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HYDROGEOPHYSICAL EVALUATION OF GROUNDWATER POTENTIAL OF MAKURDI AND ITS ENVIRONS USING VES AND GIS, NORTHCENTRAL NIGERIA

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ABSTRACT

The development of groundwater resources is crucial to the economic and social well-being of the rural population as well as the health implications that lack of access to potable water portend. In this study, traditional hydrogeological mapping and the geographic information system (GIS) technique were combined for a better prediction of the groundwater potential of the Southwestern part of Makurdi where the study area lies. Results from the geologic, hydrogeologic mapping and hydrogeophysical survey were integrated with the groundwater occurrence controlling factors derived from field work and remote sensing to delineate the groundwater potential zones. A total of 23 locations were studied and sampled which was used to generate the geologic map of the area, aquifer parameters and the geo-electric layers. These data were compared to the remotely sensed data to produce the hydrogeological map of the area. Using the Analytical Hierarchical Process (AHP), the groundwater potential of the area was categorized into four units; poor, fair, good and excellent. 37% of the area under study shows very poor to poor groundwater potential, 40% indicates fair potential and 23% displayed good to excellent potentials. From the vertical electrical sounding curve analysis, weathered (unconfined) and weathered/fractured (unconfined) aquifer types were identified in the area. Hence, the developed groundwater potential map in this study can be harnessed for optimal groundwater resource management of the Southwestern part of Makurdi.

Keywords: Analytical hierarchy process (AHP), Aquifer parameters, Geo-electric, Groundwater potential mapping, Hydrogeophysical

INTRODUCTION

One of the major problems faced by the populaces of developing countries is inadequate potable water supply. Despite the economic growth and industrial development recorded in the 19th and 20th centuries, many of these countries cannot provide adequate potable water for their inhabitants (Akinwumiju & Olorufemi, 2016). Groundwater exploitation remains one of the most efficient ways to guarantee a continuous supply of safe water (UNICEF, 2022). Groundwater is the largest freshwater resource on Earth, which makes it an important source for human consumption and the overall development of a region. Mapping groundwater potential zones is essential for planning the location of new abstraction wells to meet the increasing water demand. The occurrence, distribution and movement of groundwater mainly depend upon the geological and hydro-geomorphological features of the area (Saaty, 1991). A detailed study of groundwater occurrences can be made by surface and subsurface investigation methods. However, the occurrence, distribution and flow of groundwater are discontinuous and it is determined by the dynamic interactions of various environmental factors such as geo-tectonic structures, lithology, overburden thickness, weathering grade, geomorphology, fracture extent, drainage pattern, land use/land cover and climate (Surrette & Allen, 2007). Consequently, groundwater is not uniformly distributed in terms of quantity and quality. Depending on the hydrogeological and climatic conditions, either the magnitude of natural groundwater resources or the hydraulic parameters of rocks represent the limit of groundwater development (Krasny, 1997; Martin, 2012). Nevertheless, the influence of topography on borehole yield has been emphasized with a general result that wells located in valleys and flat areas show higher yield than wells located on slopes and hilltops (Neves& Morales, 2007).

The integrated use of remote sensing, GIS, Satellite data, and resistivity data is time and cost-effective means to assess and manage groundwater resources (Adiat, Nawawi, & Abdullah, 2012), (Verma, Thakur, Shashwat, & Singh, 2013). Several science communities have already reported the importance of different hydrological factors viz, geomorphology, geology, Land use/land cover, slope, soil cover, drainage density, surface temperature, among others controlling the groundwater potential of any area. However, the extent to which they affect it may differ from place and time (Sener, Davraz, & Ozcelik, 2005)(Sreedevi, Owai, Khan, & Ahmed, 2009), (Ayoade, 1983); It is important to consider these factors very precisely with inputs from different scientific experts and field observation. Therefore, a systematic approach to groundwater exploration using modern techniques is essential for the proper evaluation, exploitation and management of groundwater resources to ensure sustainable development of this seemingly valuable resource.

The Study Area

The area under investigation falls within the Middle Benue Through which lies between latitude 7°30′00″ to 7°45′00″N and longitude 8°30′00″ to 8°45′00″E covered by the topographic sheet 251SW on a scale of 1:50,000. The area is underlain by rocks of Cretaceous Makurdi and Eze-Aku sandstone Formations.

