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GEOSPATIAL ANALYSIS OF GROUNDWATER POTENTIAL ZONES IN OMALA LOCAL GOVERNMENT AREA, KOGI STATE, NIGERIA

Marcus Ameh AMEDU Magic Fingaz Biz World,
Ahmadu Bello University, Zaria

Benedine AKPU Department of Geography &
Environmental Management
Ahmadu Bello University, Zaria

Ibrahim Jaro MUSA
Department of Geography &
Environmental Management
Ahmadu Bello University, Zaria

Abstract

Water is one of our most important natural resources. Without it, there would be no life on earth. Poor knowledge about groundwater potential zones, due to its hidden nature and its occurrence in complex subsurface formation is a big obstacle to the exploration of this important resource. This study applied geospatial techniques in analyzing the groundwater potential zones in Omala Local Government Area. The objectives were to characterize the groundwater influencing factors, identify and map out the groundwater potential zones in the area as well as calculate approximately the spatial extent of the identified groundwater potential zones. Analytical Hierarchy Process (AHP) was used to characterize the groundwater influencing factors (lineament density, land use/land cover drainage density, slope, geology, rainfall and soil) while Weighted Index Overlay Analysis in ArcGIS 10.1 was used to produce the groundwater potential zones map. The findings revealed that; areas with very high rainfall have favourable conditions for very good groundwater potentials compared to other groundwater determinant factors as areas dominated by land use are unfavourable for groundwater potentials (very poor groundwater potential) as they tend to increase runoff. The groundwater potential map revealed the dominant influence of rainfall in groundwater potentials of the area accounting for 33% of the weight while land use/land cover had the least contribution of 3%. Very high groundwater potential zones were located mainly in the southern part of the study area accounting for 20.8% of the area while the very low groundwater potentials were mostly in the northern part accounting for 15.1% of the area. It was concluded that though groundwater is available everywhere, the potentiality varies over space owing to the role played by the different factors influencing groundwater potentials. It was recommended that Government should provide alternative water sources in areas found to be located on the very low and low groundwater potential zones in order to ameliorate water scarcity in such areas.

Keywords: *Analytical Hierarchy Process, Groundwater, Groundwater Potential Zones, Remote Sensing,*

GIS

INTRODUCTION

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Because of its several inherent qualities, it has become an immensely important and dependable source of water supply in all climatic regions including urban and rural areas of developed and developing countries (Waikar & Nilawar, 2014).

Groundwater is a form of water occupying all the voids within a geological stratum. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storing water. Its identification and location is based on indirect analysis of some observable terrain features such as geologic, geomorphic, landforms and their hydrologic characteristics (Ndatuwong & Yadav, 2014).

The term groundwater potential denotes the amount of groundwater available (i.e. the quantity) in an area and it is a function of several hydrologic and hydrogeological factors (Jha, Chowdary& Chowdhury, 2010). From a hydrogeological exploration point of view, this term may be defined as the possibility of groundwater occurrence in an area. Proper assessment of groundwater potential can serve as a useful guideline for decision maker in identifying suitable groundwater policies within an area and proper management of aquifer system in sustainable manner (Al-Abadi & Al-Shamma'a, 2014).

In Omala Local Government Area, availability of surface water is seasonal; during the relatively dry period of November to February each year, hand-dug wells and boreholes dry up as a result of wrong siting. The inadequate water supply despite the available boreholes poses serious challenge especially with increase in population and economic activities in the area.

Attempts have been made in different parts of the world as well as in some parts of Nigeria in delineating groundwater potential zones by various scholars like Kartic & Jatisankar (2012), Nezar, Ali & Mohammed (2012), Mayilvagana, Mohana & Naidu (2011), Abdullahi, Rai, Momoh &Udensi (2013), Fashae, Tijani, Talabi &Adedeji (2014).They arrived at groundwater prospects by deriving thematiclayers from satellite data, toposheets and by integrating them in GIS environment.

The State Government has resorted to the use of isolated borehole schemes for water supply to the settlements within Omala Local Government Area. Private developers also sink boreholes or wells for their domestic and industrial uses. Today, there are several boreholes scattered throughout Omala. However, majority of these boreholes are not properly constructed, maintained, and properly sited as a result they work temporarily due to poor yield.

