AMERICAN JOURNAL OF
GEOSPATIAL TECHNOLOGY (AJGT)
ISSN: 2833-8006 (ONLINE)
VOLUME 2 ISSUE 1 (2023)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Geospatial Technology (AJGT)

Volume 2 Issue 1, Year 2022
ISSN: 2833-8006 (Online)
DOI: https://doi.org/10.54536/ajgt.v2i1.2063
https://journals.e-palli.com/home/index.php/ajgt

Geo-Spatial Assessment of Groundwater Potential Zones in Birnin-Kudu Local Government Area Jigawa State, Nigeria

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Article Information

Received: August 27, 2023

Accepted: September 25, 2023

Published: October 02, 2023

Keywords

AHP, Geographic Information System, Groundwater Potential Zone, Remote Sensing

ABSTRACT

The study attempted to identify the groundwater potential zones in Birnin Kudu Local Government Area of Jigawa State, Nigeria using Remote Sensing and Geographic Information System techniques. Groundwater is an important source for water supply, considering its availability, quality, cost and time effective to develop, and simple accessibility. The study used thematic maps like Rainfall, Lineament, Geology, Soil, DEM Soil, Drainage and Land Use Land Cover map as GIS layers in geo-database. The rankings/weights of factor contributing to groundwater prospects in the study area were evaluated by pair wise comparison using Analytical Hierarchy Process (AHP). Weightages of the factors influencing groundwater prospects zones in the study area shows that rainfall is one of the major contributor, and was weighed as the highest contributor with (34%) followed by lineament (24%) and geology was weighed (14%). The least groundwater contributor in the study area is the land use land cover with (2%). The study showed that the very high groundwater potential areas occupy 59.92 km^2 (2.89%) of the area, the high potential zones constitute about 527.52km^2 (25.45%) of the study area and the moderate potential area has the highest area of 602.69km^2 (29.07%). The low and very low potentials occupy an area of about 528.13 km^2 (25.48%) and 354.75 km^2 (17.11%) respectively. The study concluded that the study area has an abundance.

INTRODUCTION

Water is a chemical substance with a chemical formula H_2O which can exist in different states as; solid, liquid and gaseous forms. Water covers 70.9% of the earth's surface and it is vital for all known forms of life. On earth, water is found mostly in oceans, rivers, lakes, ponds and other surface water bodies (Rilwanu and Haruna, 2014). Groundwater is the water beneath the surface of the ground. In other words, it is the water that flows or collects beneath the earth's surface. Groundwater originates from rainfall, melting snow and ice which infiltrates into the ground, percolates through porous rocks and stored in aquifers. Groundwater, being a hidden natural resource is not amenable to direct observations and hence, exploration or assessment of this vital resource plays a pivotal role in determining locations of water supply, monitoring wells and in controlling groundwater pollutions (Pandian and Jeyachandran, 2014).

Aquifers, springs and wells are recharged by the flow of groundwater. Groundwater is regarded as a finite resource which is very essential for agriculture, industrial activities and human consumptions since its supply has a profound impact on the quality of life. Nowadays, about 34% of the world's water resources belong to groundwater and is an important source of drinking water (Zeinolabedin and Esmaeily, 2015).

Groundwater potentials in an area is controlled by many factors such as geology, geomorphology, climate, drainage, slope, depth of weathering, presence of fractures, surface water bodies, canals and irrigated fields amongst others (Stanley, 2017). Slope for example is one of the factors that control the rate of infiltration of rainwater into the subsurface and could therefore be used as an index of groundwater potential evaluation. On a gentle slope area the run-off is slow allowing more time for rain water to percolate, whereas steep slope areas facilitate high run-off allowing less residence time for rain water to percolate, hence comparatively less infiltrations (Stanley, 2017).

