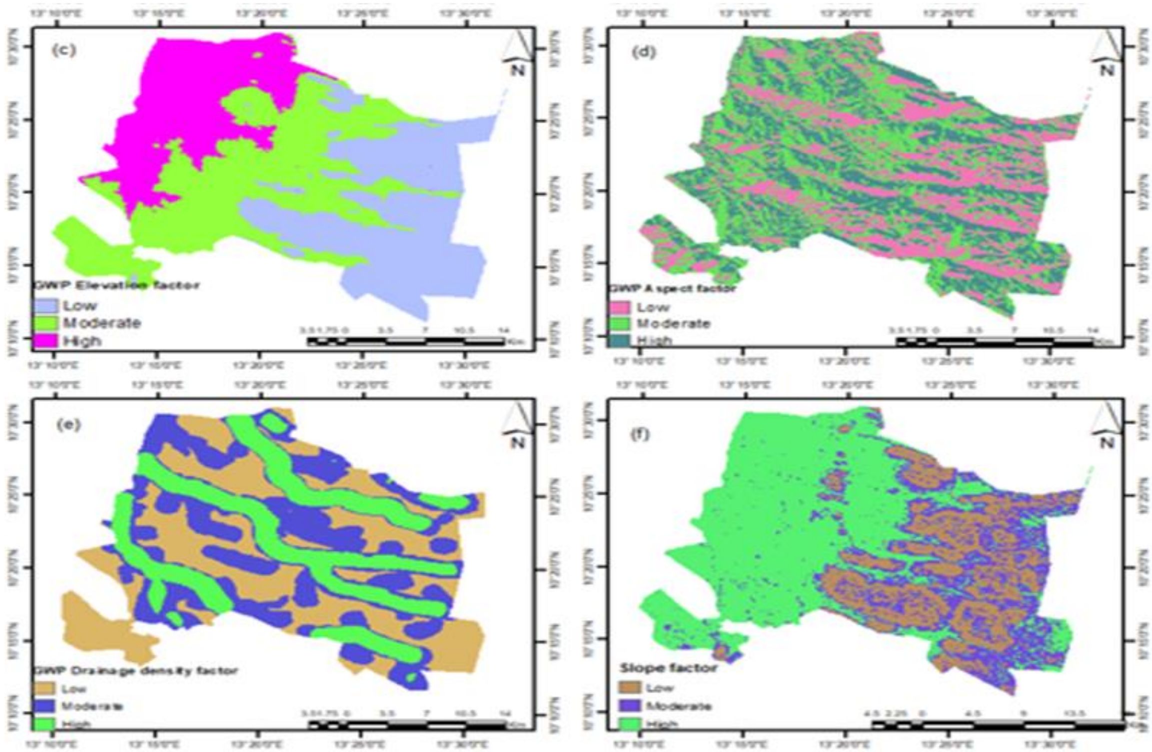

Figure 3. Ground Potential Factor Maps of the Study Area: (a) Soil Factor Map, (b)LULC Factor Map, (c)Elevation Factor Map, (d)Aspect Factor Map, and (e) Density Factor Map, (f) Slope Factor Map

The Aspect data, representing the direction of the slope, was reclassified into three categories based on its potential influence on groundwater movement - Areas with north-facing slopes that may have limited evaporation and potential groundwater recharge were assigned the value 3, areas with east and west-facing slopes were assigned the value 2, while areas with south-facing slopes that may have higher evaporation and potential groundwater discharge were assigned the value 1 (see figure 3d).

The weights assigned during the overlay analysis prioritized Drainage density, Slope, Soil, and Elevation in determining a composite groundwater potential map (see figure 4).The spatial distribution of groundwater potential areas in Mubi North LGA exhibits significant variations across the wards and settlements. Within the areas identified as having "High" groundwater potential, settlements such as Wamizhili in Betso Ward and Yelon in Digil Ward are noteworthy. These regions are characterized by favorable conditions for groundwater storage and replenishment, making them potential sources of water supply.In the "Marginally High" groundwater potential areas, settlements like Grimana A and Wafago in Bahuli Ward, as well as Rebano in Digil Ward, indicate moderate potential for groundwater resources. These regions may require additional exploration and management strategies to optimize groundwater utilization sustainably.

