GROUNDWATER MODELLING USING GEOSPATIAL TECHNOLOGY IN KACHIA LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA

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Abstract: The provision of potable water for the teeming population is one of the cardinal objectives of governance in the developing countries. The continuous change in global Climate, increase in population, inadequate supply of pipe borne water and drying up of wells during dry season over the years are the major reasons for inadequate supply of adequate quantity of quality potable water to meet the demands of the population. The study examined groundwater modeling using geospatial technology in Kachia Local Government Area, Kaduna state Nigeria. Remote sensing, Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis techniques were used to analy ze digital layers of lineament, rainfall, geological structure, drainage, soil, slope, land use/cover and topography to detect the most promising sites for groundwater exploration in the area. Results from the study revealed five groundwater zones in the area; very good, good, moderate, fair and poor. Very good zones had the highest groundwater potential located at the eastern part of the study area and occupy about 14.1%. Areas of good potential occupy 22.4%, moderate occupy 15.0% while fair occupy 23.9%. A large portion of the study area has low groundwater potential with aerial coverage of 24.6%, dominantly at the western part of the study area.The study concluded that, the usefulness of remote sensing and GIS in providing efficient and effective information that save time and money in mapping promising sites for groundwater potential zones cannot be over emphasized. The final groundwater map is a vital source of information for geologist, engineers, borehole drillers and the government in locating the most promising sites of water resources for sustainable development of the area.
Keywords: GIS, remote sensing, multi-criteria decision analysis, groundwater.

Introduction

Water is the primary sustainer of life, and the most important resources next to air, without which human existence will not have been possible. About three-quarter of the earth's surface is covered by water. More than 95% of the water resides in the world's oceans. A large portion of the remaining is frozen up in glaciers (1.953%) and 0.614% are found beneath the surface as underground water, leaving only about 0.015% as surface water in rivers, streams, ponds, canals, springs and lakes which are the major sources of water that can be easily accessed. In most cases, these sources of water harbor agents that cause diseases such as typhoid fever, cholera, dysentery, and infectious hepatitis (Sander *et al.*, 2007).
The provision of potable water for the teeming population is one of the cardinal objectives of government in the developing countries. Many water provision initiatives have been undertaken over the years and although achievements have been recorded in certain areas, water provision cannot be described as a complete success story. The continuous change in global climate and the increase in population over the years have resulted to increasing scarcity of adequate quantity of quality water to meet the demands of the population of Kachia area of Kaduna State. The continues inadequate supply of pipe born water and drying up of shallow wells of near-surface aquifers during dry season, uncontrolled land-use and the pollution from human and industrial wastes have exacerbated water scarcity and serious danger to the availability of water resource of the study area (Obaje, 2009).
Ground water has long been considered as one of the purest and most reliable sources of water available to man, due to its ability to remain relatively constant through seasonal and climatic change. Groundwater is the occurrence of water below the water table, which occupies the pore spaces between grains in bodies of sediments and clastic sedimentary rock, cracks, and crevices of rock. According to Todd and Mays (2005), ground water is water occupying the empty spaces within geologic formations; the most prolific being defined as aquifers, which are those geologic formations made of sufficiently saturated, porous and permeable materials, able to host significant quantities of groundwater for deliveries to water wells and springs. Groundwater is a significant global resource, comprising of about 96% of the earths freshwater and a major source of water feeding springs and streams, supporting wetlands, and maintaining land surface stability (Subbarao, 1992).
The occurrence, storage, and distribution of groundwater are influenced by different geological factors. Most often, the occurrence of groundwater in Basement Complex terrains is localized and confined to weathered/fracture zones (Ariyo and Adeyemi, 2009). Test drilling and stratigraphy analysis are reliable ways of determining the location of an aquifer and its characteristics. However, these methods are costly, time consuming and rarely used (Fetter, 1994). An alternative technique for exploring groundwater resources that overcomes the above limitations is the use of geophysical methods of Electrical resistivity. Most groundwater development projects have mandated the use of geophysical surveys as a pre-requisite to any successful groundwater resources development (Olorunfemi and Fasuyi, 1993).
Studies have shown that over 50 boreholes were drilled from 2000-2010 in Kachia area of Kaduna state, 80% of the bore holes has stopped yielding water. The breakdown of the borehole has being attributed to poor maintenance and inadequate information on good ground water potential zone in the area. Since geo-physical survey used in groundwater prospecting is time consuming and

