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# Groundwater Potential Zones Mapping Using Remote Sensing and Geographic Information System Techniques (GIS) in Zaria, Kaduna State, Nigeria

Sani Badamasi[a*], B.A. Sawa[b], M.L. Garba[c]

[a]*Department of Surveying and Geoinformatics, Nuhu Bamalli Polytechnic, Zaria-810222, Nigeria*
[b,c]*Department of Geography, Ahmadu Bello University, Zaria-810222, Nigeria*
[a]*Email: badamasisani1@gmail.com*
[b]*Email: senatorsawa@gmail.com*
[c]*Email: mlgarba@abu.edu.ng*

**Abstract**

This study has attempted to map groundwater potentials in Zaria, Kaduna State, Nigeria using the techniques of remote sensing and Geographic Information System. Groundwater is a very important source for water supply, considering its availability, quality, cost and time effective to develop, and simple accessibility. It is virtually everywhere and yet variable in quantity. In some areas within the study area it was observed that there are frequent occurrences of well/borehole dry-up. Therefore, it is important to assess the variation of groundwater in the area in order to enhance its exploration as well as conserving and managing the resource. Landsat ETM+ and GDEM by ASTER, conventional data as well as meteorological data were used to characterize the underground resource by direct observation of the surface and sub-surface hydrologic controlling factors. Based on these factors eight thematic maps of drainage density, geology, geomorphology, land cover, lineament, rainfall, slope, and soil were developed. The influence of each theme and sub units/classes to groundwater recharge based on previous studies was evaluated using the analytical hierarchical process (AHP). The groundwater potential map was produced by the weighted index overlay model in GIS. The groundwater prospects were mapped in five categories: very good, good, moderate, low and very low zone. The very good zones cover 2.99km$^2$ (0.55%) of the total size of the study area. While the good, moderate, low, and very low zone covers 59.72km$^2$ (11.00%), 263.85km$^2$ (48.60%), 197.89km$^2$ (36.45%), and 18.46km$^2$ (3.40%) respectively. Very good and good groundwater promising zones occur in the alluvium deposits along river channels and vegetated areas.

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* Corresponding author.

The very low zones occur in the low lineament density, high drainage density, high slopes, luvisol, built up, and rock outcrops. The results of the study have contributed to the existing body of knowledge by adding information on the location of favorable zones of groundwater and well/borehole failures. Hence, the study will facilitate the reduction of time, cost, and labor in the quest for groundwater in the area.

***Keywords:*** GIS; Groundwater Mapping; Remote Sensing; Sustainable Development; Water Supply.

## 1. Introduction

The quest for groundwater can be enhanced by mapping the sub surface water potential sites using remote sensing and GIS techniques. The technique is inexpensive, rapid, accurate, and wide area coverage as well as reducing time and cost of field surveys [18, 20]. Water is needed by man for agricultural, domestic, and industrial purposes [9]. Human survival on earth as well as sustainable development and security depends on water [6].

Most parts of Northern Nigeria fall under the arid and semi-arid environment thereby making groundwater a necessary alternative for water supply[19]. The geology of the area is made up of the crystalline basement rocks in which the aquifers exist in deeply weathered and fractured systems and hence supply of water is in discontinuous fashion and variable in space [7]. It is therefore important to assess the variation of the availability of groundwater by mapping the resource in order to sustainably exploit and manage it-which is in tune with the sustainable development goals (goal number six).

The challenges faced by groundwater development in many parts of Nigeria include the non-uniform, discontinuity, and complexities of the aquifer systems in the crystalline basement rocks which result in well/borehole dry ups [7]. Other obstacles encountered include lack of data, equipment, methods, and manpower which would have aided the identification of the promising high yield well/borehole sites [3, 7, 11]. Groundwater exploration in Nigeria is rudimentary and improvement in the technology is slow paced, hence there is need for cost effective, accurate, and technologically appropriate solutions to groundwater exploration in the country [19].

