

Geospatial Analysis of Groundwater Potential Zones in Keffi, Nassarawa State, Nigeria

ABSTRACT

Aim: Employ the use of Remote Sensing and Geographic Information System (GIS) to analyze areas of groundwater potentials in Keffi LGA to meet the rate of water demand.

Study design: The study is designed to delineate and analyze the drainage characteristics, and map out the groundwater potential zones.

Place and Duration of Study: The study is conducted in Keffi LGA of Nassarawa State, Nigeria in 2018.

Methodology: Both spatial and non-spatial data were utilized for this research, including the Ground Control Points, satellite imageries, and maps. The data generated consisting of the rainfall, NDVI, lineament, geology, slope, and relief were prepared into thematic layers and used for the drainage morphometric parameters and multi-criteria overlay analysis. Each of the layer used has inputs were ranked based on their relative importance in controlling groundwater potential, and divided into classes using the hydro-geological properties. The groundwater potential analysis reveals four distinct zones representing high, moderate, less, and least groundwater potential zones. The delineated groundwater potential map was verified using the available GPS location of boreholes across the study area.

Results: The drainage of the study area falls in the 4th order, with the drainage density ranging from 0.2 to 1.6. From the groundwater potential map generated using the rainfall, lineament, geology, drainage density, slope, soil, and NDVI attributes, areas categorized having the moderate groundwater potentials cover about 89.1km² while the least covers 0.1km² of the study area. Validating the result with borehole locations across the location shows that the boreholes are dug based on the availability of water in accordance with the groundwater potentials; and 59.8% of the settlement area falls within the moderate groundwater potential classes.

Conclusion: The area has adequate capacity for water supply, and only those within the high groundwater potential classes can access groundwater throughout the year.

Keywords: Groundwater, Geospatial, Keffi, MCE, Potential

1. INTRODUCTION

Water resources, one of the most important natural resource asides air, are unevenly distributed across the globe. Water covers about three-quarter of the earth's surface with more than 95% of its total coverage being oceans. A large portion of the remaining is frozen in the glaciers and found beneath the earth surface as underground water. Only a small fraction of about 0.015% are surface water in rivers, streams, ponds, canals, springs, and lakes. This small fraction serves as the major source of water accessible for human use, but the continuous population growth has led to an increase in water usage and consequently resulting in a shortage. Climate change and spatiotemporal demands, urbanization and

24 agricultural activities are increasing the competition for water, hence causing civil unrest,
25 mass migration, and conflicts between countries (UN_WWDR, 2003, 2018). The foregoing
26 conditions has increased the drive to create channels to further explore groundwater
27 (Madan *et al.*, 2010).

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29 Groundwater resource comprises of about 95% of the earth`s freshwater. It occur below the
30 water table, occupying the pore spaces between grains in bodies of sediments and clastic
31 sedimentary rock, cracks, and crevices of rock (Diary and Lanja, 2016). It is a major source
32 of water feeding springs and streams, supporting wetlands, stabilizing the land surface
33 (Subbarao *et al.*, 1996). These attributes make it one of the purest and most reliable sources
34 of water available to man because it is relatively available through seasons, even with
35 climatic changes. This has thus increased groundwater researches, not only with regards to
36 its availability, but also its adequacy for human use (Fashae *et al.*, 2014).

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38 In line with the importance of groundwater, a number of researches have been conducted to
39 explore groundwater. For instance, Mukherjee (1996) reported that studies in hard rock
40 terrain is complex considering the nature of occurrence, storage, and the distribution
41 according to geological factors. The authors further opined that the most prolific water in
42 rocky terrains are aquifers (a geologic formation significantly saturated, porous and
43 permeable materials which hold significant amount of groundwater recharge wells and
44 springs) (Todd *et al.*, 2005). According to Ariyo and Adeyemi (2009), the occurrence of
45 groundwater in Basement Complex terrains is localized and confined to weathered/fractured
46 zones. Factors such as topography, geological structures, fracture density, lithology,
47 aperture and connectivity, secondary porosity, groundwater table distribution and recharge,
48 slope, drainage pattern, landforms, landuse/landcover, climatic conditions, and the
49 interrelationships among these factors (Greenbaum, 1992; Roy, 1996) govern the
50 occurrence and movement of groundwater, especially in the fractured bedrock aquifers in a
51 given area.