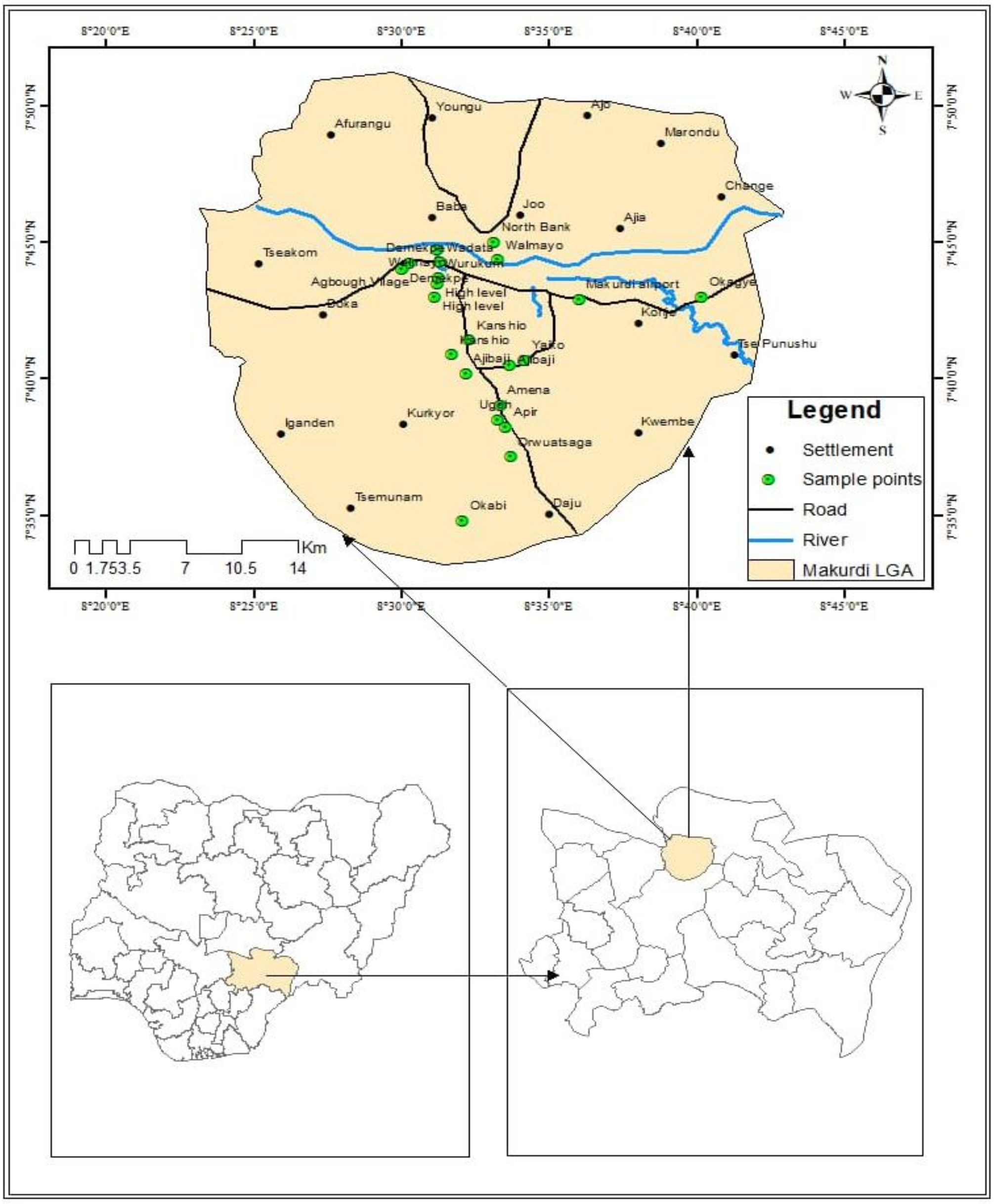

Figure 1: Location map of the study area. (updated from Federal Survey, Nigeria. 1967)

MATERIALS AND METHODS

The investigation follows the creation and application of a combined GIS-based approach to groundwater potential assessment in the area under study by using already existing geo-spatial datasets as inputs (Table 1). After this, actual field mapping and geophysical survey were carried out to produce the geologic map, determine the overburden and aquifer thickness and confirm the reliability of the approach and its limitation. The methodology consists of processing images digitally for the extraction of features such as rivers and lineaments (linear features), GIS processing: line density analysis, rasterization of vector layers and analyses for the extraction of input layers from remotely sensed data including; land use land cover map, drainage density map, topographical map, soil map and the evaluation of remotely sensed data (Landsat Imagery and DEMs). Others are field studies that include geophysical and geological investigations.

Table 1: Types and Sources of Data

Type of Data	Source	Purpose
SRTM-30	Global land cover facilities, university of Maryland website	For DEM creation, topography and slope
LANDSAT 8 (2019)	Global land cover facilities University of Maryland website	Production of land use/land cover and soil
Geological map 1:50,000	Fieldwork and mapping of the study area	Production of the geologic map of the area
Overburden thickness	Geophysical Survey	To determine the overburden thickness of the area.

Before the integration of the data sets, individual weights and map scores was assessed based on (Saaty, 1991), Analytical Hierarchy Process (AHP). In this method, the relative importance of each class within the same map was compared to each other and eight importance matrices were prepared for assigning weight to each class. The AHP was used to characterize the zones into; poor, fair, good, and excellent. These zones were characterized based on the aquifer properties, soil type, geology and topography. Table 2 shows the process involved in weight assignment using AHP and Table 3 shows the criteria used for the reclassification of slope, geology and lineament according to (Solomon, 2003).

Table 2: Procedure for Assigning Weightages in Analytical Hierarchy Process

Scale	Degree of Preference	Explanation
1	Equal importance	Two elements contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favour one element over another.
5	Strong or essential importance	Experience and judgement strongly favour one element over another.
7	Very strong importance	One element is favoured very strongly. Its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring 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, 1991)

The above criteria were used to create each thematic map of the groundwater control parameter. These thematic maps were integrated to generate the groundwater potential map of the study area as shown:

Groundwater potential zones = GL + EL + LD + DD + SL + LU + SO +OT + AT

Where: GL = geological map
EL = Elevation map
LD = lineament density map
DD = drainage density map
SL = slope map
LU = land use map
SO = soil map
OT = overburden thickness map
AT = aquifer thickness map

The weight of all the factors was overlaid and integrated to ascertain the area of influence of each of the factors, to determine the level of possible recharge on different parts of the study area delineating groundwater potentials of different parts of the study area.

Groundwater Potential Factor Establishment.

Before the integration of the data sets, individual class weights and map scores were assessed based on (Saaty, 1991), Analytic Hierarchy Process (AHP). In this method, the relative importance of each class within the same map was compared to each other pairwise and nine importance matrices were prepared for assigning weight to each class. 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.

The procedure for determining the relative rates of each factor is presented in the following tables: the extent of the influence of every factor on groundwater potential was assessed from the inter relationships (minor and major) among the factors. Analytical results demonstrated that the factors influencing the groundwater potential of the study area in descending order are: lineament, geology, drainage, overburden thickness, slope, soil and aquifer thickness.