Remote sensing and Geographic Information System (GIS) techniques identify the groundwater potential zones which improve success in selecting the favorable sites for boreholes and wells, which is efficient and effective [15, 20]. The technique incorporates the information that influences groundwater accumulation to model the groundwater potentials. Data of rainfall, geology, geomorphology, lineament, slope, drainage, land cover and soil can be integrated by weighted index overlay method to produce the groundwater potential model [8]. The influence of any factor on groundwater occurrence is to determine weights by analytical hierarchical process (AHP) [14].

## 2. Materials and Methods

### *2.1 Study aim and objectives*

The aim of this study is to map out the groundwater potential zones in Zaria area with the aid of remote sensing and GIS techniques. The specific objectives are to:

- develop thematic maps of factors influencing groundwater potentials in the area
- weighting each of the thematic maps using the analytical hierarchical process (AHP)
- map the groundwater potential zones of the area by weighted index overlay in GIS

**2.2 *Study Area***

The study area, Zaria, is located between latitude 10$^{o}$ 58′ N to 11$^{o}$ 15′ N and longitude 7$^{o}$ 33′ E to 7$^{o}$ 46′ E on the high plains of Northern Nigeria, 652.6 meters above sea level and 950 kilometers from the coast. The study area covers 542.9 square kilometers. Zaria has two distinct seasons the wet and dry, mean minimum and maximum temperatures can reach 13$^{o}$ and 42$^{o}$ in January and April respectively. Mean annual rainfall is about 1000 mm [17]. The area lies on the crystalline basement complex rocks of Northern Nigeria, and is composed of granites, gneisses, and schists belonging to the Precambrian age. This geological formation is primarily highly impervious except where deeply weathered or fractured. Therefore, groundwater occurrence and movement is based on secondary porosity provided by the weathered residual overburden and bedrock fractures, joints, faults and dykes [1, 5]. The area's drainage is made up of Galma, the only perennial river; other rivers forming its tributaries include Saye, Kubanni, Basawa, and Shika (Fig 1).

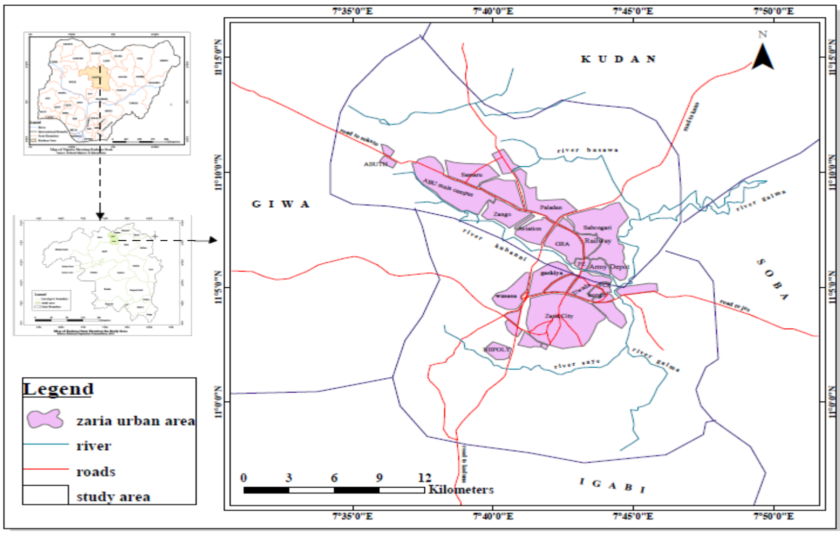



**Figure 1:** Study Area

Source: Adapted from Google Earth Pro and Modified by Authors

***2.3 Data and software used***

Data used include remotely sensed data like Landsat 7 (ETM+) image of Zaria of year 2014 and ASTER Global Digital Elevation Model (GDEM); conventional maps (geomorphology, geologic, soil map of the study area); and the rainfall data. Softwares used include ArcGIS 9.3, Erdas Imagine 9.2, Google Earth Pro, and Surfer 10

(Table 1).