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53 Over the years, different methods of exploring groundwater have been developed. These
54 methods include but not limited to test drilling and stratigraphy analysis, the use of
55 geophysical methods of electrical resistivity. However, the integrated approach based on
56 advanced application of geospatial technology offers an efficient and effective result-oriented
57 method for identifying and managing of water resources. The concept of geospatial
58 technology, integrates remote sensing and GIS in a novel manner, and it has proven to an
59 efficient tool in groundwater studies (Gustafsson, 1993; Saraf *et al.*, 1994).

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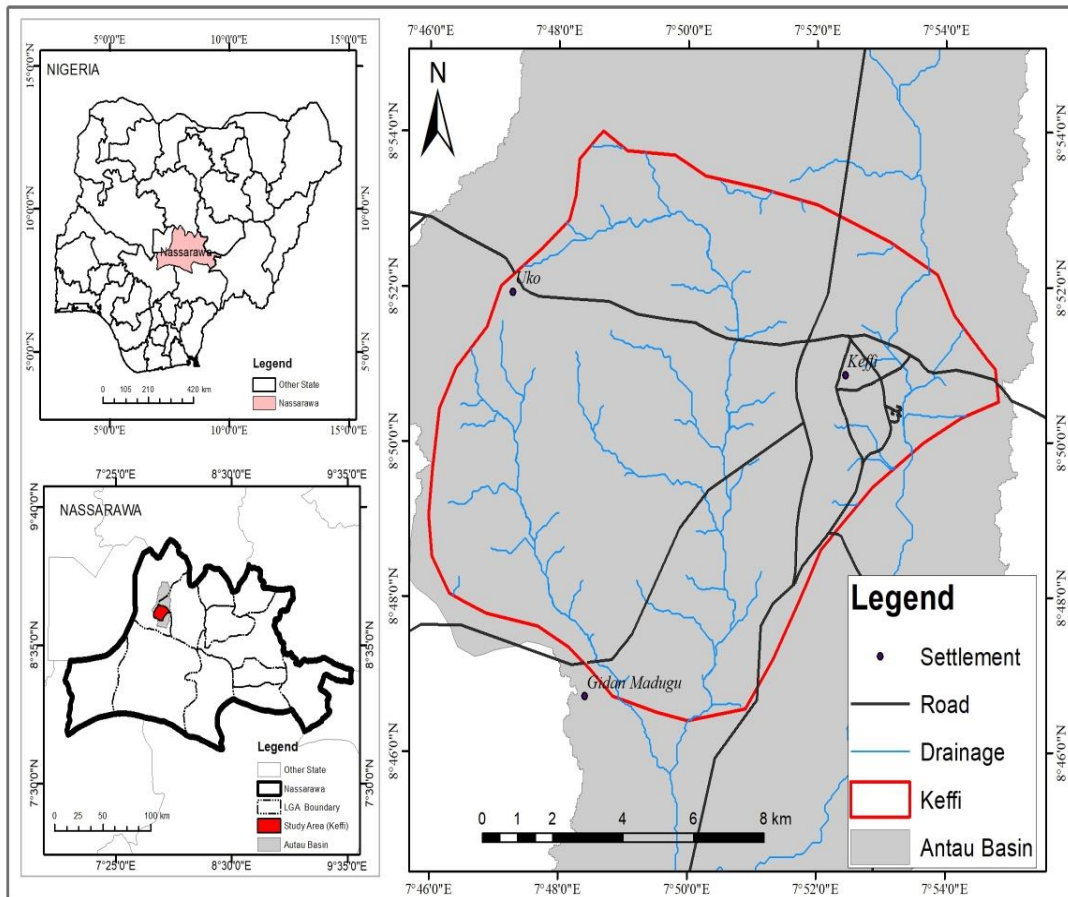
61 Population growth and infrastructural development in Keffi Local Government Area (LGA) of
62 Nassarawa State, Nigeria has increased the competition for water usage and has resulted in
63 scarcity of water for various use. This condition has led to more individuals drilling boreholes
64 and artisan wells to access groundwater. It is therefore important to thoroughly understand
65 the potential areas where groundwater has high recharge rate within this LGA to enhance its
66 efficiency and performance in planning, utilization, and management. We must work with
67 nature, instead of against it so as to increase the supply of water in a sustainable way that
68 does not jeopardize future use and degradation of the ecosystem. In view of the situation,
69 the ultimate goal of the study is to employ the use of Remote Sensing and Geographic
70 Information System (GIS) to analyze areas of groundwater potentials in Keffi LGA to meet
71 the rate of water demand. The specific objectives aims to delineate and analyze the
72 drainage characteristics, and map out the groundwater potential zones.