Table 3: The different values assigned to Geological materials as parameters for groundwater control

Geology	Potential / value
Alluvium	(Very High) 80
Basalt	(Very High) 80
Foliated metasediments amorphic	(High) 70
Metasediment	(High) 70
Granite (syntectonic)	(Moderate) 60
Granite (post tectonic)	(Moderate) 60
Non-foliated metasediments amorphic rocks	(Moderate) 60
Laterite	(Low) 40
Kaolinized granite	(Very low) 10

Table 4: The different values assigned to the slope as a parameter for groundwater control

Slope	Potential value
0 – 3	(Very High) 80
4 – 7	(High) 70
8 – 11	(Moderate) 60
12 – 15	(Low) 40
>15	(Very Low) 10

Source: (Solomon, 2003)

Table 5: Values Assigned for Soil as a Groundwater Control Parameter

Soil	Weightage	Rank
Sandy Loam, Sandy Clay Loam	1	High
Gravel Sandy Clay	1	
Sandy Clay Loam, Gravelly Clay Loam Kankar Bed	2	Medium
Sandy Clay Loam	2	
Clay Loam	3	Low
Clay	3	

Source: Pandian and Kumanan (2013)

Table 6: Values Assigned to lineament as a Groundwater Control Parameter

Lineament	Potential / Value
0 – 50m	(Very High) 80
50 – 100	(High) 70
100 – 150	(Moderate) 60
150 – 200	(Low) 40
200 – 250	(Very Low) 10

Source: Solomon (2003)

Table 7: Values Assigned for different Groundwater Control Parameters.

Land cover	Weightage	Rank
Cropland	1	High
Water bodies	1	
Plantation	1	
waterlogged	1	
Land with shrubs	1	
Built up	2	Medium
Barren rocky	3	Low
Fallow land	3	

Source: (Pandian, 2013)

Table 8 Values Assigned for different Groundwater Control Parameters.

Drainage density	Weightage	Rank
0 – 0.9	1	Low
1.9 -2.9	2	Moderate
2.9 – 3.9	3	High
>3.9	4	Very High
Elevation		
1760 – 2134	5	Very High
2134 – 2509	4	High
2509 – 2883	3	Moderate
2883 – 3257	2	Low
3257 – 3631	1	Poor

Source: (Tewodros, 2005)

Identification and mapping of groundwater Potential Zones from the Thematic Maps:
Integration of the thematic maps was carried out in ArcGIS 10.8 using the weighted overlay in spatial analysis tools by using a formula (Mogaji, Aboyei and Omosuyi, 2011).
Groundwater potential zones = GL + EL + LD + DD + SL + LU + SO + OT + AT
Where: GL = geological map, EL = elevation map, LD = lineament density map, DD = drainage density map, SL = slope map, LU = land use map, SO = soil map, OT = overburden thickness map, AT = Aquifer thickness map
The weight of all the factors was overlaid and integrated to know which of the factors, influence the recharge of groundwater to delineate groundwater potential zones.
Estimation of the spatial extent of the identified groundwater potential zones:
Each layer (very poor, poor, fair, good and excellent zones) from the groundwater potential zones raster map was converted individually to geo-database file format using the conversion toolbox in ArcGIS 10.8. This process of conversion to geo-database file format automatically calculates the area of each of the groundwater potential zones. Hence, the sampled points in the hydrogeological field mapping in the study area were overlaid on the groundwater potential map to see their spatial spread and on which zone of groundwater potential they fall in the study area. The groundwater potential zones in the study area were estimated in ArcGIS by converting the potential zones to shape files and using it to calculate the geometric tool on the attribute table to calculate each of the potential zones.

RESULTS AND DISCUSSION

Lineaments are indicators of subsurface faults and fractures influencing the occurrence of groundwater acting as canals and reservoirs. Lineament density of an area can ultimately expose the groundwater potential since the presence of lineaments usually signifies a permeable zone. Lineaments map was extracted from the satellite image using automated extraction techniques. The lineament extracted was imported into the ArcGIS environment and the spatial analyst tool was used to generate the lineament density map of Makurdi Town as shown in Figure 2.

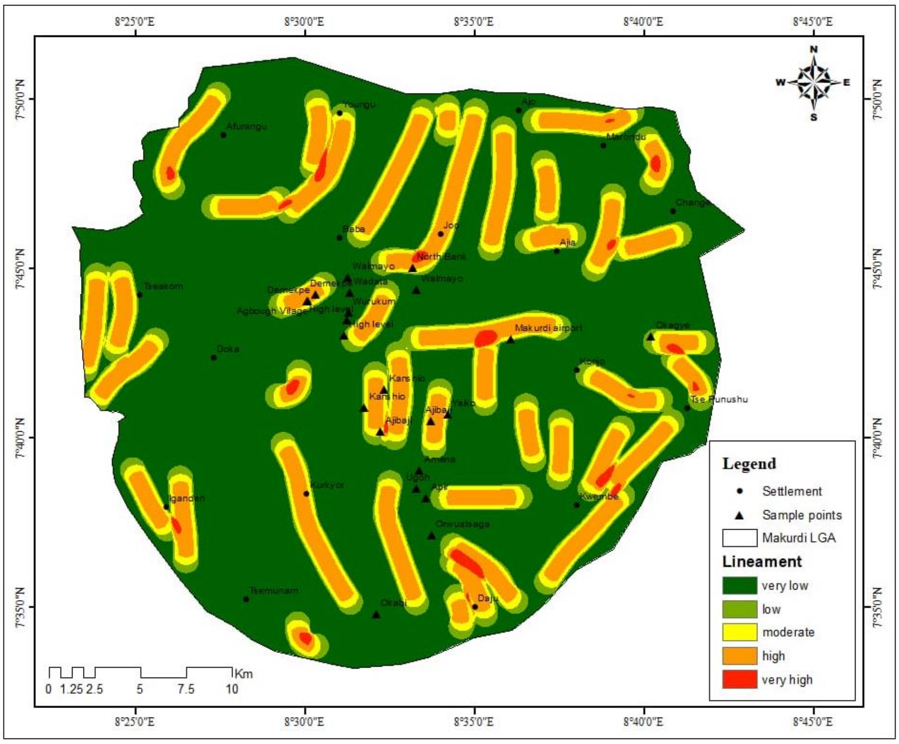

Figure 2: Weighted Lineament Map

Geology

It is well established that geology is one of the major factors which plays a vital role in the distribution and occurrence of groundwater. A geological map of the study area was created from data collected from field mapping of the study area.