This paper therefore, aims at applying geospatial techniques in analyzing groundwater potential zones in Omala Local Government Area of Kogi State, Nigeria in order to guide water supply planning decision and reduce borehole failures in the study area. The specific objectives include to: characterize the groundwater potential determinant factors in the study area; identify and map the groundwater potential zones in the study area; and estimate the spatial extent of the identified groundwater potential zones in the study area.

THE STUDY AREA

Omala Local Government Area lies between Latitudes 07°30'48″N - 08°02'10″N and Longitudes 07°21'27″E - 07°50'45″E of the Greenwich Meridian with an a real coverage of 1.667km² (Ishaka, 2012) as shown in Figure 1.

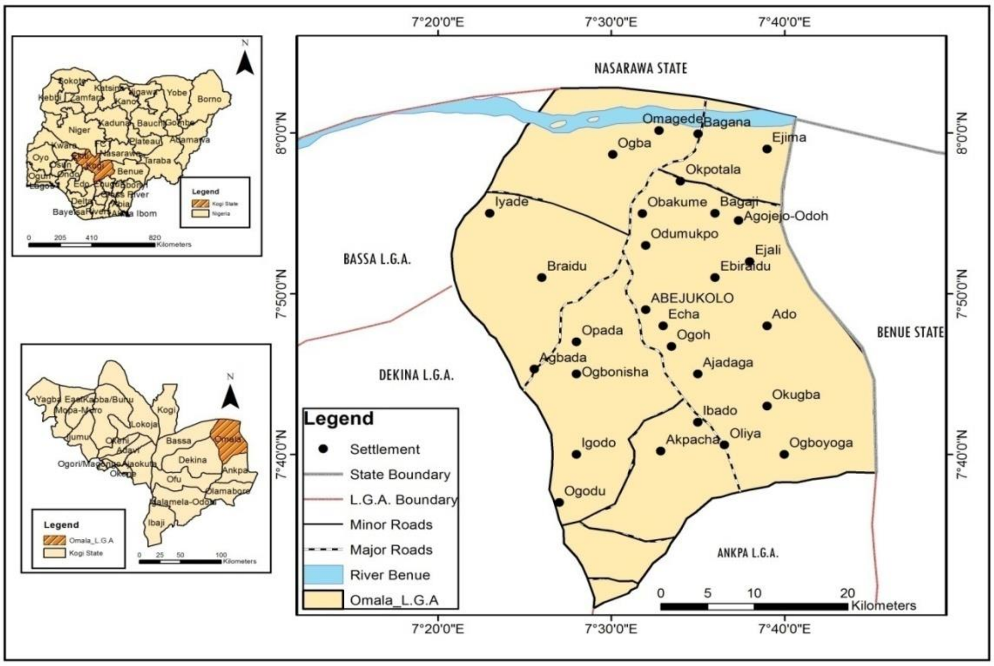

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Figure1: Omala L.G.A. (The Study Area)

Source: Modified from Administrative Map of Kogi State

MATERIALS AND METHODS

The data used, their sources as well as what they were used for are presented in Table 1.

Table 1: Materials used, Sources and their Uses

	Data	Source	Use
1.	Landsat 8 ETM +	www.glovis.usgs.gov	Land use Land Cover map, drainage density, and Lineament Map
2.	Rainfall Data	Nigeria Meteorological Agency	Rainfall Map
3.	Soil Data	Faculty of Agriculture, Kogi State University, Nigeria	Soil Map
4.	Geology	Geology Department, ABU Zaria	Geology Map
5.	SRTM	www.ftp/flcflandsat	Slope Map

Thematic maps were produced for all seven (7) factors considered for the determination of groundwater potential zones in the study area and inputted into ArcGIS environment for proper analysis by creating a geo-database for proper data management of all datasets involved in the study. The dataset included; lineament, land use/ land cover, drainage density, slope, geology, rainfall, and soil. All data layers derived were converted to raster data sets having the same pixel size. Each data set in a single map was given weight by pair wise comparison using Saaty's (2008) Analytical Hierarchy Process and each of the factors on groundwater occurrence was reclassified. The weighted index overlay analysis (WIOA) using a multi-criteria approach was used to investigate the potential zone for groundwater prospecting through integration of the thematic maps generated. In estimating the spatial extent of the groundwater potentials in the study area, the various groundwater classes were grouped after which the spatial extent were determined using SQL Queries in ArcGIS. The area coverage was displayed for each of the groundwater classes in square kilometers. The flowchart showing the methodology adopted for the study is represented in Figure 2.