### *2.4 Data processing*

#### *2.4.1 Procedure for Developing Thematic Maps*

To develop thematic maps of groundwater potential of the study area, the Lineament and land cover maps were derived from the Landsat 7 ETM+ image using PCI Geomatica and Erdas Imagine softwares respectively. Maximum likelihood classification (MLC) was employed for producing the current land use land cover map of the study area. The slope and drainage maps were derived in the slope tool of the spatial analyst tool and the archydro module of ArcGIS respectively. For derivation of the thematic maps from the secondary data, all the collected hard copy maps (geology, geomorphology, and soil) were scanned and imported into the ArcGIS software then georeferenced to World Geodetic System (WGS 84) coordinate system.

**Table 1:** Data Types and Sources

| Data types | Sources | Resolution/Scale |
|---|---|---|
| **Landsat ETM+ (2014) Image** | Glovis (http://glovis.usgs.gov) (2014) | 30m |
| **GDEM (ASTER)** | Glovis (http://glovis.usgs.gov) (2014) | 90m |
| **Rainfall** | Nimet (2014), IAR Samaru Zaria, (2014); FCE Zaria, (2014) | - |
| **Soil Map of Nigeria** | Center for World Food Studies (SOW-UV) (1997) | 1:1,300,000 |
| **Geological Map** | Geological Map of Kaduna State, Nigeria (2008) | 1:100,000 |
| **Geomorphology Map** | (M.B. Thorp) Dept. of Geography, ABU, Zaria (1970) | 1:100,000 |

#### *1.4.2 Procedure for Weighting the Thematic Maps*

Weighting of the thematic maps was carried out using the AHP. The AHP calculates weights based on the consideration for each theme’s influence on groundwater accumulation by the technique of pair wise comparison to compare influence of one criterion with another on a scale of 1 to 9. Thus, 1-denotes equal importance between a pair of criteria, 3-moderately more important, 5-strongly more important, 7-very strongly more important, and 9-extremely more important of one criterion to the other. While 2, 4, 6, and 8 were used as intermediate values [14]. The scale for comparison was determined based on previous studies [8, 10, 16].

#### *1.4.3 Procedure for Groundwater Potential Mapping (Modeling)*

The mapping of the groundwater potentials of the study area was done by weighted index overlay method in the ArcGIS 9.3. Before the overlay operations the next step after weighting the maps was to carryout reclassification. This was done by assigning the new weight values to the maps' sub-units (sub criteria) computed from the AHP. The reclass tool in the spatial analyst tool of the ArcGIS 9.3 was used for this task. The groundwater potential zones map of the study area was produced by overlaying all thematic layers using the weighted index overlay.