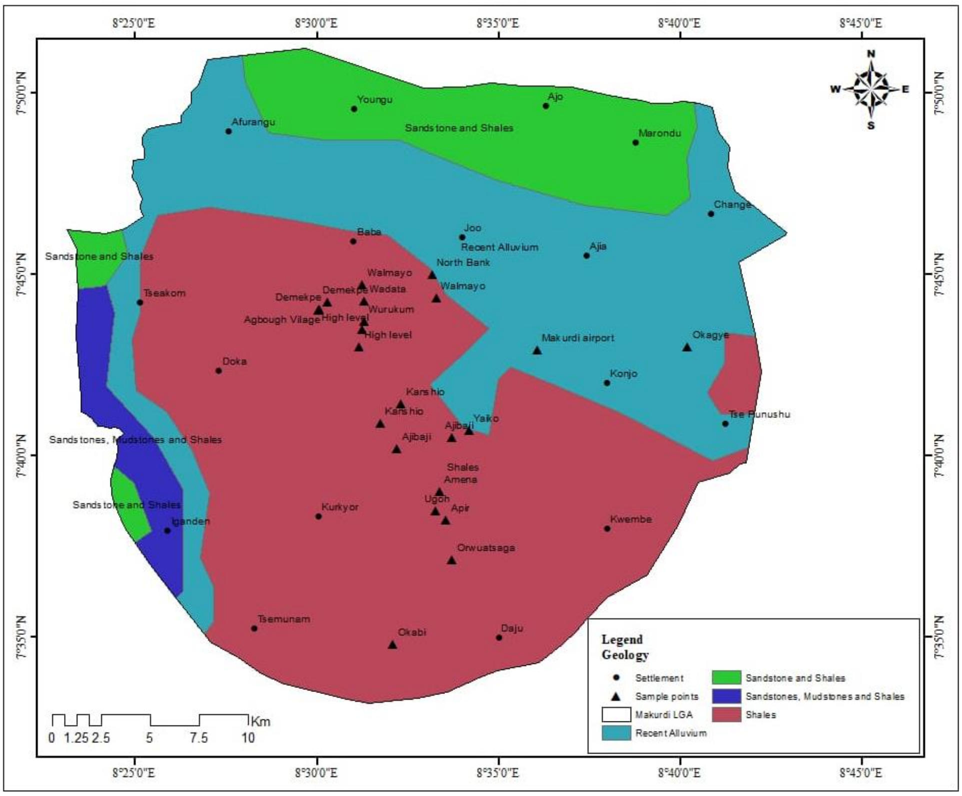

Figure 3: Weighted Geologic map

Drainage Density
The density of drainage plays a major role in groundwater potential zones. The water runoff will be high if the density of drainage is high. Hence, the infiltration of water into the ground would be less, whereas in low drainage density, surface water runoff will be less so the infiltration of surface water into the ground will be high. The drainage pattern of the study area was derived from SRTM data through on-screen digitization as shown in Fig 4. The drainage density was calculated directly in ArcMap using spatial analyst extension.

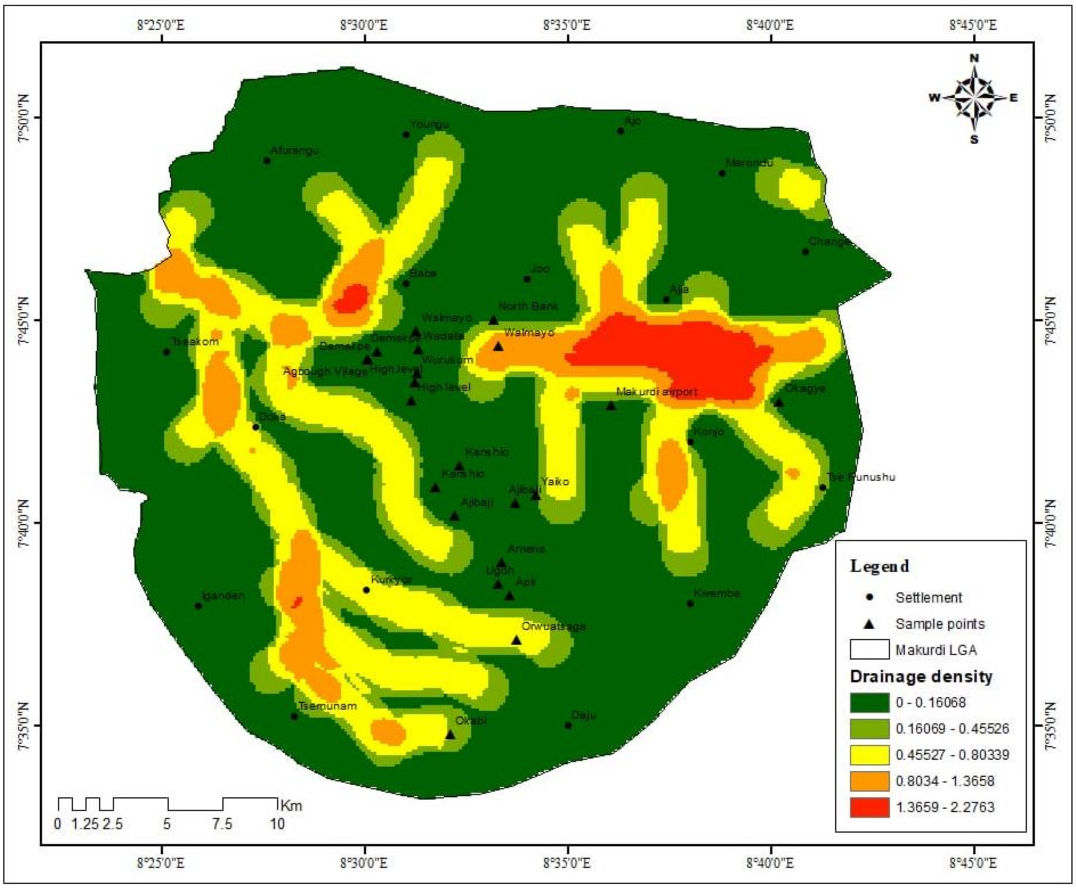

Figure 4: Weighted Drainage Map

Overburden Thickness
The overburden thickness of the study area ranges from 0.5 m – 27.5 m. Parts of the study area characterized by thick overburden are characterized by low groundwater potential. However, the groundwater potential of weathered layers depends on the physiochemical properties of the parent rocks.