Consequences of unsustainable and improper groundwater exploration are increasingly evident in several parts of the world due to ever-increasing population, urbanization, industrialization and intensified human activities (Pandian, and Jayachandran 2014). The main concern for groundwater assessment is to maintain groundwater supply on a long-term basis for a sustainable growth and development. The major sources of water in several parts of the developing worlds are taps, boreholes, hand pumps, open wells, streams and rivers. In the absence of available good and safe water sources, people begin to use unsafe sources and this resulted in some health problems.

Increasing population and water scarcity have raised the importance of groundwater zones, as they are a major source of freshwater. Integrated remote sensing and GIS are widely used in groundwater mapping. Locating potential groundwater targets is becoming more convenient and cost effective with the advent of a number of satellite imageries. Remotely sensed based groundwater exploration has made it feasible to explore the areas with limited human access, for the wide visual range, short time cycle, and increasing spatial resolution (Huajie, *et al* 2016).

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Geographic information systems (GIS) have emerged as powerful tools for handling spatial data and decision-making in several areas including engineering and environmental fields. Since the delineation of groundwater prospect zones involve a large volume of multidisciplinary data, an integrated application of RS and GIS techniques has become a valuable tool. Moreover, GIS has the ability to process multiple of data, which may reveal certain relationships and visualize different types of information simultaneously. In contrast, remote sensing (RS) technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time. GIS has been a very useful tool for the assessment, monitoring and management of groundwater resources in different parts of the world (Engman and Gurney 1991, Jha *et al* 2007).

MATERIALS AND METHOD

Study aim and Objectives

The aim of this study is to assess the spatial variation of groundwater potential zones in Birnin Kudu Local Government Area of Jigawa State, Nigeria. The specific objectives are to:

- Characterize the factors contributing to groundwater potentials in the study area;
- Identify and map the groundwater potential zones in the study area, and
- Analyze the spatial extent of groundwater potentials in the study area.

Study Area

The study area Birnin Kudu Local Government is located between Latitudes 11º 20'N to 11º39' North of the equator and Longitudes 09º 10'E to 09º 40' East of the Greenwich meridian. It covers area of about 2,073 square Kilometers. The main elevation of the plain surface of the area is between 400 - 420m above mean sea level. The total annual rainfall received ranges between 500-600mm in the region (Olofin 2008). The area is characterized by a long dry season which lasts on average of 8 months from October to April or May. The mean monthly temperature in the area ranges between 30°C and 35°C. The wet season mean annual temperature is about 25°C and diurnal range of about 10°C to 13°C. Relative humidity ranges from 80% in August to 23% between the month of January and March. The major rivers of the area are River Birnin Kudu, River Masaya and Kiyako (Murtala and Yazid, 2019).