Groundwater Potential Zone Map (GWPZ) = $\sum_{i,j=1}^{8} WiXj$

Where Wi = % weight for each thematic map

And Xj = reclassified map

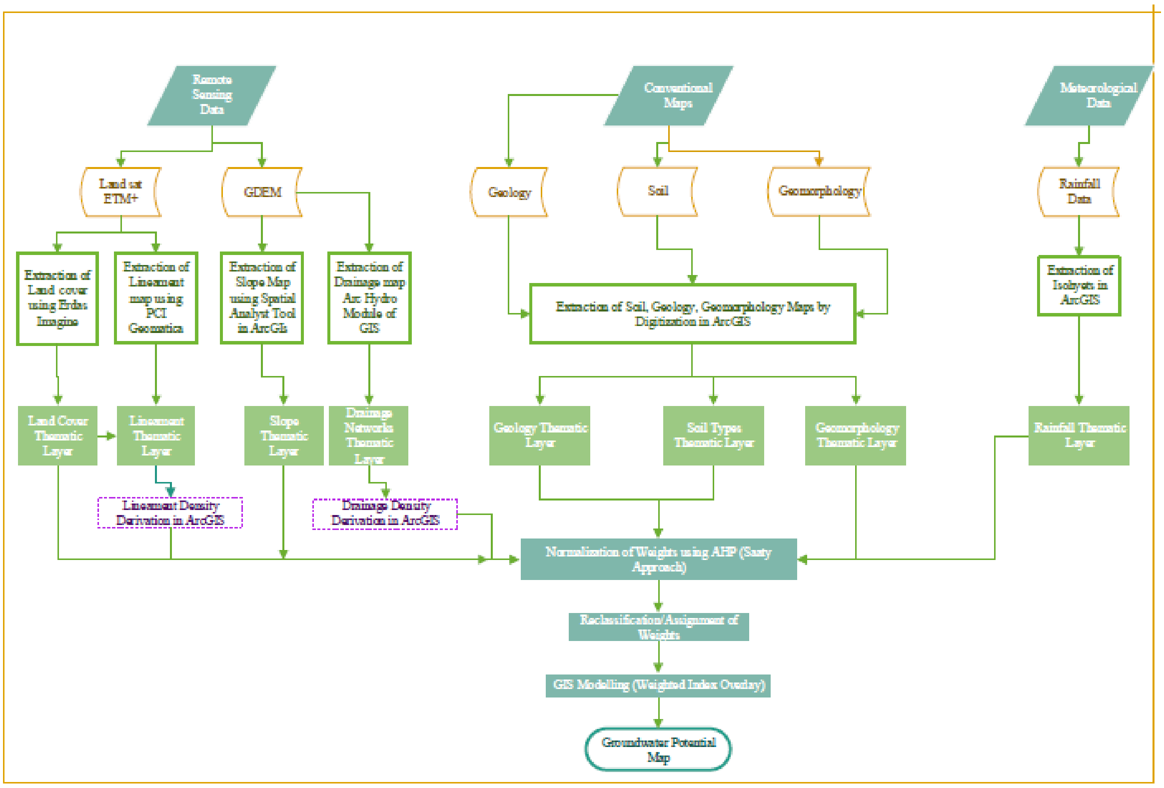
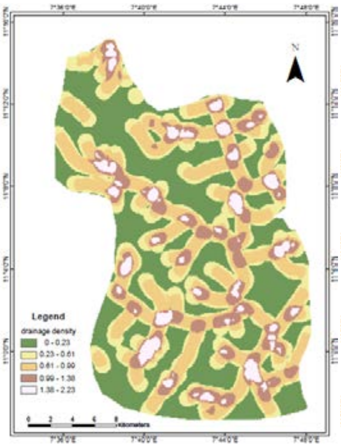


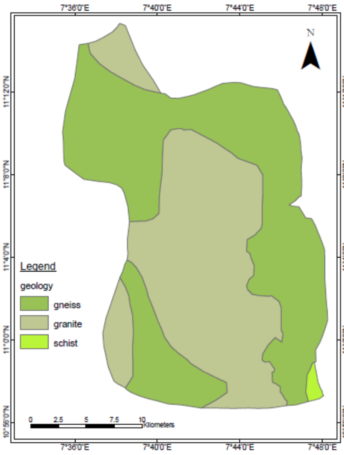

**Figure 2:** Flowchart of Methodology

## 3. Results and Discussions

### *3.1 Results*

Results are shown in figures and tables. Figures 3, 4, 5, 6, 7, 8, 9, and 10 are used to show the developed thematic maps, while Figure 11 is the resultant map: model of the groundwater potential zones in Zaria. Table 2 is used to show the calculated weights, the areal coverage and percentage cover for the themes as well as for all sub-units/classes within each theme. The areal extent and percentage for each zone of the groundwater potentials in the study area was calculated in the ArcGIS and presented using a Table 3. Sub-units/classes contributing to the five (5) groundwater potential zones are presented in Table 4.