Settlements within the "Average" groundwater potential areas, including Ngura in Bahuli Ward and Mudzara Kasa in Muchalla Ward, represent regions with moderately favorable conditions for groundwater occurrence. While groundwater is likely available, the sustainability of extraction may require careful monitoring and management practices.The areas characterized as having "Low" groundwater potential include settlements like Wuro Alhaji in Bahuli Ward and Koyim in Mijilu Ward. These regions may face limitations in groundwater availability, making them less suitable for extensive water supply schemes. Finally, settlements such as Mbidiwe in Bahuli Ward and Bagira Sama in Muchalla Ward are situated in regions with "Very Low" groundwater potential. These areas exhibit minimal suitability for groundwater resources, necessitating alternative water sources for the communities.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume VIII Issue IV April 2024

Overall, the spatial distribution of groundwater potential areas in Mubi North LGA highlights the need for region-specific water resource management strategies. The classification of settlements based on groundwater potential will aid in informed decision-making for water supply planning, sustainable development, and resource allocation within the local government area. The integration of RS and GIS techniques in this study provided valuable insights into the distribution and potential availability of groundwater resources in Mubi North LGA, contributing to a more informed approach towards water resource management and development in the region. It is worth noting that the study area presents significant variations in groundwater potential, with approximately 12,757.44 hectares falling under the category of "High" groundwater potential, covering settlements like Wamizhili and Yelon. Areas with "Marginally High" groundwater potential cover approximately 19,362.08 hectares and include settlements such as Grimana A, Wafago, and Rebano.