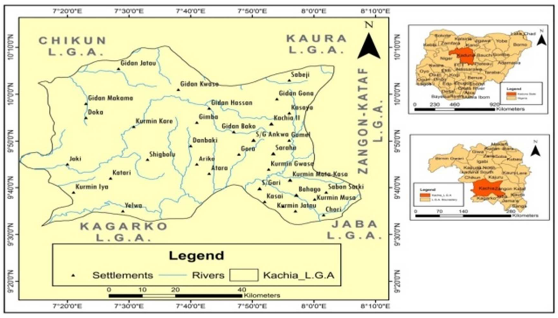
expensive, most water engineers tend to boycott the surveys process, leading to poor yield and future break down of the boreholes (Babu, 2011). There is the need for accurate, less expensive and temporal information on groundwater to improve the speedy degradation of adequate water supply in the study area. Geospatial technology has been proved to be a very useful tool in exploring, evaluating, and determining groundwater potential zones. Remote sensing and GIS are efficient, less expensive and accurate tools that provide quicker and useful information on the occurrence and movement of groundwater using factors controlling ground water resources (Samere, 2003).This study used Remote Sensing and GIS techniques in investigating groundwater potential zones in Kachia Area of Kaduna State.

Materials and Methods

The study area

The study area lies within latitudes 09° 32′ and 10° 10′N of the Equator and longitude 07° 14′ E and 08° 04′E of the Greenwich meridian. It occupies an area of about 4,632 km² with population of 244,274 people according to the 2006 provisional census figure. Kachia LGA is bordered in the north by Chikun and Kauru LGAs, in the west by Niger State, in the East by Zangon-Kataf LGA and in the south by Kagarko and Jaba Local Government Areas as shown in Fig. 1. The annual rainfall of the area is about 1000 mm with temperature range between 36°C in April and 27°C in the heart of rainy season. The vegetation of the study area is Northern Guinea Savannah with scattered trees, shrubs and grasses hardly higher than 15ft. The seasonal characteristics of rainfall in the area have influenced the vegetation which turns evergreen during the wet season and pale brown in the dry season respectively (Oguntoyinbo, 1983). The soils in the area are zonal soils developed under climatic regimes; they are made up of several feet of grey white loamy coarse sand with layers of grey heavy molten occurring at varying depths.

The geology is part of the basement complex of central Nigeria composed of older high grade-metamorphosed gneiss interspersed by belt of young metasediment of mainly quartzite and schist. The region is underlain by older granitic crystalline, metamorphic rocks of Precambrian to low Paleozoic age (Oguntoyinbo, 1983). It also consists of gneisses which has suffered intense weathering and have remained stable for millions of years. The prolonged weathering under tropical bioclimatic condition has produced rolling plains dotted with residuals of different origin. The area is drained by river Kaduna with its source from the highland of Plateau state and characterized by high stream frequencies and drainage density. The river drains mostly during the raining season, and characterized by seasonal and ephemeral attributes (Oguntoyinbo, 1983).



Source: Modified from the administrative map of Kachia LGA

Fig. 1: Geographical map of Kachia Local Government Area in Kaduna State, Nigeria

Data and materials

The data and materials used for this study were Lands at 7 with 28.5 m resolution acquired in November, 2015 with 7 bands and orthorectified. The spectral bands ranges from the panchromatic data having 15m resolution, six band in the visible, near-IR and mid-IR at a resolution of 30 m and one thermal band at 60 m resolution. Also the Shuttle Radar Topographic Mission (SRTM) imagery of 90 m resolution covering the study area was also employed. Other types of data used include geological, soil and topographic maps of the study area, all at a scale of 1:50000. Rainfall data of the study area spanning a length of 10 years from the Nigerian meteorological Agency was also used. The primary data derived from these data sets are geology, topography, slope, lineament, land use/cover and drainage of the study area.