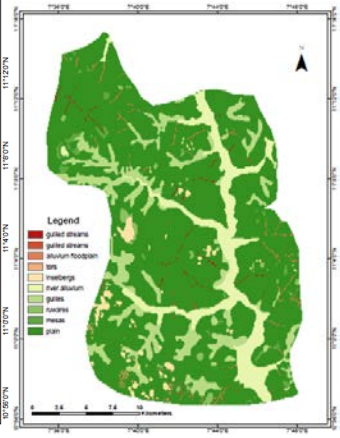



**Figure 3:** Drainage density map

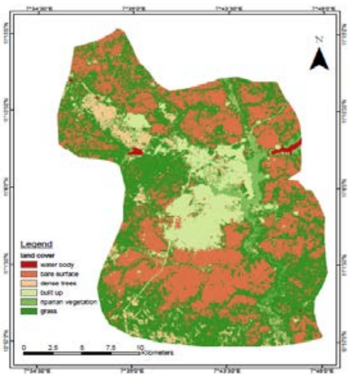
Source: GIS Analysis, 2015

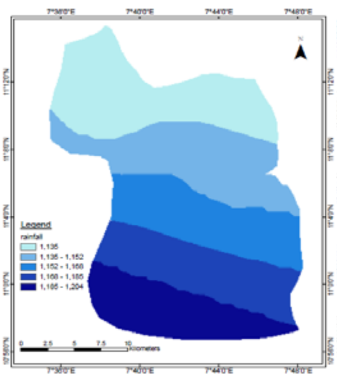
**Figure 4:** Geology map

Source: GIS Analysis, 2015

**Figure 5:** Geomorphology map

Source: GIS Analysis, 2015





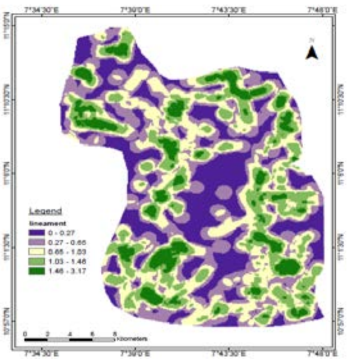


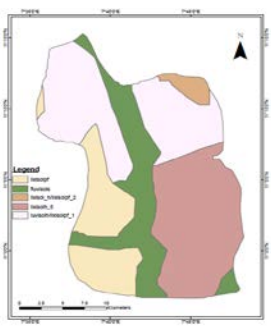
**Figure 6:** Land cover map Analysis, 2015