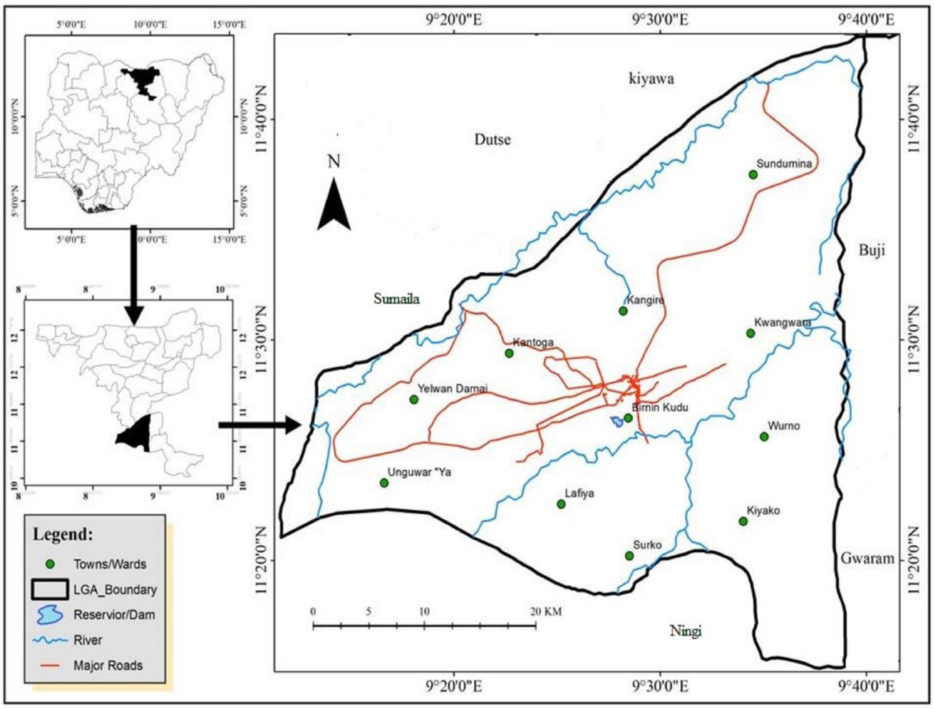

Figure 1: The Study Area (Birnin Kudu LGA)
Source: Modified from Administrative Map of Nigeria.

Data and Software Used

Data used include remotely sensed data like Landsat 7 (ETM + 30m) image of Birnin Kudu and ASTER Global Digital Elevation Model (DEM); other maps are geology, lineament, drainage density, soil map of the study area; and the rainfall data. Software used include ArcGIS 10.8, PCI Geomatica and Google Earth Pro.

Data Processing

Characterization of Factors Contributing to Groundwater Potential

The Analytic Hierarchy Process (AHP) introduced by Saaty (1980) was used to determine the weight of groundwater parameters by integrating the various thematic maps (layers) of the factors contributing to groundwater

Table 1: Procedure for Assigning Weightages in Analytical Hierarchy Process (AHP)

Scale	Degree of Preference	Explanation
1	Equal importance	Two elements contributes equally to the objective
3	Moderate importance	One Criterion is moderately important than the other.
5	Strong or essential importance	One Criterion is strongly important than the other
7	Very strong importance	One Criterion is extremely important than the other
9	Extreme importance	One Criterion is extremely more important than the other.
2,4,6,8	Values for inverse comparison	Can be used to express intermediate values

Source: Saaty (1991)

Table 2: Weights of all the Factors Influencing Groundwater Potentiality

	Rainfall	Lineament	Geology	Slope	DEM	Soil	Drainage	LULC	Weight
Rainfall	1	3	3	4	5	6	7	9	34
Lineament	1/3	1	2	3	5	6	7	9	24
Geology	1/3	1/2	1	2	2	3	4	7	14
Slope	1/4	1/3	1/2	1	2	3	4	5	10
DEM	1/5	1/5	1/2	1/2	1	3	4	5	8
Soil	1/6	1/6	1/3	1/3	1/3	1	3	5	5
Drainage	1/7	1/7	1/4	1/4	1/4	1/3	1	3	3
LULC	1/9	1/9	1/7	1/5	1/5	1/5	1/3	1	2

Source: Author's Analysis, 2023

potentials in the study area. AHP is an effective tool for dealing with complex decision making and may help the decision maker to set priorities and make the best decision without being biased. The AHP was used to characterize the zones into very good, good, moderate, low and very low. These zones were characterized based on the aquifer properties, soil type, geology and topography. Table 3.1 shows the processes involved in weight assignment using AHP and Table 3.2 shows weight for the factors according to Solomon (2003).

Groundwater Potentials Zones Mapping

Integration of the thematic maps of Rainfall, lineament, geology, slope, DEM, soil, Drainage density and LULC) was carried out in ArcGIS environment. The prediction model of groundwater potentials formulated by Hopkins (1977) for generating suitability maps was adopted. It is given as:

GwP = DDw + Gw + Tw + SStw + Rw + SCw + LDw…Ow (1)

Where; GwP = Groundwater potentials, DD = drainage density, Gw = Geology, T = Topography SS = Slope steepness, R = Rainfall, SC = soil and clay ratio, LD = Lineament density, w = weightage, O = other parameters. This was modified for the study as adopted by Mogaji, Aboyeji and Omosuyi (2011), Mary (2016) and Nasiru (2017).