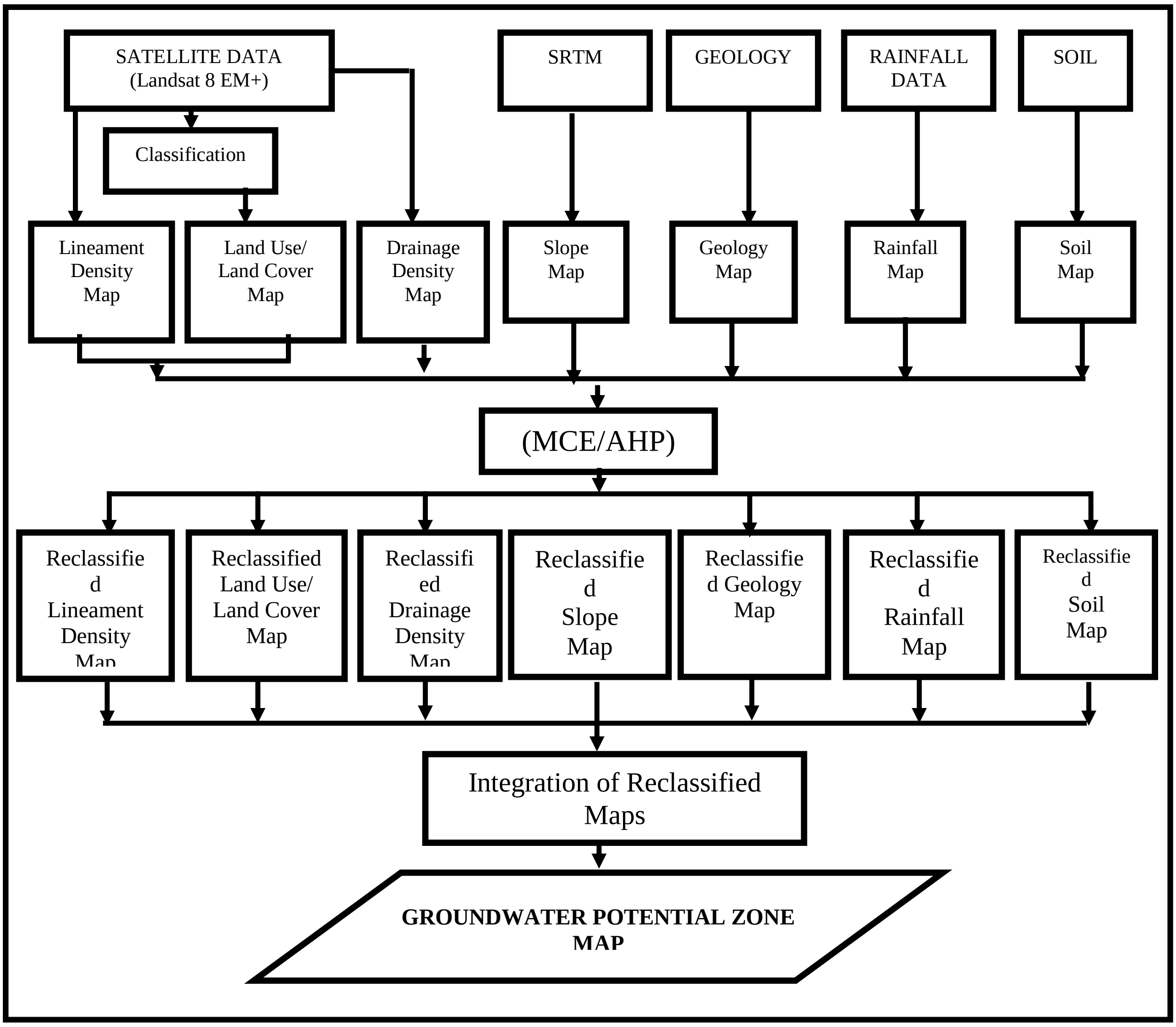

Figure 2: Flowchart of the Study Methodology

RESULTS AND DISCUSSION

Characterization of groundwater potential determinant factors in the study area

Characterization of the thematic maps was achieved through a pair wise comparison of the dataset to generate weights for determining the influence of the factors determining the occurrence of groundwater in the area. According to Saaty (2008), Consistency Ratio (CR) should be less than or equal to 0.1. Thus a value of 0-0.1 is accepted in practice. With CR of less than 0.1 for each dataset, the results were accepted. The maximum value is given to the feature with the highest groundwater potentiality and minimum being to the lowest potential feature. Based on these ranks their weight age are calculated and added to each layer (Table 2).