**Figure7:** Lineament density map

Source: GIS Analysis, 2015

**Figure 8:** Rainfall map GIS

Source: GIS Analysis, 2015



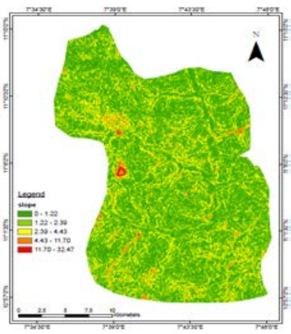


**Figure 9:** Slope Map

Source: GIS Analysis, 2015

**Figure 10:** Soil map

Source: GIS Analysis, 2015

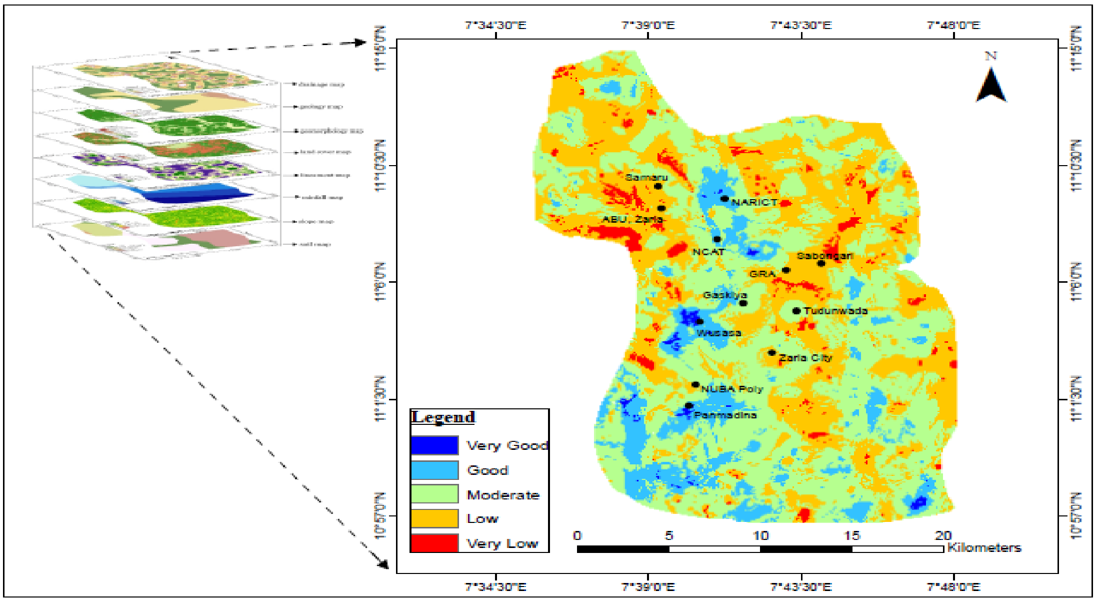



**Figure 11:** Groundwater Potential Zones Map of Zaria

Source: GIS analysis, 2015

**Table 2:** Weights for thematic layers and classes' areas and percentages cover

| Factors | Classes | Ranks | weights | Area ($Km^2$) | Area (%) |
|---|---|---|---|---|---|
| **Geology** | Granite | 50 | 23 | 292.68 | 53.91 |
| | Gneiss | 30 | | 247.07 | 45.51 |
| | Schist | 16 | | 3.15 | 0.58 |
| **Lineament density** | 0.00-0.27 | 3 | 23 | 122.42 | 22.55 |
| | 0.27-0.65 | 8 | | 137.65 | 25.35 |
| | 0.65-1.03 | 14 | | 133.82 | 24.65 |
| | 1.03-1.46 | 21 | | 101.79 | 18.75 |
| | 1.46-3.17 | 54 | | 47.23 | 8.7 |
| **Geomorphology** | River alluvium | 30 | 13 | 54 | 10.02 |
| | Floodplain | 23 | | 3.8 | 00.70 |
| | Plain | 15 | | 399.03 | 73.50 |

| | | | | | |
|---|---|---|---|---|---|
| | Gulled streams | 9 | | 2.17 | 0.40 |
| | Gullies | 9 | | 63.52 | 11.70 |
| | Tors | 5 | | 0.81 | 0.15 |
| | Mesas | 5 | | 5.21 | 0.96 |
| | Ruwares | 2 | | 4.56 | 0.84 |
| | Inselbergs | 2 | | 9.39 | 1.73 |
| **Drainage density** | 0.00-0.23 | 50 | 13 | 256.78 | 47.3 |
| | 0.23-0.61 | 27 | | 168.84 | 31.1 |
| | 0.61-0.99 | 14 | | 81.43 | 15.0 |
| | 0.99-1.38 | 7 | | 33.12 | 6.1 |
| | 1.38-2.23 | 2 | | 2.72 | 0.50 |
| **Slope** | 0-2 | 43 | 8 | 214.98 | 39.6 |
| | 2-4 | 28 | | 224.21 | 41.3 |
| | 4-8 | 20 | | 94.46 | 17.4 |
| | 8-21 | 6 | | 8.14 | 1.5 |
| | 21-63 | 3 | | 1.08 | 0.2 |
| **Rainfall** | 1214-1192 | 42 | 8 | 86.32 | 15.9 |
| | 1193-1175 | 26 | | 98.26 | 18.1 |
| | 1176-1159 | 16 | | 100.97 | 18.6 |
| | 1160-1143 | 10 | | 119.98 | 22.1 |
| | 1144-1125 | 6 | | 137.35 | 25.3 |
| **Soil** | Fluvisol | 42 | 8 | 102.61 | 18.9<br>29.6 |