Groundwater Potential Zones Gwp= Rw+LDw+Gw+Sw+DEMw+Sw+DDw+LULCw

where;

Rw = Rainfall weight
LDw = Lineament Density weight
Gw = Geology weight
Sw = Soil weight
DEMw = DEM weight
Sw = Soil weight
DDw = Drainage Density weight
LULCw = LULC weight

Estimating Spatial Extent of Groundwater Potential Zones in the Study Area

Each prospect zone from the groundwater potential zones map was converted individually to shape file in ArcGIS environment. Geometry calculator tool was used in calculating the areal extent of the various potentiality of the groundwater in the study area. The result is presented in a table.

RESULTS AND DISCUSSIONS

The result from the Weights of the factors influencing groundwater prospects zones in the study area shows that rainfall is the major contributor, and weighed as the highest contributor with (34%) followed by lineament (24%) and geology was weighed (14%). The least groundwater contributor in the study area is the land use land cover with (2%). The study showed that the very high groundwater potential areas occupy 59.92 sq. km (2.89%) of the area, the high potential zones constitute about 527.52 sq. km (25.45%) of the study area and the moderate potential area has the highest area of 602.69 sq. km (29.07%). The low and very low potentials occupy an area of about 528.13 sq. km (25.48%) and 354.75 sq. km (17.11%) respectively. The very high and high groundwater potentiality are observed in Sundumina,