Table 2: Thematic Maps, Classification, Weights and Groundwater Potentiality

Thematic Map	Classification	Weight	Weight * 100	Consistency Ratio (CR)	Potentiality
	64.6-106.2	0.54	54		Very High
	45.1-64.5	0.22	22		High
Lineament Density (km/km^2)	28.8-45	0.11	11	0.01	Moderate
	10.9-28.7	0.08	8		Low
	0-10.8	0.05	5		Very Low
	Water Body	0.51	51		Very High
	Agric Land	0.26	26		High
Land use/land cover	Forest	0.13	13	0.05	Moderate
	Built-up	0.06	6		Low
	Bare Ground	0.03	3		Very Low
	0-12.6	0.49	49		Very High
	12.7-34.9	0.23	23		High
Drainage Density (km/km^2)	35-57.2	0.14	14	0.02	Moderate
	57.3-85.8	0.09	9		Low
	58.9-145.8	0.05	5		Very Low
	0-0.4	0.59	59		Very High
	0.5-1	0.19	19		High
Slope (Degrees)	1.1-4.8	0.11	11	0.03	Moderate
	4.9-10.8	0.7	7		Low
	10.9-16	0.5	5		Very Low
	Coal sandstone/ siltstone	0.56	56		Very High
	Quartzite/ Quartz schist	0.15	15		High
Geology	Sandstone, Iron stone	0.14	14	0.05	Moderate
	Feldspathic sandstone/ Siltstone	0.11	11		Low
	Amphibolite	0.05	5		Very Low
	1393-1446	0.48	48		Very High
	1361-1392	0.24	24		High
Rainfall (mm)	1329-1360	0.13	13	0.07	Moderate
	1293-1328	0.08	8		Low
	1242-1292	0.07	7		Very Low
Soil	Sandy Loam	0.64	64	0.1	Very High
	Sandy Clay	0.36	36		High

Lineament Density

The result shows that the lineament density varies from less than 10.8 km/km^2 which covers 7 % of the total area to 106.2km/km^2 which covers 54% of the study area. This implies that areas with high lineament density may have important groundwater prospects even in hilly regions which otherwise have nil groundwater prospects than areas with low lineament density (Ndatuwong & Yadav, 2014). Thus, the 5 classes of lineament density shown in Fig. 3were compared against each other. The pairwise comparison indicates that areas with very high lineament densities have a high importance with a weight of 54. Comparing the very high lineament density with the very low lineament density gave a ratio of 1/9 which means that very high lineament density has extreme importance or influence on groundwater potentials with a weight. The pairwise comparison done for lineament density thus revealed that for areas with high and moderate lineament densities, weights of 22 and 11 were calculated respectively while areas with low and very low drainage densities had low weights of 8 and 5 respectively. The CR generated stood at 0.01, thus the decision was accepted.

Land use/Land Cover

The land use/land cover classes include water body, forest land, agricultural land and built-up areas (Fig. 4). Pairwise comparison reveals water body compared to other factors is the most important over all other land uses with a weight of 0.51(51%). Further comparison shows that bare ground is less important than all other land uses.

Drainage Density

The pairwise comparison revealed that very high drainage density had a weight of 0.49 representing 49% of the drainage classes while very low drainage density had a weight of 0.5 representing 5%. This implies that areas with low drainage density have a very high groundwater potential while areas with very high drainage density have very low groundwater potential at a consistency ration of 0.02. This is in line with the findings of Bagyaraj, Ramkumar, Venkatramanan & Gurugnanam (2012) who found out that low drainage density areas permit more infiltration and recharge to the groundwater reservoir, hence can be described as a good potential zone for groundwater prospect.Figure5presents the reclassified drainage density map based on the weights

Slope

Based on the influence of slope with respect to infiltration and groundwater recharge, areas with less than 0.4° slope (i.e. nearly flat surfaces to very gentle slopes) which constitute about 59% of the study area were rated very high in terms of groundwater potentiality with weighted factor of 0.59 compared to areas with slope greater than 10° with weighted factor of 0.5 which covers 5% of the study area. The overall implication is that part of the study area dominated by low slope has very high groundwater potentials. Figure 6 presents the reclassified slope map based on the weights in Table 1.