| | | | | | |
|---|---|---|---|---|---|
| | Lixisol-h5 | 27 | | 160.7 | 2.43 |
| | Lixisolh/lixsolpf-2 | 16 | | 13.03 | 17.43 |
| | Lixisolpf | 10 | | 94.79 | 31.64 |
| | Luvisol-pf/lixisol-i | 5 | | 172.05 | |
| **Land cover** | Riparian Vegetation | 39 | 4 | 57.00 | 10.5 |
| | Dense Trees | 26 | | 2.71 | 0.5 |
| | Grassland | 16 | | 242.13 | 44.6 |
| | Water Body | 8 | | 188.92 | 34.8 |
| | Bare land | 8 | | 30.95 | 5.7 |
| | Built up | 3 | | 21.17 | 3.9 |

Source: Laboratory Analysis, 2015

**Table 3:** Groundwater Potential Zones with Area and Percentage Coverage

| Groundwater Zones | Areal Extent ($Km^2$) | Percentage Extent (%) | Settlement overlying the zone |
|---|---|---|---|
| **Very Good** | 2.99 | 0.55 | Wusasa |
| **Good** | 59.72 | 11.00 | Aviation, Paladan, Layin Zomo, Hanwa, Panmadina and NARICT |
| **Moderate** | 263.85 | 48.60 | Nigerian Railway Corporation (NRC), ABU Teaching Hospital Shika, ABU Kongo Campus, Gyellesu, FCE, Nuhu Bamalli Polytechnic, parts of Zaria City, Gaskiya Layout and Tukur Tukur, Tudunwada |
| **Low** | 197.89 | 36.45 | Samaru, ABU main campus, Sabongari, parts of Zaria City |
| **Very Low** | 18.46 | 3.40 | ABU main campus |

Source: laboratory analysis, 2015

**Table 4:** Sub-themes/Classes Contributing to the Five (5) Groundwater Potential Zones

| **Zones** | **Sub themes/Classes** |
|---|---|
| **Very Good** | River alluvium, Alluvium floodplains, Fluvisol, Lower slopes, High lineament density, Riparian vegetation, lower drainage density |
| **Good** | Dense trees, grassland, plains, lixisols, high lineament density, low drainage density, low slopes, older granite |
| **Moderate** | Gentle slopes, medium drainage density, plains, lixisol, gneiss, water bodies, gullied streams |
| **Low** | Steep slopes, high drainage density, schist, gullies, bare surface, low lineament density |
| **Very Low** | built up areas, luvisols, low lineament density, higher slopes, high drainage density, mesas, inselbergs, tors |

Source: GIS analysis, 2015

### *3.2 Discussion of Results*

The results from the weighted overlay showed that the moderate zone occupied largest portion of the study area by 48.60% equivalent to 263.85 $km^2$, and then followed by low, good, very low, and very good zones with 36.45%, 11.00%, 3.40%, and 0.55% equivalent to 197.89 $km^2$, 59.72 $km^2$, 18.46 $km^2$, and 2.99 $km^2$ respectively (Table 3). The classes contributing to these zones are listed in Table 4.

The overlay analysis showed that some parts of Zaria are overlying not only one zone but crisscrossing over two to more zones. For instance, Zaria City (the ancient city within the defensive walls) overlies both the low and very low groundwater. The parts overlying the low and very low zones include Kofan Kuyanbana, Ang-iya, Limanci Kona, Kusfa, Kofan Gayan, parts of Kaura, and Ang- Juma. However some parts of Zaria City fall under the moderate groundwater zones. This includes areas such as Kwarbai, parts of Amaru, Lemu, Ang-Alkali, Rimin Tsiwa, Bambale. The Tudunwada sub-settlement mostly lies over the moderate zones, while Nuhu Bamalli Polytechnic Main Campus, Low Cost, and Gambo Sawaba General Hospital lies over the low GWPZ.