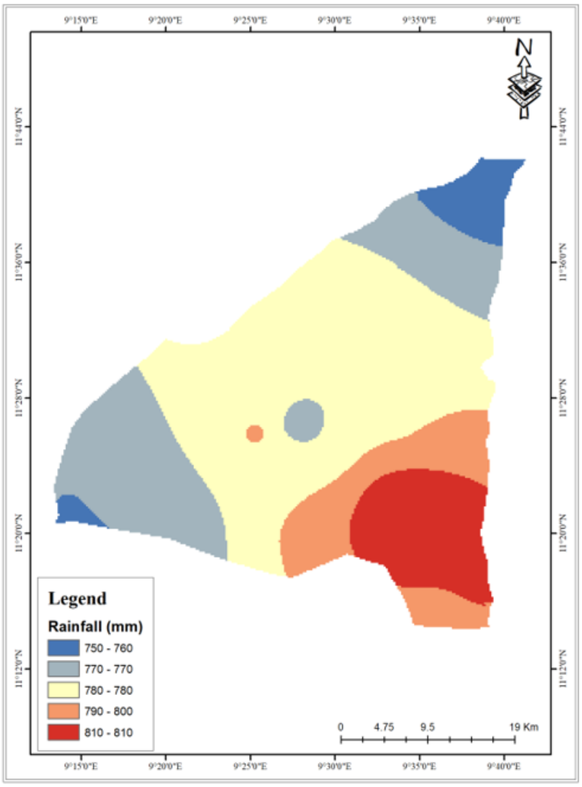

Figure 2: Rainfall Map
Source: GIS Analysis, 2023

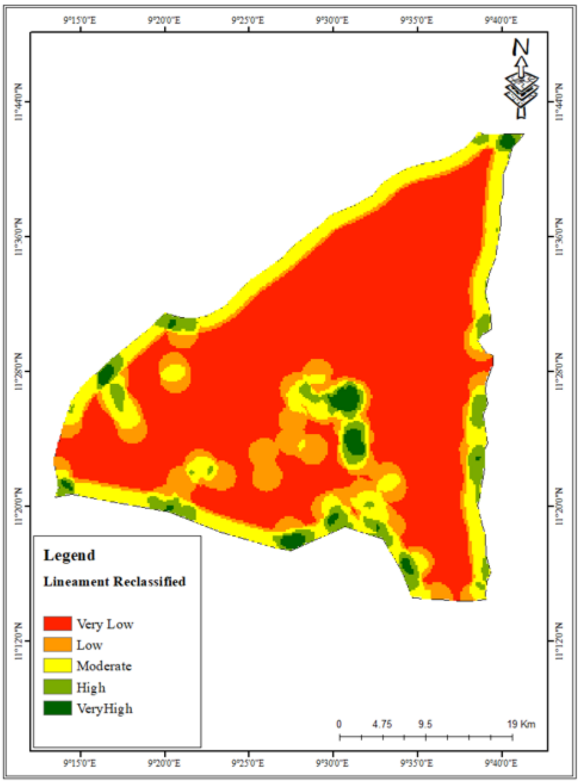

Figure 3: Lineament Map
Source: GIS Analysis, 2023

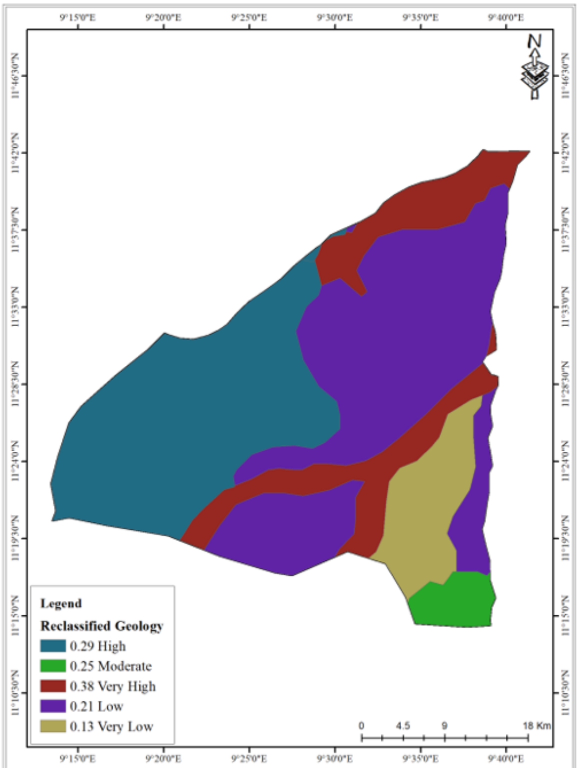

Figure 4: Geology Map
Source: GIS Analysis, 2023

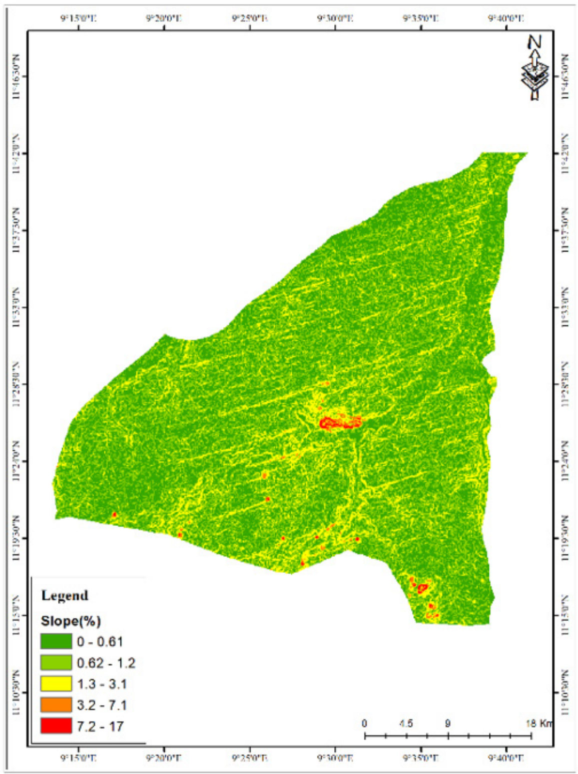

Figure 5: Geology Map
Source: GIS Analysis, 2023