Geology

The study area has been categorized into 5 based on the geological formation of the area. The classes include; Amphibolite, Quartzite and Quartz schist, Sandstone and Iron stone, coal sandstone and shale and feldspathic sandstone and siltstone. A pairwise comparison was carried out on each of the classes and weights were generated (Table 1).

From the pairwise comparison, coal sandstone/siltstone were weighted 0.56(55%) which accounts for very high groundwater potential with amphibolites weighing 0.05(5%) representing very low groundwater potential. This classification was based on rock porosity. The reclassified map is presented in Figure 7.

Rainfall

The rainfall distribution in the study area ranges from 1,242mm to 1,446 mm suggesting a humid tropical terrain with the entire study area receiving more than 1,000 mm of rainfall annually (Fashae*et al.*, 2014) (Figure 8)

Areas with the highest amount of rainfall have weightage factor of 0.48 signifying very high groundwater potential (48 %) while areas with the lowest amount of rainfall have weightage factor of 0.07 (7%), suggesting very low groundwater potentiality. A closer look at the rainfall thematic map revealed that the northern part have relatively lower rainfall (1,242-1,293 mm) which can be attributed to the influence of the receding rain-bearing South-West trade wind. Generally, the southern part received high rainfall (1,393-1446mm).

Soil

Fine-grained soils limit infiltration due to apparently low permeability unlike coarse-grained soil materials where water can infiltrate easily because of high permeability (Fashae *et al.*, 2014). In this study, two main soil units were identified based on Food and Agricultural Organization of the United Nations (FAO, 2014): sandy loam soils and sandy clay soils covering 64% and 36% of the total study area, respectively.

Given the relationship between the sand content/coarse-grained materials and permeability, higher weightage was given to soils with relatively higher permeability; thus sandy loam units were assigned a weightage factor of 0.64 indicating very high groundwater potential compared to that of sandy clay with a factor of 0.36 indicating lower groundwater potentials. The reclassified soil map is shown in Figure 9.

The Groundwater Potential Zones

The result of the pairwise comparison carried out with the seven (7) factors considered in this research is presented in Table 3and the groundwater potential zone map using the weightage index was generated (Figure 10).