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74 **2. STUDY AREA**

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The study area as shown in Figure 1 lies between 7°46'E and 7°55'E Longitude and 8°46' and 8°54'N Latitude. The elevation of the area is 400 meters above the mean sea level. In 1976, the Area Council was created and it has since witnessed rapid population growth and infrastructural development due to its proximity to the Federal Capital Territory, Abuja. Keffi LGA has a population density of 450-500 persons per square kilometer (NPC, 2006), making it one of the most densely populated LGA in Nassarawa State.



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Figure 1: Map of the Study Area


Source: Digitized from the Administrative Map of Nigeria

88 Keffi LGA falls into the tropical sub-humid climate, having the wet and dry seasons roughly
89 coinciding with the summer and winter seasons of the northern latitudes. It has an average
90 annual daily temperature of 25°C within the two distinct seasons. The vegetation is Guinea
91 savannah and the floral composition is heterogeneous with species made up of small trees
92 (scattered), interspersed with shrubs, grasses, and arable crops.

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The area is low-lying plain with few undulating areas with the prominent among them being Maloney and Judah Amama hills. The area is drained by Antau River, rising from Gunduma

96 hill and flow as far as Kogin Koto near Nasarawa LGA, proceeding into River Benue. Other
97 rivers forming tributaries to the farmlands are dendritic drainage in nature.

98 Several rock outcrops are found all over the area and extrusions of the basement complex.
99 These outcrops fall into the Lafia sandstone formation, consisting of siltstone and imbedded
100 clays all of Cretaceous characteristics. Laterite is well-developed in some areas. Weathering
101 in the area has produced a gentle to almost flat topography. 

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103 Keffi LGA like every other Hausa towns exhibits three patterns of spatial morphology: the
104 core, intermediate (transition) and the outer periphery (outskirt) areas. The transition and
105 outskirts areas are populated by inhabitants with higher socio-economic characteristics than
106 the core areas. The people are predominantly farmers growing food crops such as cassava,
107 yam, maize, and rice.

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110 3. METHODOLOGY

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112 3.1 Data Type and Sources

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114 Data consisting of both spatial and non-spatial attributes were utilized for this research.
115 Ground Control Points (GCPs) were also established using the GPS device, satellite
116 imageries, and maps as displayed in Table 1.

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119 **Table 1:** Spatial Data Characteristics

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S/N	Type	Format	Scale/ Resolutio n	Path/Ro w	Date	Source
1.	LandSat 8	Digital	30 m	Path 188 Row 54	2018	Earth Explorer
2.	Soil	Analogue	1:1,300,00 0	-	1997	Wageningen , Netherlands
3.	SRTM DEM	Digital	30 m	-	2000	Earth Explorer
4.	Geology	Analogue	1:500,000	-	2006	NGS
5.	Rainfall	Digital	-	-	1981 -2017	CHIRPS

121 **Source:** Authors Report

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128 **3.1 Methods**

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130 **Area of Interest (AOI) Delineation**

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132 The AOI was generated using the SRTM-DEM data with the spatial analyst tool and
133 subsequently, the basin was delineated using the ArcSWAT extension tool in the ArcGIS
134 10.4 software. The derived delineated basin was exported as a shapefile and serves as a
135 reference to subset all the participatory thematic geo-referenced dataset images used for
136 this research.

137 **Spatial Analysis of Morphometric Parameters**

138 The capability of spatial analysis is broken down into categories or groups of related
139 functionalities. For this research, spatial analytical functions such as the geometric
140 generation of attribute data, mathematical computation, and multi-linear layers weighted
141 overlay were utilized, together with the data analysis involving editing, coding, interpolation,
142 classification, tabulation, and charts. The preparation of the physical thematic layers required
143 for the drainage morphometric parameters and multi-criteria overlay analysis includes
144 Rainfall, NDVI, Lineament, Geology, Slope, and Relief datasets.

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146 The aim of the groundwater potential model is to map out the availability of water through
147 pixel or grid-based and weighting analysis of the influential factors of water potential, and
148 simplifying the process with the utilization of GIS and statistical software. The grid model
149 approach is a weighting process or weighted sum model where weights for each layer is
150 assigned according to its significance in promoting or reducing erosion.

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152 In general, suppose we define an MCDA problem on m alternatives and n decision criteria.
153 Furthermore, let us assume that all the criteria are beneficial, that is, the higher the values
154 are, the better it is. Then, we denote w_j as the relative weight of importance of the criterion
155 C_j and a_{ij} is the performance value of alternative A_i when evaluated in terms of criterion C_j .
156 Then, when all criteria are considered simultaneously, the total importance of alternative A_i ,
157 denoted as A_i WSM-score, is defined as follows:

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$$\sum_{j=1}^n w_j a_{ij}, \text{ for } i = 1, 2, 3, \dots, m.$$

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161 Where:

162 WSM = weight sum model,

163 w = relative weight, and

164 a = performance value (Fishburn, 1967).