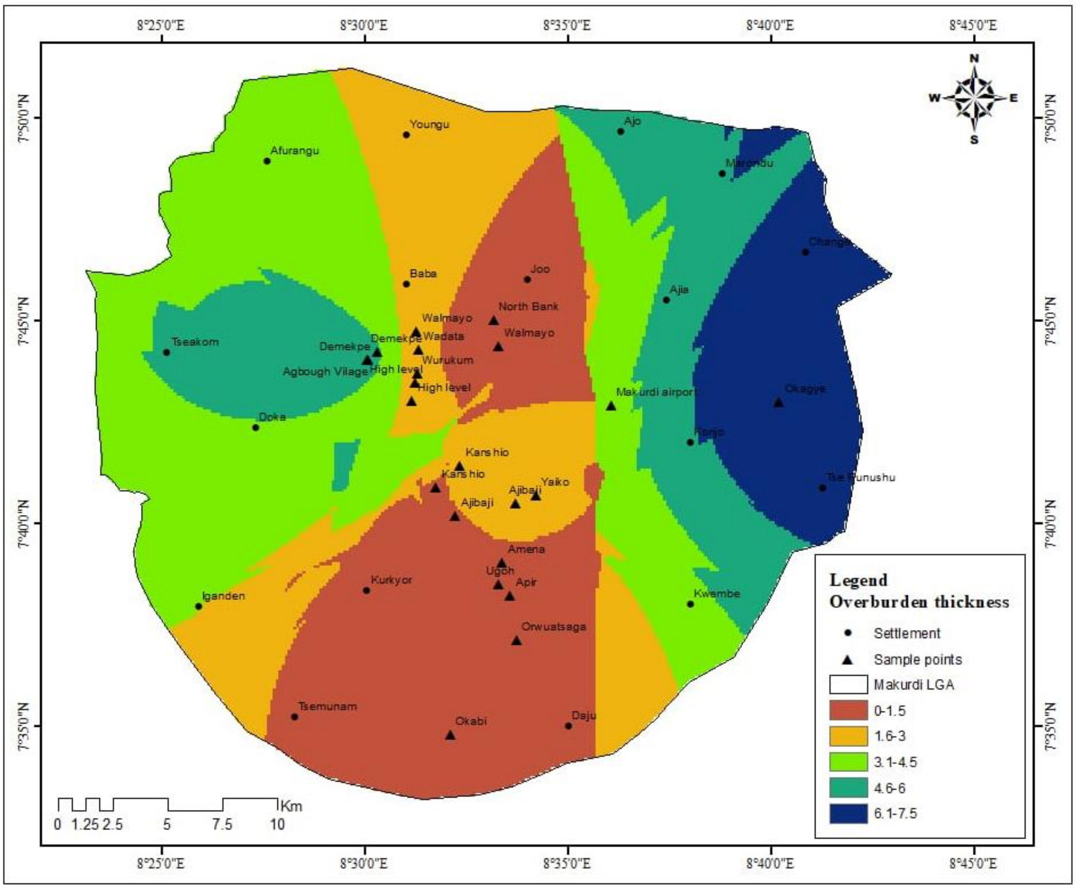

Figure 5: Weighted Overburden Map

Slope/Elevation

With groundwater, flat areas where the slope angle is low are capable of holding rainwater which in turn facilitates recharge whereas in elevated areas where the slope angle is high, there will be high run-off and low infiltration (Magesh, 2011). Figure 6.

Soil

Soil texture type is one of the significant parameters for agricultural production and also influences the recharge of groundwater. It controls the penetration of surface water into an aquifer system. The weights have been assigned based on their corresponding infiltration rates (Kumar, 2016). Figure 7

Aquifer Thickness

The internally weighted aquifer thickness map is presented in Fig 8. Two types of aquifers were delineated within the study and these include the fractured aquifer and weathered layer.