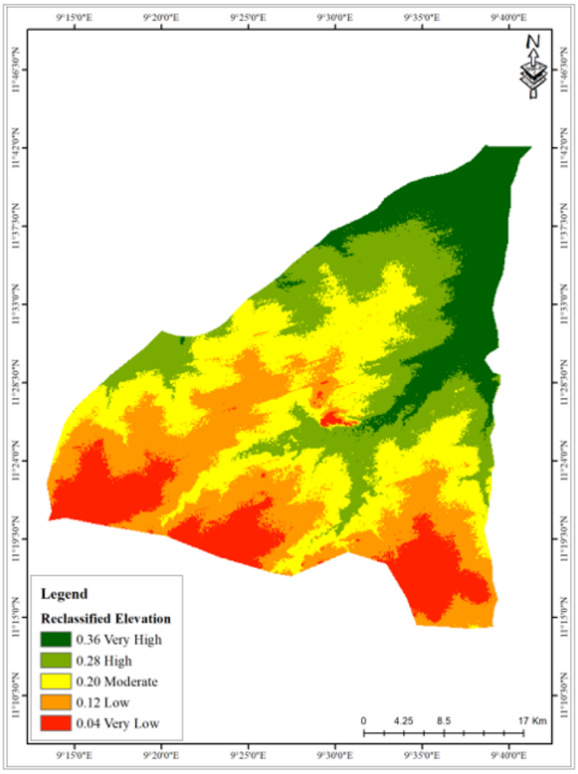

Figure 6: Rainfall Map
Source: GIS Analysis, 2023

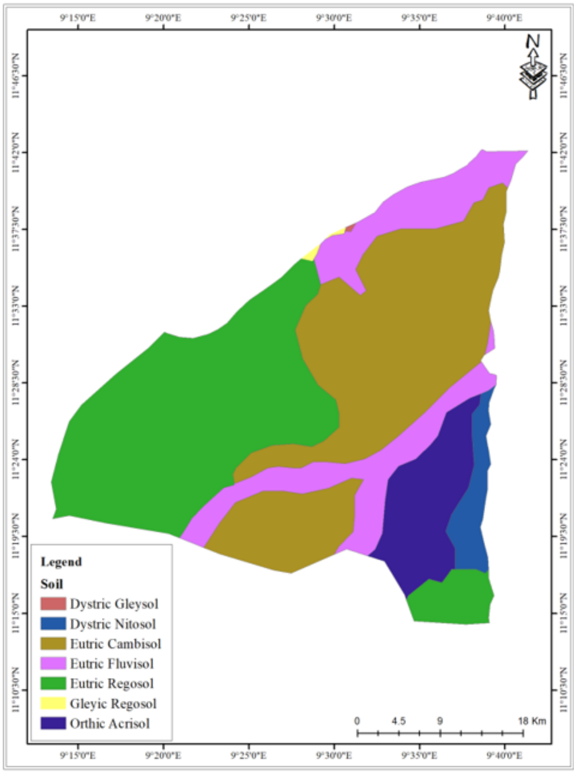

Figure 7: Lineament Map
Source: GIS Analysis, 2023

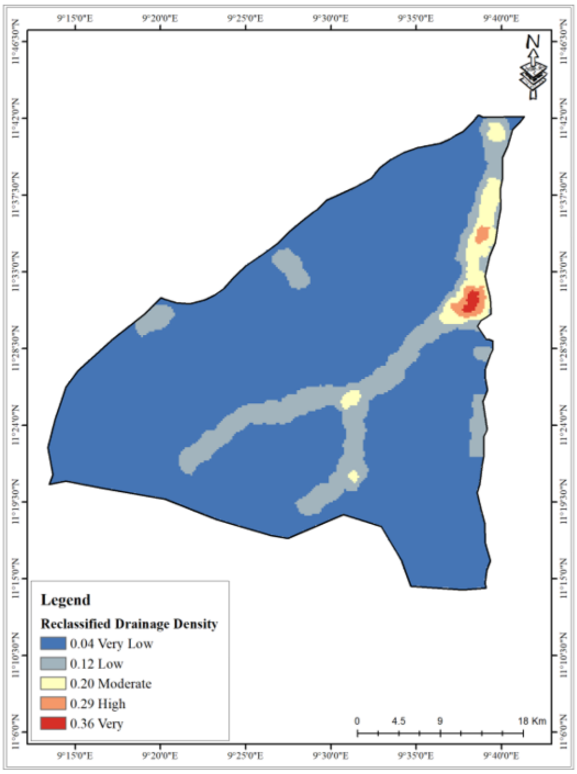

Figure 8: Drainage Map
Source: GIS Analysis, 2023

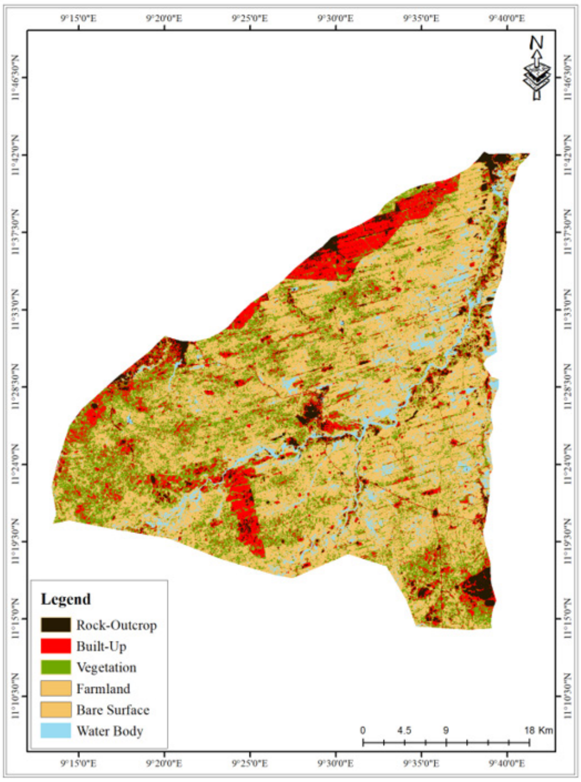

Figure 9: Land use Land cover Map
Source: GIS Analysis, 2023