Aviation, Paladan, Layin Zomo, Hanwa, Panmadina lie over good zone as well as NARICT. Wusasa overlies the very good zone. Groundwater of Nigerian Railway Corporation (NRC) lies under the moderate zone while some parts of Sabon Gari lie over the moderate, some low and some very low potential. The main campus of ABU, Zaria lies mostly over the low and very low zones. Samaru town lies over the moderate and low zones. Most of ABU Teaching Hospital Shika, ABU Kongo Campus, Gyellesu and FCE overlie the moderate zones. NUBA Poly annex and Magume are over the moderate and low zones. Gaskiya Layout and Tukur Tukur lies over the moderate zone.

The findings of this research have shown agreement or correlation with the field data in most locations within the study area. For instance, [4] carried out geophysical survey (VES) at NCAT and found out that aquiferous zone thickness varies between 17.13 to 36.1 meters with fractures that enhance groundwater permeability and storage. It is imperative to point that the thickness of the aquiferous zone (weathered and fractured basement) influences to great extent its groundwater potential [24]. The depth from surface to the aquiferous zone is shallow ranging from depth of 2 to 6 meters, while the depth from the earth's surface to the bedrock varies between 2.5 to 37.75m. While [2] did a groundwater potential of ABU Kongo Campus using geophysical survey, and found out that the weathered basement thickness average is around 15 meters and depth to bedrock averaged between 12 to 29 meters. When [13] worked at NUBA Poly main campus and found that the weathered basement thickness average range from 5 to 11 meters and the fractured basement thickness average from 3 to 6 meters, while the overburden thickness ranges from 1 to 14 meters and depth to bedrock averaged between 12 to 29 meters. The authors [23] carried out geoelectric investigation of the groundwater potential in the Institute for Agricultural Research Farm, Samaru, Zaria, showed that the thickness of the weathered basement around the area varies from 3.4 to 30.4m and depth to fresh basement was 40m. Similarly, [15], carried out a comprehensive geophysical survey over the premises of Federal College of Education, Zaria, showed that the thickness of the top soil of the area ranges between 3.5 and 14m while the thickness of the weathered basement ranges between 9 and 36.5m. The depth to bedrock varies from 5 to 14m.

In the same vein [21]associated the reason why Muchia, Kwangila, Tudun Jukun and Zango areas have good water supply because of local relief and sufficient groundwater in wells.While according to [22] the worst hit areas by water scarcity includeZaria City, Kofan Gayan, Low Cost and Samaru, while areas mildly affected included Sabongari and Tudunwada. These studies have correlated with the findings of the present research.

## 4. Conclusion and Recommendation

In conclusion the findings of this study indicated that the five groundwater potential zones mapped include the very good, good, moderate, low, and very low with areal coverage of 0.55% (2.99 $km^2$), 3.40% (18.46 $km^2$), 11.00% (59.72 $km^2$), 36.45% (197.89 $km^2$), and 48.60% (263.85 $km^2$) respectively (Table 3). Findings of this research were validated using some existing studies on groundwater in Zaria based on geophysical survey. The studies include [13] found out that the aquiferous zone thickness in Nuhu Bamalli Polytchnic Zaria as 5m to 11m averagely. [2,4,15] studied at ABU Kongo Campus near Tudunwada, Nagerian College of Aviation Technology Zaria, and Institue of Agricultural Research Samaru Zaria respectively and found out the aquifer thickness as 15m, 17.13m- 36.1m, and 3.6m-30m respectively. This correlates with the findings of this present study.

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

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