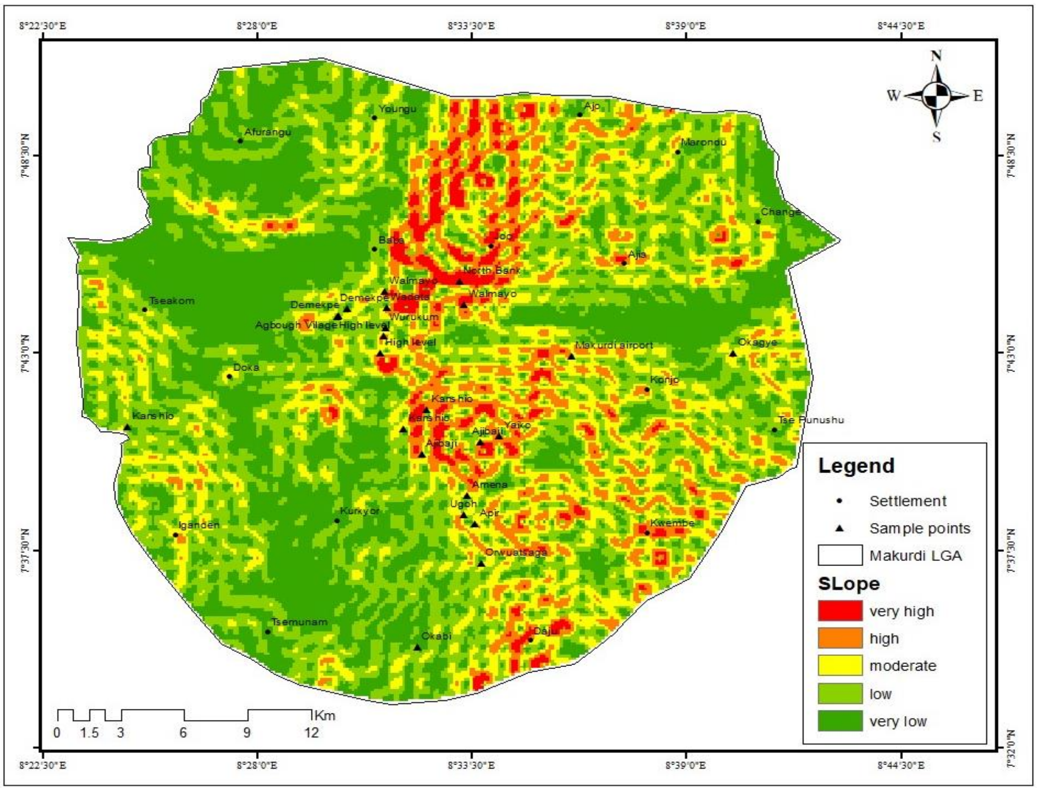

Figure 6: Weighted Slope Map

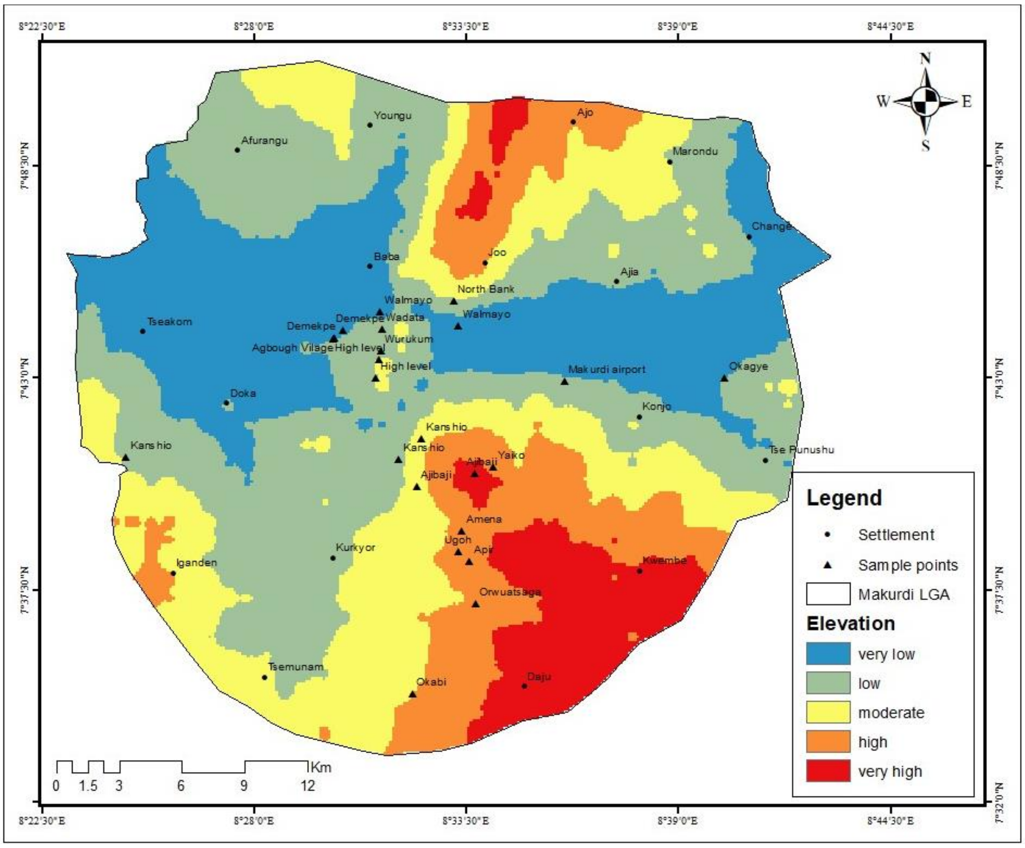

Figure 7. Weighted Elevation map

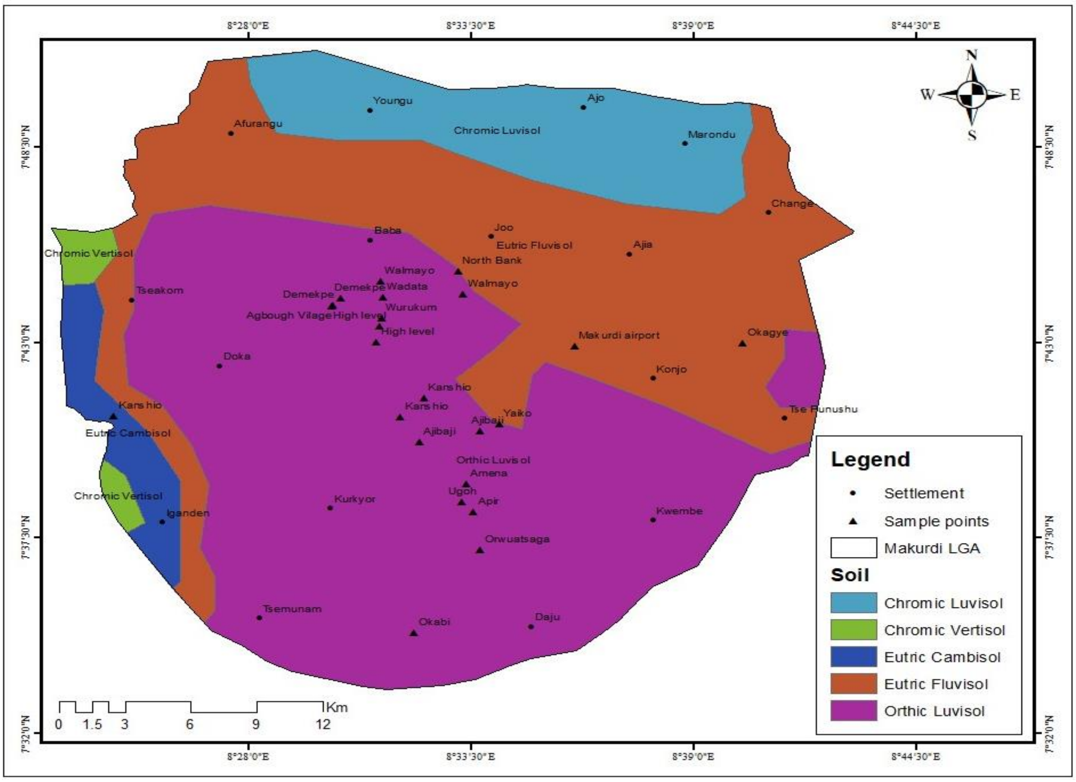

Figure 8. Weighted Soil Map

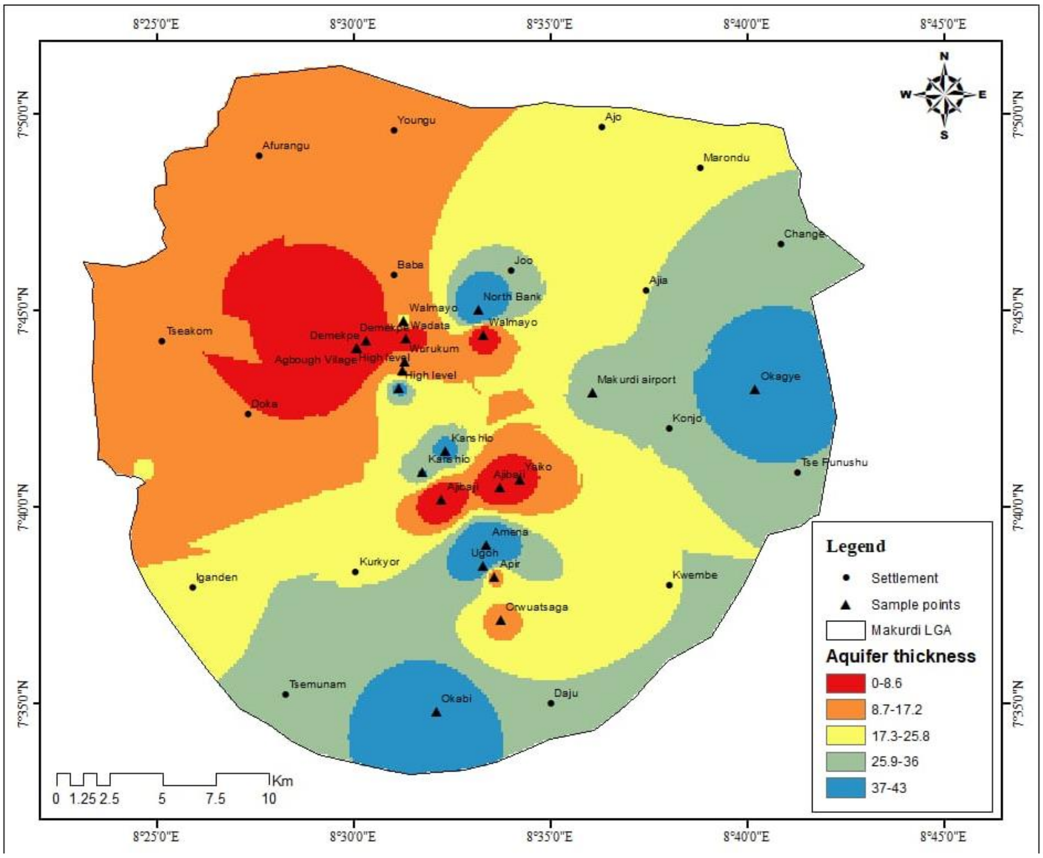

Figure 9. Aquifer Thickness Map

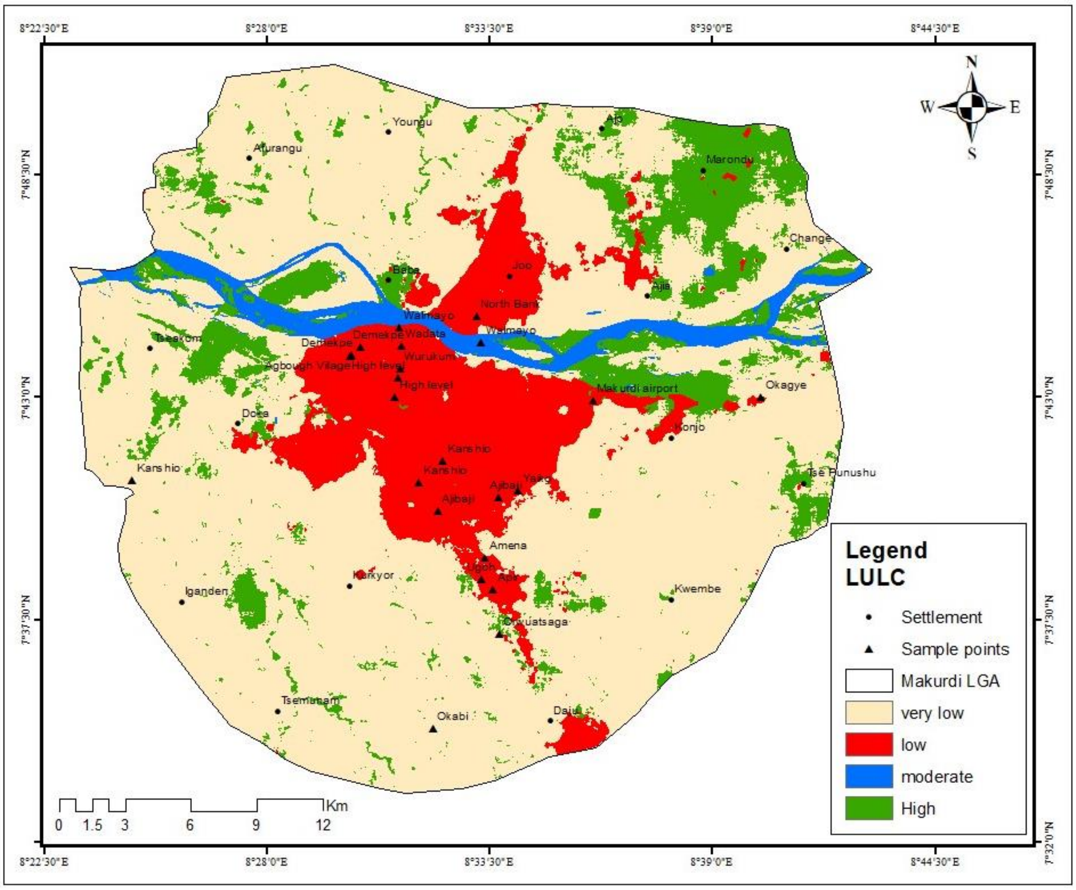

Figure 10. Land Use Land Cover Map.

Groundwater Potential Zones of Makurdi Town

In an attempt to determine the groundwater potential zones in Makurdi Town, all the thematic maps of the various factors influencing groundwater recharge in the study were weighed and integrated. 37% of the area under study shows poor groundwater potential, 40% indicates fair potential, 14% displayed good and 9% indicated excellent potential.