Techniques of data analysis

Multi-Criteria Decision Analysis was adopted, using Analytical Hierarchy Process to combine all the data sets; aquifer properties, soil type, slope, lineament, geology, topography, land use/cover using weighted overlay. The attributes of each of these data sets were also ranked into factors extremely high, moderate, low and very low to provide quantitative measures for GIS modelling. Table 1 presents the processes involved in weight assignment in AHP.

Table 1: Procedure of assigning weight in analytical hierarchy process

Scale	Degree of preference	Explanation
1	Equal importance	Two elements contributes equally to the objective
3	Moderate importance	Experience and judge slightly favor one element over another
5	Strong or essential importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another. It dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Values for inverse comparison	Can be used to express intermediate values

Source: Saaty and Vargas (1991)

Procedures of analysis

The datasets were rasterized to have a uniform cell size of 30 m. Most importantly, the weights obtained for all the attributes of each factor was used to reclassify them in the GIS environment. Each factor is compared with each other using the pair-wise comparism of the AHP to produce weights for each of them based on their contribution to groundwater occurrence. To aid further analysis and uniformity for analysis in the GIS environment, the Weights (Eigen Vector) of each factor was multiplied by 100 to obtain integer values required for the integration of the datasets. Finally, weighted overlay is done to generate the groundwater potential of the study area.

Identification the ground water prospect zones from the thematic maps

The integration of the thematic maps of factors contributing to groundwater potential was carried out in ArcGIS 10.1 using the weighted overlay in spatial analysis tool using the formula from equation (1) Underground water potential zones = GL+RF+LD+DD+SL+LU+TP …………. (1)

Where: GL= Geological map; RF= Rainfall map; LD= lineament density map; DD= Drainage Density map; SL= Slope map; LU= Land use/cover Map; TP= Topography map.

Estimation of the area coverage of the underground water potential zones

The aerial coverage of each groundwater zone; very good, good, moderate, fair and low from the ground water potential zones raster map was converted individually to geodatabase file format using the conversion toolbox in ArcGIS version 10.1 and automatically calculates the area of each of the groundwater potential zones. The methodology employed in this study is summarized in Fig. 2.