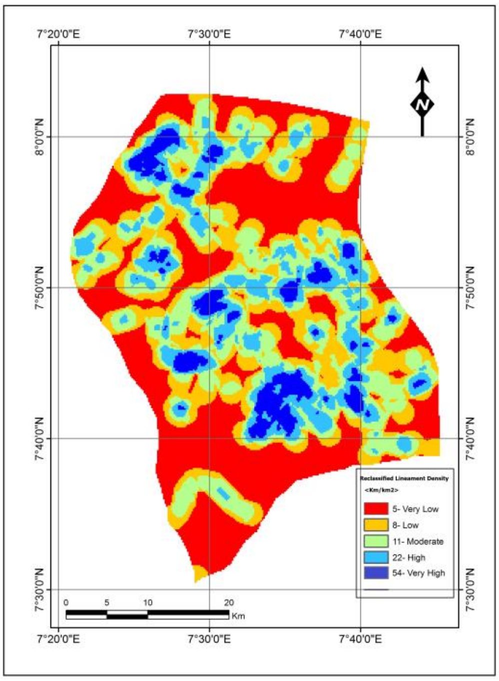

Fig 3: Reclassified Lineament Density Map

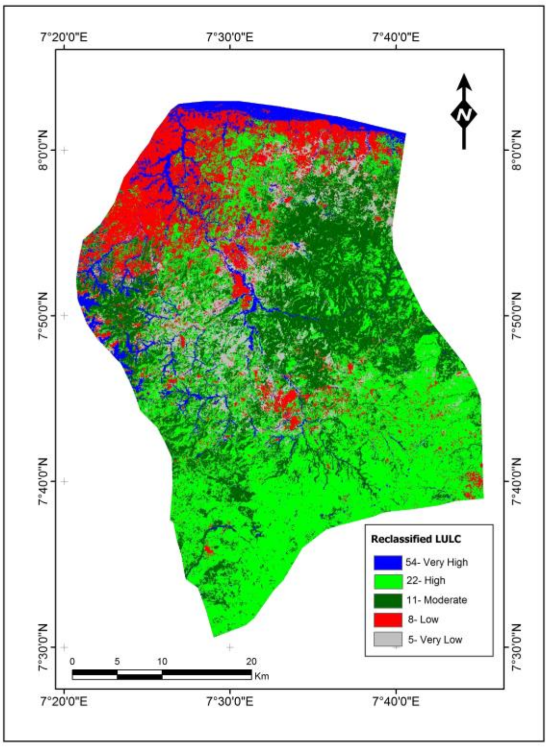

Fig 4: Reclassified Land use Land CoverMap

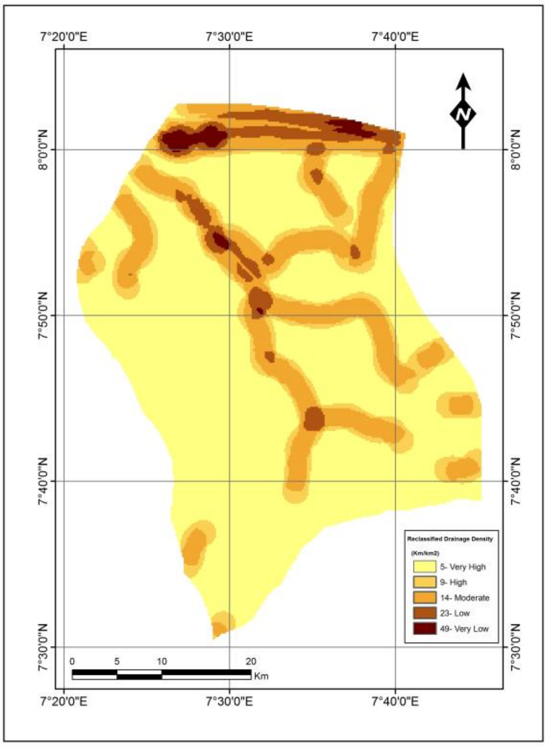

Fig 5: Reclassified Drainage Density Map

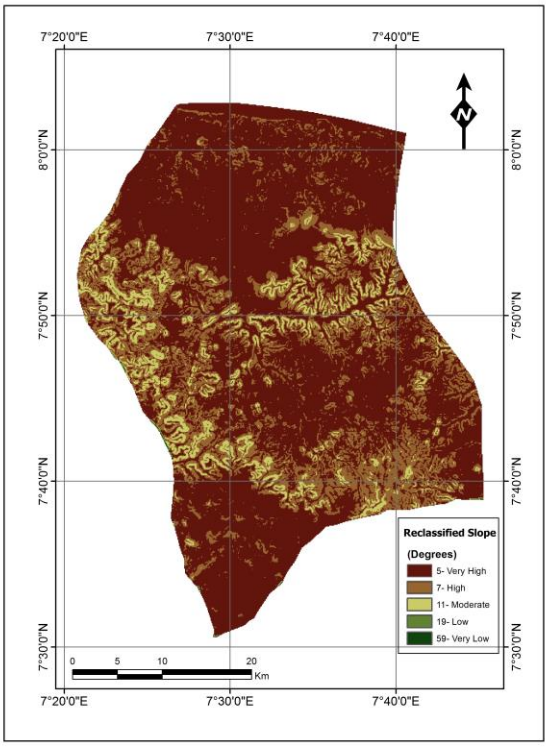

Fig 6: Reclassified Slope Map

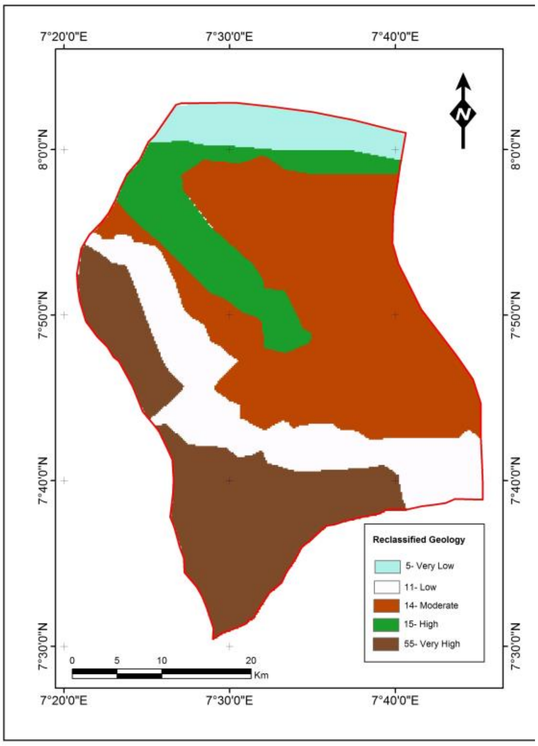

Fig 7: Reclassified Geology Map

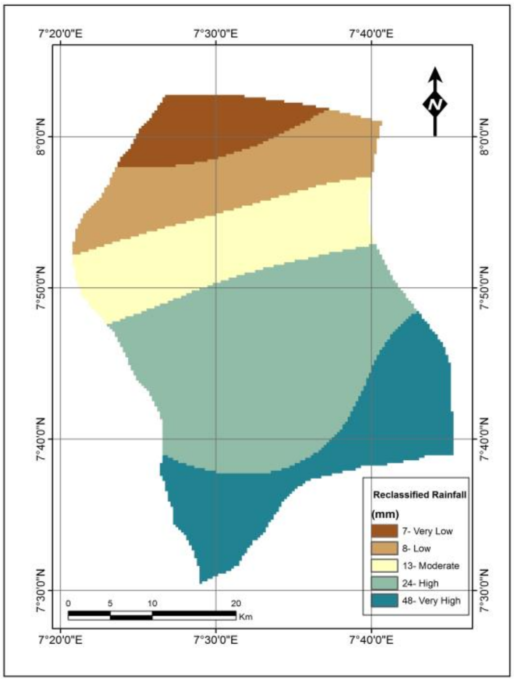

Fig 8: Reclassified Rainfall Map

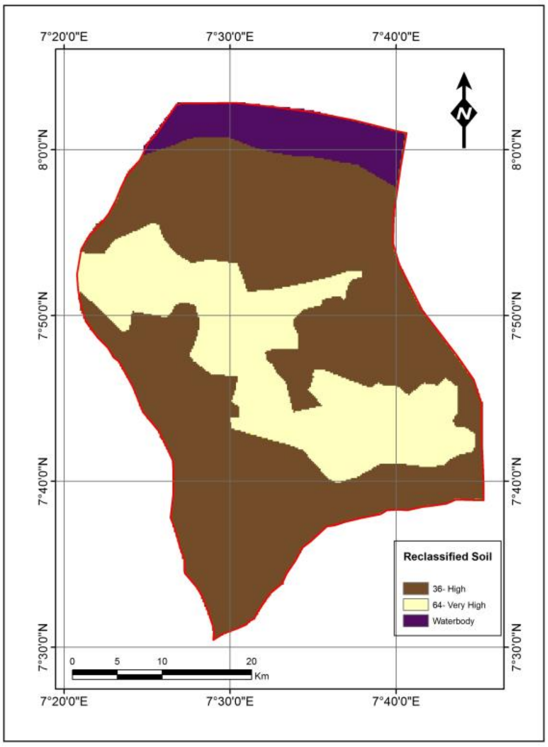

Fig 9: Reclassified Soil Map

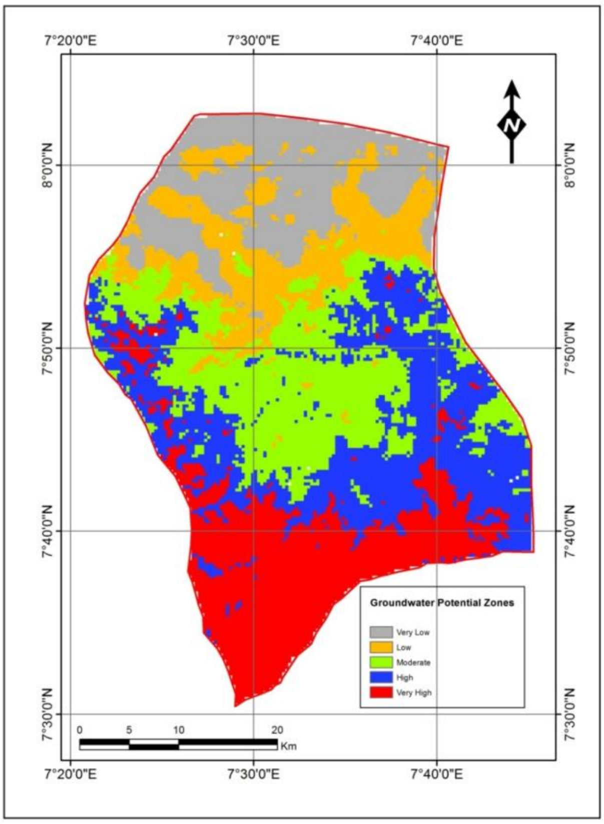

Fig 10: Groundwater Potential Zones of the Study Area

Table 3: Weight for all Factor Maps

	Rainfall	Lineament	Geology	Slope	Soil	Drainage	LULC	Weight	Weight *100
Rainfall	1	1	3	3	7	7	9	0.33	33
Lineament	1	1	2	3	5	6	7	0.28	28
Geology	1/3	½	1	2	2	3	4	0.14	14
Slope	1/3	1/3	1/2	1	2	3	4	0.11	11
Soil	1/7	1/5	1/2	1/2	1	3	4	0.07	7
Drainage	1/7	1/6	1/3	1/3	1/3	1	3	0.04	4
LULC	1/9	1/7	1/4	1/4	1/4	1/3	1	0.03	3
				Total					100

Consistency Ratio = 0.02

Source: Author's Analysis (2015)

Table 3 shows the contribution of each of the groundwater determinant factors in the study area. The results revealed that rainfall was the major factor influencing groundwater potentials in the area with a weight of 33%. This was followed by lineament with a weight of 28% of the entire factors while land use/land was the lowest factor with a weight of 3% influencing groundwater potentials in the area. This result is similar to the findings of the study carried out by Kartic & Jatisankar (2012) who stated that rain water is mainly responsible for the groundwater recharging for West Bengal, India. The groundwater potential map of the study area is shown in Figure 9.