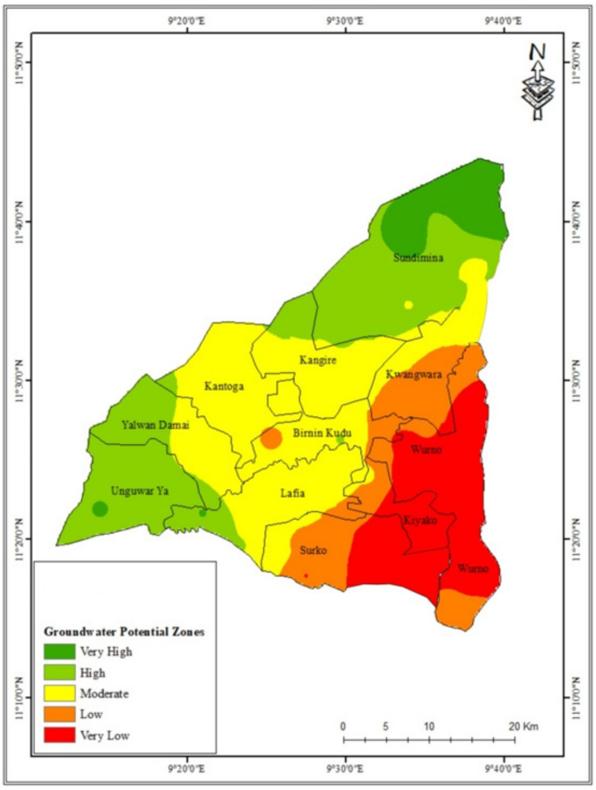

Figure 10: Groundwater Potential Zones of Birnin Kudu L.G.A.
Source: GIS Analysis, 2023

Table 3: Spatial Extent of Groundwater Potentials in the Study Area

Groundwater Potential Zones	Area in Sq. Km	Percentage (%)
Very High	59.92	2.89
High	527.52	25.45
Moderate	602.69	29.07
Low	528.13	25.48
Very Low	354.75	17.11
Total	**2,073**	**100**