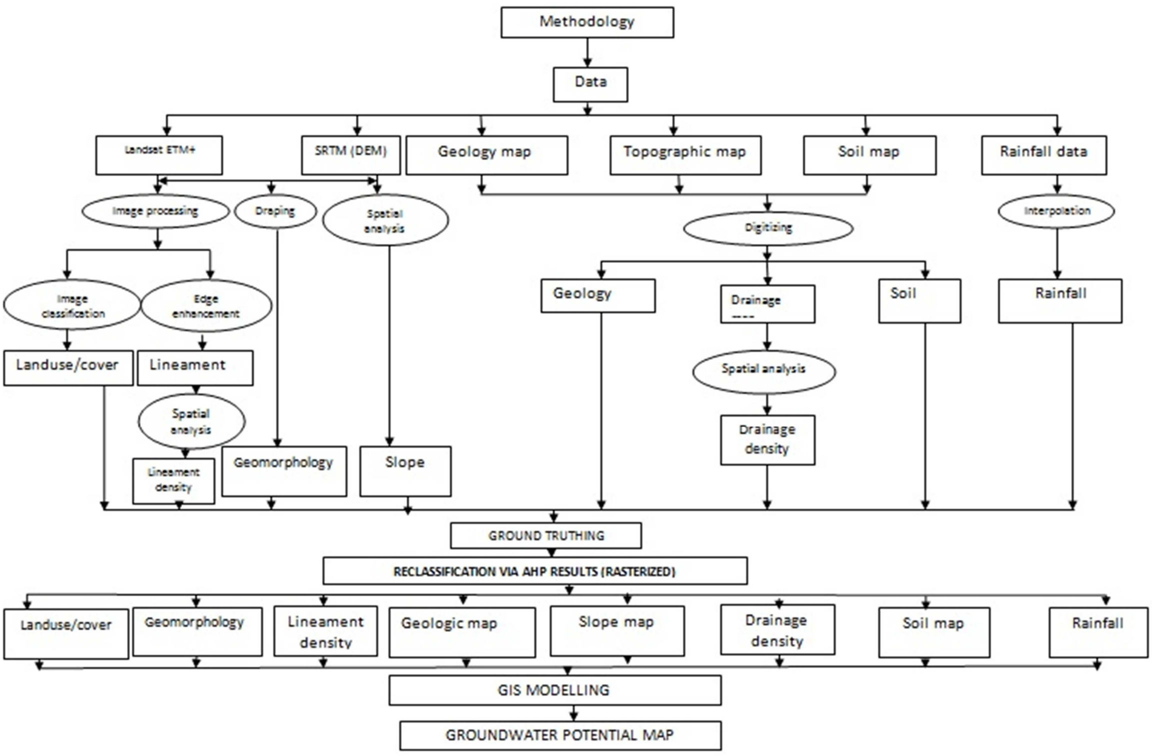


Fig. 2: Graphical Presentation of method employed in this study

Results and Discussion

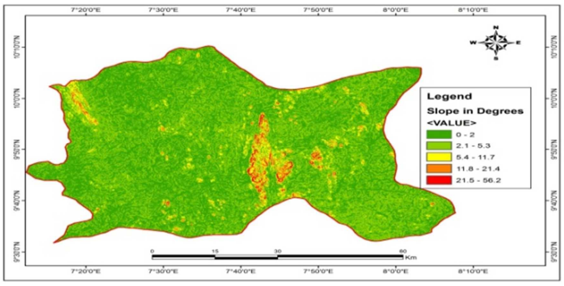
Slope analysis

From Table 2, flat terrain with slope value ranging from 0-2% has very good groundwater potentials; areas with steep slope ranging from 21.5-56.2% have low water potential. The degree of slope has a lot of influence on the accumulation of groundwater of an area. Generally, flat areas are capable of holding rain water, which in turn promote infiltration and ground water recharge. Elevated and steep slope areas encourage run-off with little or no infiltration and low groundwater recharge. Studies have also shown that movement of the hinge line between inflow and outflow is a result of the changing slope of the water table in response to changes in ground-water recharge in the adjacent uplands (Solomon, 2003).

Table 2: Groundwater potential zones of the study area base on slope

Slope (%)	0-2	2.1–5.3	5.4–11.7	11.8–21.4	21.5–56.2	Weighted	Potential
0-2	1	2	5	7	9	0.47	Very Good
2.1-5.3	1/2	1	3	5	9	0.3	Good
5.4-11.7	1/5	1/3	1	3	7	0.14	Moderate
11.8-21.4	1/7	1/5	1/3	1	5	0.07	Fair
21.5-56.2	1/9	1/9	1/7	1/5	1	0.03	Low

Consistency Ratio=0.06



Source: Authors' analysis, 2015

Fig 3: Slope map of the study area

Land use/cover

Land use/cover is a major parameter that affects ground water availability of an area. The characteristics of each land use/cover type permit or inhibit run-off or infiltration, which in turn increase or reduce the recharge of underground water. The categories of land use/cover for this study are water body, vegetation, bare surface, cultivated land and build up areas.

Table 3: Aerial coverage of LULC of the study area

LULC	Area in Sq. Km	Percentage
Vegetation	1078.6	23.5
Cultivated Land	1895.7	41.2
Bare Land	921.8	20.0
Build-up Areas	631.2	13.7
Water body	71.9	1.6
Total	**4599.2**	**100**

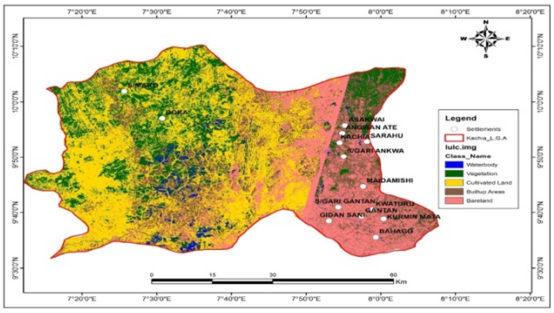
Source: Authors' analysis, 2015

The land use/cover of the study area generated from digital image classification of Landsat imagery shows that cultivated land occupies 41.2%, vegetation 23.5%; bare land 20.0%; built-up areas 13.7% and water body 1.6%. Results from Table 3 showed that areas around the water body have very good ground water potential, followed by vegetated areas. The bare land was weighed moderate while cultivated land and built-up areas have fair and low ground water potential, respectively.