From Figure 8, the very high groundwater potential zone which is predominantly in the southern part of the study area could be attributed to the high amount of rainfall as shown in the reclassified rainfall map (Fig. 8). The map shows an increase in the mean annual rainfall from the north to the southern part of the study area. Some settlements located within areas with very high groundwater potential include Igodo, Ogodu & Ogboyaga. The high groundwater potential zones are areas occupied by settlements such as Ibado, Ado & Okugba. Abejukolo which is the study area capital is found on the moderate groundwater potential zone as well as settlements like Ogoh & Opada. The low and very low groundwater potential zones cover settlements such as Obakume, Agojeju-Odoh, Okpotala & Iyade. Figure 2 shows a decrease in groundwater potential northwards which could be attributed to the decrease in rainfall from the south to the northern part of the study area.

Spatial Extent of the Groundwater Potential Zones

The calculate geometry tool in ArcGIS was used to calculate the area of coverage for each of the potential zones (very high, high, moderate, low and very low) in the attributes table after converting the potentials to shape files. The estimated area coverage of the groundwater potential zones is as presented in Table 4.

Table 4: Areal Coverage of Groundwater Potential Zones

Groundwater Potential Zones	Area in Sq.Km	Percentage %
Very High	342.76	20.8
High	470.96	28.5
Moderate	337.16	20.4
Low	250.54	15.2
Very Low	248.43	15.1
Total	**1649.85**	**100.0**

Source: Author's Analysis, 2015

Table 4 reveals that high groundwater potential zones account for the largest areal coverage as it covers 28.5% of the study area while very low groundwater potential zones account for the least with coverage of 15.1% of the study area. This implies that the high groundwater potential zones are much more in coverage than the low groundwater potential zones in the area.

CONCLUSION AND RECOMMENDATION

The study identified and mapped out groundwater potential zones in the area. The findings showed that areas that fall within the southern part of the study area had a very high groundwater potential. It therefore means that high lineament density, few low drainage density, low slope, and high rainfall highly favoured availability of groundwater in the area.

Thus, it was concluded from this study that although groundwater is available everywhere, the potentiality varies over space owing to the role played by the different factors influencing groundwater potentials as rainfall played a dominant role in this study. The study recommends that the Kogi State Government should provide alternative water sources in areas found to be located on the very low and low groundwater potential zones in order to ameliorate water scarcity in such areas.

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