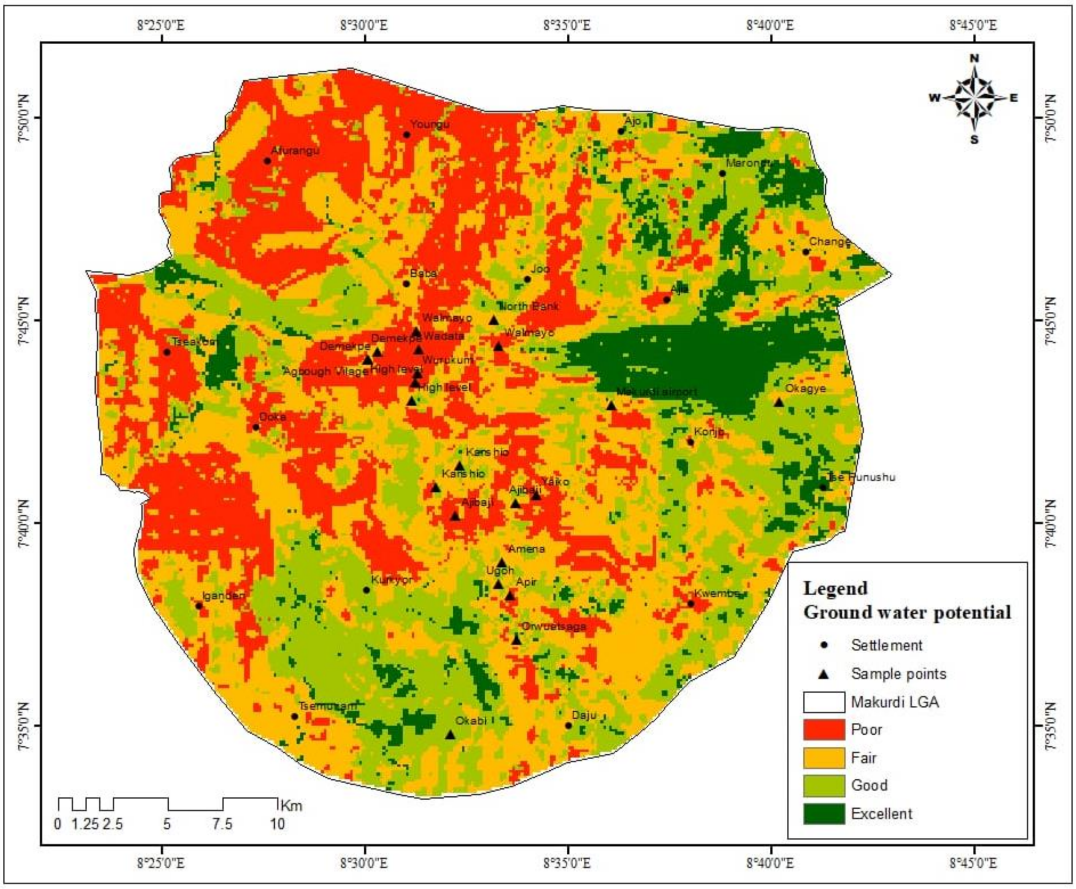

Figure 11: Groundwater Potential Map of Makurdi (Sheet 251 SW) Town

CONCLUSION

This study implemented GIS procedures to integrate a set of groundwater control factors (lineament, drainage density, geology, soil, slope, overburden thickness and aquifer thickness) to investigating the groundwater potential across the Southwestern part of Makurdi Town, Northcentral Nigeria. The study showed that lineament which is a surface expression of the faults and fractures; has a dominant influence on the potential for groundwater in the study area. The spatial pattern of groundwater also reflects the influence of geology on the groundwater potential of the study area. All factors analyzed have varying influences on groundwater potential of the study area. The study identified and delineated four (4) groundwater potential zones comprising: poor, fair, good and excellent potentials. The study concludes that the groundwater potential is generally fair in southwestern Makurdi town. However good groundwater potentials are evident in the Eastern part of the study area and a significant part of the Southern area of the map. Therefore, the groundwater prospect for the study area is suitable for small to medium-scale development.

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