Table 4: Groundwater potential from land use/cover

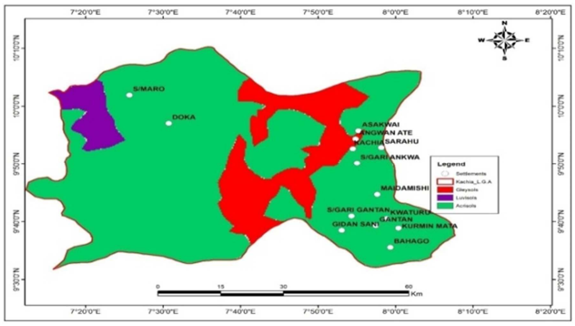
LULC	Water body	Vegetation	Bare Land	Cultivated Land	Build-up Areas	Weighted	Potential
Water body	1	5	7	6	9	0.56	Very Good
Vegetation	1/5	1	3	4	9	0.23	Good
Bare Land	1/7	1/3	1	2	7	0.11	Moderate
Cultivated Land	1/6	1/4	1/2	1	4	0.07	Fair
Build-up Areas	1/9	1/9	1/7	1/4	1	0.03	Low

Consistency ratio=0.12



Source: Authors' analysis

Fig. 4: Land use/cover of the study area



Source: Authors' analysis, 2015

Figure 5: Soil types of the study area

Soil type

The influence of soil on groundwater recharge depends on the texture, grain size, and porosity, which influence infiltration. Table 5 represents the weight of the groundwater potential in the study area. Of the 3 types of soil of the study area, gleysols have good infiltration rate, luvi soil have moderate andacrisols has the lowest groundwater potential.

Table 5: Groundwater potential for soil

Soil	Gleysols	Luvisols	Acrisols	Weigh	Potential
Gleysols	1	3	5	0.64	Good
Luvisols	1/3	1	3	0.26	Moderate
Acrisols	1/5	1/3	1	0.1	Low

Consistency Ratio=0.04

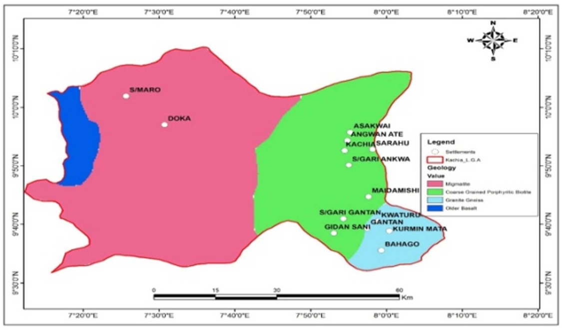
Geology

The lithologic units in the study area are Coarse Grained PorphiriticBiotite, Granite Gneiss, Migmatite and Older Basalt. It is well established that geology plays a vital role in the distribution and occurrence of ground water. Fig. 6 and Table 6 present the geology of the study area and the weights. The rocks occurring in the study area were ranked based in their aquifer characteristics, with the Coarse Grained Porphiritic Biotite ranked with the highest water bearing capacity because they serve as natural hosts of aquifers for groundwater. In contrast, migmatite and older granite have poor hosts for groundwater because of their low level of secondary porosity, and clay nature which does not support groundwater accumulation

Table 6: Groundwater potential for geology

Geology	Coarse Grained Porphiritic Biotite	Granite Gneiss	Migmatite	Older Basalt	Weight	Potential
Coarse Grained Porphiritic Biotite	1	3	3	4	0.51	Good
Granite Gneiss	1/3	1	2	3	0.25	Moderate
Migmatite	1/3	1/2	1	2	0.16	Fair
Older Basalt	1/4	1/3	1/2	1	0.09	Low