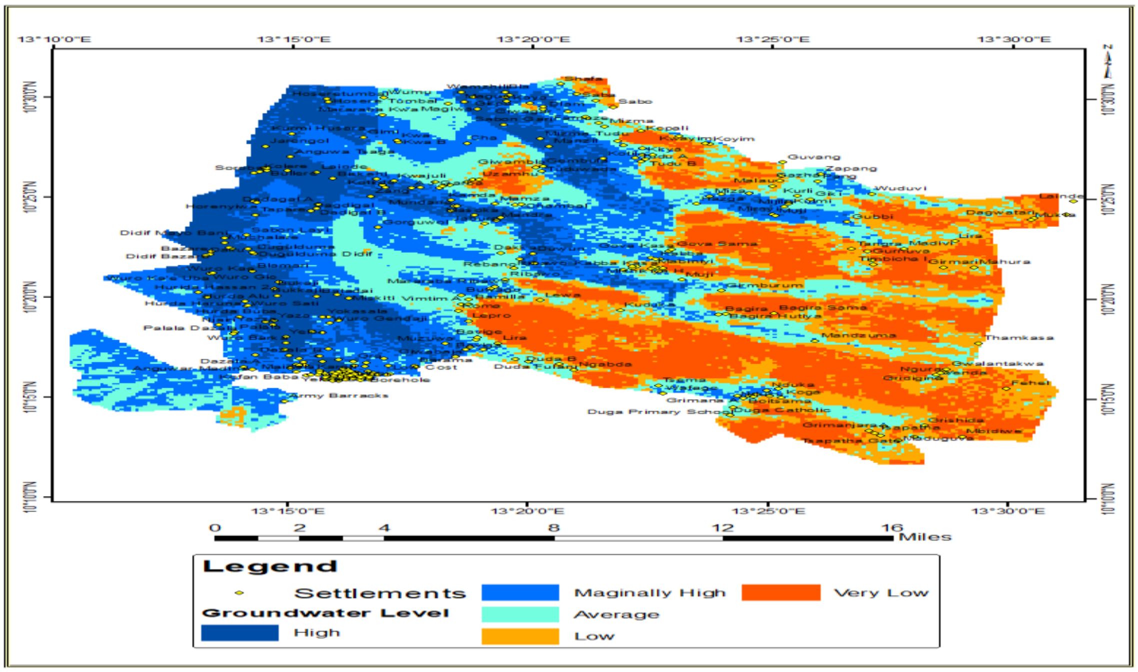

Figure 4. A composite groundwater potential map for Mubi North LGA

Settlements within the "Average" groundwater potential category cover about 18,534.86 hectares, with notable examples being Ngura and Mudzara Kasa. In contrast, areas classified as having "Low" groundwater potential encompass approximately 13,838.41 hectares, including settlements like Wuro Alhaji and Koyim.The regions with the least groundwater potential are the "Very Low" category, covering around 17,168.23 hectares, with settlements like Mbidiwe and Bagira Sama being among those facing significant limitations in groundwater availability.This comprehensive assessment of groundwater potential and its spatial distribution provides valuable information for decision-makers and stakeholders in Mubi North LGA. It enables targeted planning for water resource management, identifies suitable locations for water supply infrastructure, and helps develop strategies to address the varying groundwater conditions within the region. Additionally, this study serves as a foundation for further research and sustainable development initiatives aimed at optimizing groundwater resources and ensuring the availability of clean and reliable water for the communities of Mubi North LGA.

CONCLUSION

In conclusion, this study aimed to assess the groundwater potential areas in Mubi North Local Government Area using Remote Sensing (RS) and Geographic Information Systems (GIS) techniques. The findings of the research shed light on the spatial distribution of groundwater potential, providing valuable insights for water resource management and sustainable development in the region.

The significance of this study lies in its contribution to the understanding of groundwater availability and distribution in Mubi North LGA. By utilizing RS and GIS technologies, we were able to analyze multiple variables, including Drainage density, Slope, Soil, Elevation, Land Use/Land Cover (LULC), and Aspect, and integrate them to create a composite groundwater potential index. This innovative approach allowed us to identify areas with high, moderate, and low groundwater potentials, aiding in the development of targeted water supply strategies and the allocation of resources in the local government area.The research has also expanded on existing knowledge by providing a comprehensive assessment of groundwater potential in Mubi North LGA. Through our spatial analysis and classification of settlements into various groundwater potential categories, we have contributed new information that can be used for future studies and decision-making processes. Our findings complement existing literature and act as a foundation for further research on water resource management, particularly in areas with similar geologic formations and climatic conditions.

The significance of this project extends beyond academia and research. Access to clean and reliable groundwater is essential for the socio-economic development and well-being of communities. By identifying areas with high groundwater potential, we can guide sustainable land-use planning and water resource management initiatives, ensuring a consistent and adequate water supply for agricultural, domestic, and industrial purposes.In conclusion, this study demonstrates the efficacy of RS and GIS techniques in mapping groundwater potential areas in Mubi North LGA. The findings highlight the spatial distribution of groundwater potential and present a valuable resource for policymakers, water resource managers, and community stakeholders. The project's importance lies in its potential to foster sustainable development, enhance water security, and improve the quality of life for the people of Mubi North Local Government Area.

As we move forward, we encourage further research and collaborations to build upon this work, leading to evidence-based policies and actions that will safeguard and optimize groundwater resources in the region. By leveraging advanced technologies and combining local knowledge, we can work towards a more water-secure and resilient future for Mubi North LGA and beyond.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Tertiary Education Trust Fund (Tetfund) research grant for this study. Facilities used at theDepartmentof Surveying and Geoinformatics, Adamawa State Polytechnic, Jambutuis highly commendable for this study. The Earth Resources Observation System (EROS), the data center of the united states geological survey (USGS), and the National Aeronautics and Space Administration (NASA) are also acknowledged for the satellite data provided for this paper.

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