Source: Author's Analysis, 2023

Table 4: Weights of all the Groundwater Controlling Factors

Factors	Classes	Factors Weight	Individual Weights	Potential	Weight (%)
Rainfall	750–760	0.34	0.04	Very Low	34
	761–770		0.08	Low	
	771–780		0.14	Moderate	
	781–790		0.27	High	
	791–810		0.47	Very high	
Lineament	0 -19	0.24	0.03	Very Low	24
	20 – 55		0.07	Low	
	56 – 91		0.11	Moderate	
	92 – 134		0.23	High	
	135 - 248		0.56	Very high	
Geology	Sand Dunes over-Sandstone	0.14	0.38	Very Low	14
	Aeolian sand over Alluvium		0.29	Low	

	Aeolian sands		0.25	Moderate	
	Sand dunes over Sandstone		0.21	High	
	Undifferentiated Basement Complex		0.13	Very high	
Slope	0 – 3	0.10	0.39	Very Low	10
	4 – 7		0.30	Low	
	8 – 11		0.17	Moderate	
	12 – 15		0.09	High	
	16 – 17.3		0.04	Very high	
DEM	387 – 419	0.8	0.36	Very Low	8
	420 – 451		0.28	Low	
	452 – 483		0.20	Moderate	
	484 – 515		0.12	High	
	516 – 550		0.04	Very high	
Soil	Dystric Gleysol	0.5	0.38	Very High	5
	Eutric Regosol		0.33	High	
	Eutric Cambisol		0.29	Marginally High	
	Eutric Fluvisol		0.26	Moderate	
	Dystric Nitosol		0.21	Marginally Low	
	Orthic Aerisol		0.13	Low	
	Gleyic Regosol		0.04	Very Low	
Drainage	0 – 28	0.3	0.04	Very Low	3
	29 – 83		0.12	Low	
	84 – 134		0.20	Moderate	
	135 – 184		0.29	High	
	185 – 296		0.36	Very high	
LULC	Water body	0. 2	0.33	Very High	2
	Vegetation		0.26	High	
	Bare land		0.19	Marginally High	
	Built-up Land		0.11	Moderate	
	Rock Outcrop		0.1	Marginally Low	
			0.01	Low	

Source: Author's Analysis, 2023

Unguwar 'Ya and some part of Yalwan Damai, which could be attributed to the fact that the area receives high amount of rainfall, lie on low elevated land in the central area also highly vegetated. The Moderate areas are Birninin Kudu, Kangire, Kantoga, Lafia and some parts of Kwangwara which are more urbanized and this could attributed with run-off as a result of urbanization. While Wurno, Kiyako and Surko and some parts of Kwangwara are of low and very low potential areas.

The study has shown the spatial variability of ground water potential in the study area. The variability closely followed variability in the Rainfall, Lineament, Geology, Slope, DEM, Soil, Drainage and LULC in the study area. Based on the findings, most promising groundwater potential zone in the area is related to high rainfall, low slope and high lineament density. Most of the zones with low to very low groundwater potential lie far from lineaments.

CONCLUSION

In conclusion, the groundwater potential zones have been derived for the entire Birnin Kudu Local Government Area of Jigawa State and classified into five categories namely very high, high, moderate, low and very low potentials. It is observed from the study that the very good groundwater potential zones are located in the Northern part of the study area. It was established from the findings that the study area has abundance of groundwater potential which can sufficiently take care of the domestic needs of water supply for its populace.

The groundwater potential zones mapping using remote sensing and GIS techniques is a rapid, inexpensive, accurate with a large areal coverage. Thus, it provides range by which the most prospects zones within an area in which groundwater occurrence is expected. Hence, narrowing down the quest and site locations for boreholes and wells will reduce unnecessary work, saves time and cost. Therefore, borehole/well drilling activities in the study area should consult this study finding before commencing their work.

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