Consistency ratio=0.04



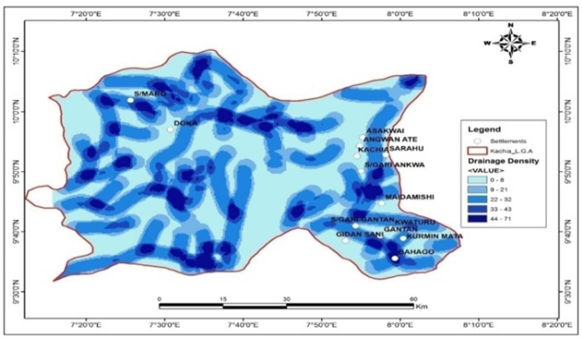
Source: Authors' analysis, 2015
Fig. 6: Geology of study area

Drainage
Drainage pattern is an important indicator of hydrogeological features because they control underlying lithology. In addition, the stream pattern is a reflection of the rate of precipitation infiltration compared with the surface runoff largely controlled by permeability, which is a function of the rock type and fracturing of the underlying bedrock (Obaje, 2009). Results from Table 7 shows that areas with low drainage density have low groundwater potentials and areas with high drainage density have very good ground water potentials.

Table 7: Groundwater potential for drainage density (DD)

DD	0-8	21	22-32	33-43	44-71	Weighted	Potential
0-8	1/6	1/6	1/4	1/2	1	0.05	Low
9-21	1/6	1/4	1/2	1	2	0.07	Fair
22-32	1/5	1/3	1	2	4	0.12	Moderate
33-43	1/3	1	3	4	6	0.26	Good
44-71	1	3	5	6	6	0.49	Very Good

Consistency ratio=0.06



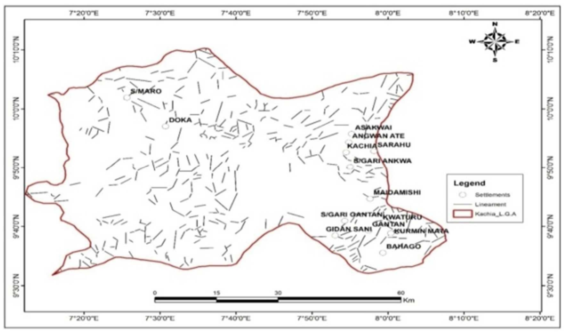
Source: Authors' analysis, 2015
Figure 7: Drainage density of the study area

Lineament density
Lineaments are underlain by zones of localized weathering and increased permeability and porosity. Previous studies have revealed a close relationship between lineaments, groundwater flow and yield (Obaje, 2009). The extension of large lineaments representing a shear zone or a major fault and can extend from hilly terrain to alluvial terrain (Solomon, 2003). It may form a productive groundwater reserve. Similarly intersection of lineaments can also be potential sites of groundwater accumulation. Therefore, areas with high lineament density may have important groundwater prospects than area with low density as presented in Table 8.

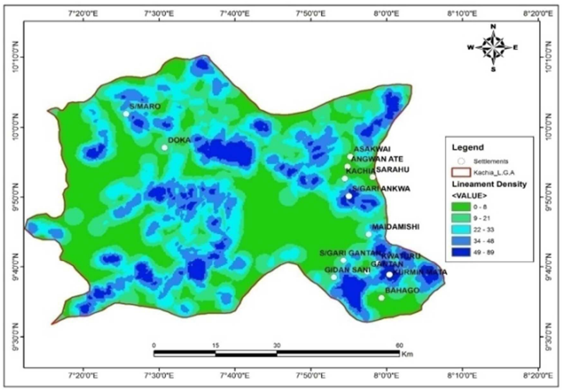
Table 8: Groundwater potential for lineament density (LD)

LD	0-8	9-21	22-33	34-48	49-89	Weighted	Potential
0-8	1/9	1/7	1/5	1/3	1	0.03	Low
9-21	1/7	1/5	1/3	1	3	0.06	Fair
22-32	1/5	1/3	1	3	5	0.13	Moderate
33-43	1/3	1	3	5	7	0.26	Good
44-71	1	3	5	7	9	0.51	Very Good

Consistency ratio=0.08



Source: Authors' analysis, 2015
Fig. 8a: Lineament of the study area



Source: Authors' analysis, 2015

Fig. 8b: Lineament density of the study area

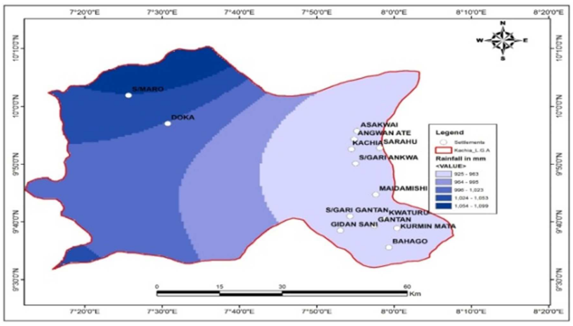
Rainfall

Rainfall is the primary sources of groundwater. Basically, infiltration of rainwater to join groundwater is modified by the topography, vegetation and surface geology; they affect the quantity of water that goes underground. Generally, high amount of rainfall is related to high occurrence of groundwater. From Fig. 9, the northwestern part of the study area has the highest annual rainfall amount, ranging between 1054-1099 mm. In the eastern part of the study area where the elevation is low, rainfall appears to be low ranging between 925 – 963 mm. These are classified as areas with good, moderate, fair and low potentials. A pair wise comparison was carried out using AHP and result presented in Table 9.

Table 9: Rainfall potential for groundwater in the study area

Rainfall	925 – 963	964 – 995	996 – 1023	1024 – 1053	1054 – 1099	Weighted	Potential
925-963	**1**	2	2	2	2	0.11	Low
964-995	1/2	**1**	2	2	2	0.14	Fair
996-1023	1/2	1/2	**1**	2	2	0.19	Moderate
1024-1053	1/2	1/2	1/2	**1**	2	0.24	Good
1054-1099	1/2	1/2	1/2	1/2	**1**	0.32	Very Good

Consistency ratio=0.01



Source: Authors' analysis, 2015

Fig. 10: Average annual rainfall of the study area

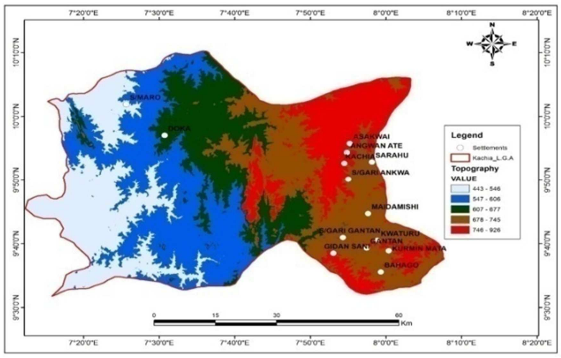
Topography

Topography plays an important role in identification of favorable zone for groundwater. More promising groundwater is in flood plains, alluvial fans and valley fills that are associated with thick alluvial and weathered materials with high porosity and permeability. Pediments generally are not favorable for groundwater potential zones. Table 10 shows that areas with low elevation values have very good groundwater potential than places on high elevation. Therefore, places on low elevation give more chance for groundwater accumulation.

Table 10: Groundwater potential for topography of the study area

Topography	443 – 566	547 – 606	607 – 677	678 – 745	746 – 926	Weighted	Potential
443-566	1	3	4	5	7	0.49	Very Good
547-606	1/3	1	1	3	5	0.20	Good
607-677	1/4	1	1	3	5	0.19	Moderate
678-745	1/5	1/3	1/3	1	3	0.08	Fair
746-926	1/7	1/5	1/5	1/3	1	0.04	Low

Consistency ratio=0.04



Source: Authors' analysis, 2015

Fig. 10: Digital elevation model (DEM) of the study area

Identification of the Ground Water Potential Zones

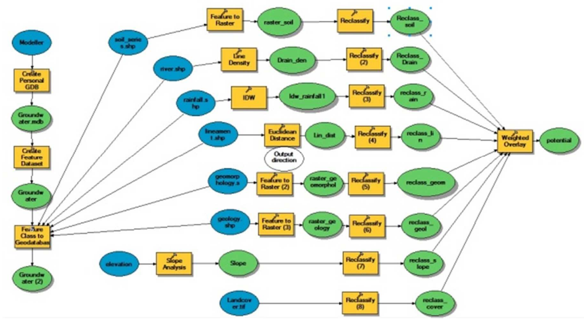


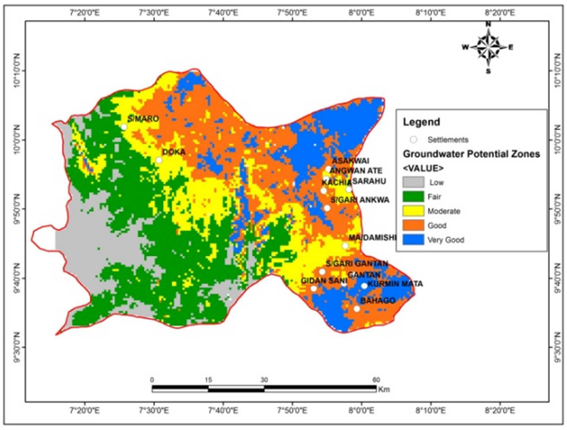
Fig. 11: A geoprocessing model for generating groundwater potential map

To calculate the groundwater prospects zones, all the thematic maps of the factors influencing the groundwater recharge in the study area are weighed and integrated. Table 11 presents the weight of the groundwater controlling factors and the groundwater prospect zones of the study area. An evaluation scale of 1 to 100 by 1 was set as the default criteria for the weighted overlay analysis and performed in GIS environment. All the derived values from the AHP were multiplied by 100% to have uniform value of raster maps and their attributes during the analysis. Finally, the groundwater potential map of the study area was generated as shown in Fig. 11.

Table 11: Weighted overlay of the groundwater factor of the study area

	Rainfall	Lineament	Geology	Slope	Elevation	Soil	Drainage	LULC	Weight	Weight *100
Rainfall	1	3	3	4	5	6	7	9	0.34	34
Lineament	1/3	1	2	3	5	6	7	9	0.24	24
Geology	1/3	1/2	1	2	2	3	4	7	0.14	14
Slope	1/4	1/3	1/2	1	2	3	4	5	0.1	10
Elevation	1/5	1/5	1/2	1/2	1	3	4	5	0.08	8
Soil	1/6	1/6	1/3	1/3	1/3	1	3	5	0.05	5
Drainage	1/7	1/7	1/4	1/4	1/4	1/3	1	3	0.03	3
LULC	1/9	1/9	1/7	1/5	1/5	1/5	1/3	1	0.02	2

Consistency ratio=0.05; Source: Authors' analysis, 2015



Source: Authors' analysis, 2015
Fig. 12: Groundwater potential zones of the study area

Conclusion

This study demonstrated the usefulness of geospatial technology and multi-criteria decision making in identifying promising sites for groundwater exploration using data of geology, topography, lineament, slope, drainage, land use/cover, rainfall and soil. Weighted overlay in spatial analyst tool of ArcGIS 10.1 was used to determine the influences of the factors thus; rainfall was weighted 34%, lineament density 24%. Geology 14%, slope 10%, elevation 8%, soil 5%. Drainage density and land use/cover were weighed the least with 2% and 3%, respectively. The aerial coverage of different groundwater zones was estimated using the geometry calculator. Groundwater is delineated: as very good, good, moderate fair and poor. Very good zones have the highest groundwater potentials, and are characterized by coarse grained porphyritic biotite with high potential of groundwater accumulation due of their high level of secondary porosity, flat topography with alluvial plains and high lineament density, and gentle slopes among others. These zones are common in the eastern part of the study area and occupy about 14.1% of the study area. The good potential zones occupy 22.4%, moderate 15.0% while fair occupies 23.9%, respectively. Based on this information, it can be concluded that the low potential zones occupies the largest portion of the study area (24.6%) commonly observed at the western part of the study area. These areas are characterized by steep slopes, older basalt, acrisols, among others. This study recommends the use of geospatial technology for groundwater exploration; they provide accurate, timely and cost effective information for identifying areas of potential groundwater. The final map is essential source information for geologist engineers' and borehole drillers for water exploration in the area.

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