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166 For the maximization case, the best alternative is the one that yields the maximum total
167 performance value (Triantaphyllou, 2000). Furthermore, each layer is classified into several
168 classes with each having its specific weight. The layer of interest for building the model
169 includes rainfall, slope, soil, drainage, NDVI, geology, lineament, and hydrology. These
170 layers were assigned weights by following their contribution to the development of
171 groundwater. The assigned weights were multiplied by its constant class and assigned an
172 index (or value), after which, the critical index for each cell of the overlaid grid was obtained
173 by the addition of all the computation results of the cell for each layer. Using specific query
174 and geo-statistics operation, the critical index value of each cell was analyzed in a GIS
175 supported weighted overlay in ArcGIS 10.4

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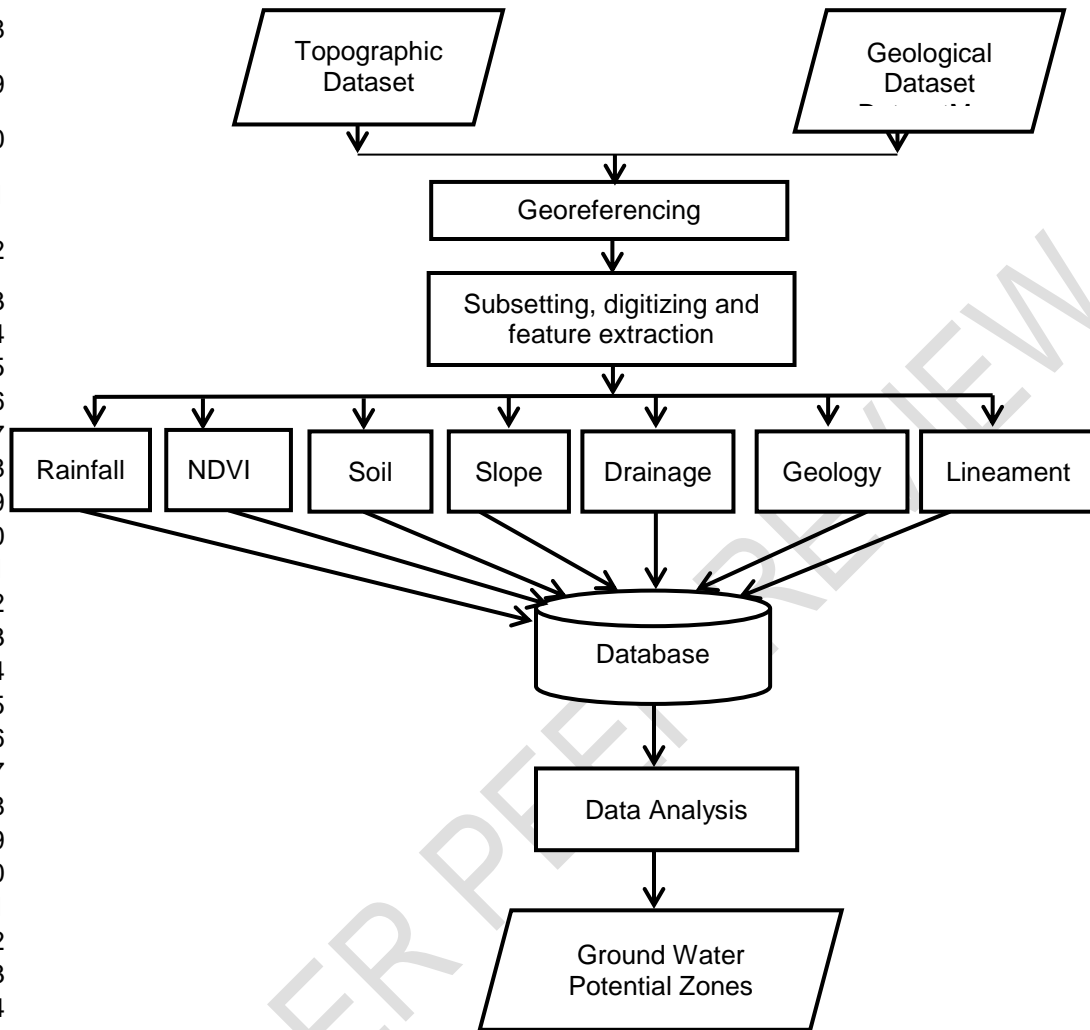


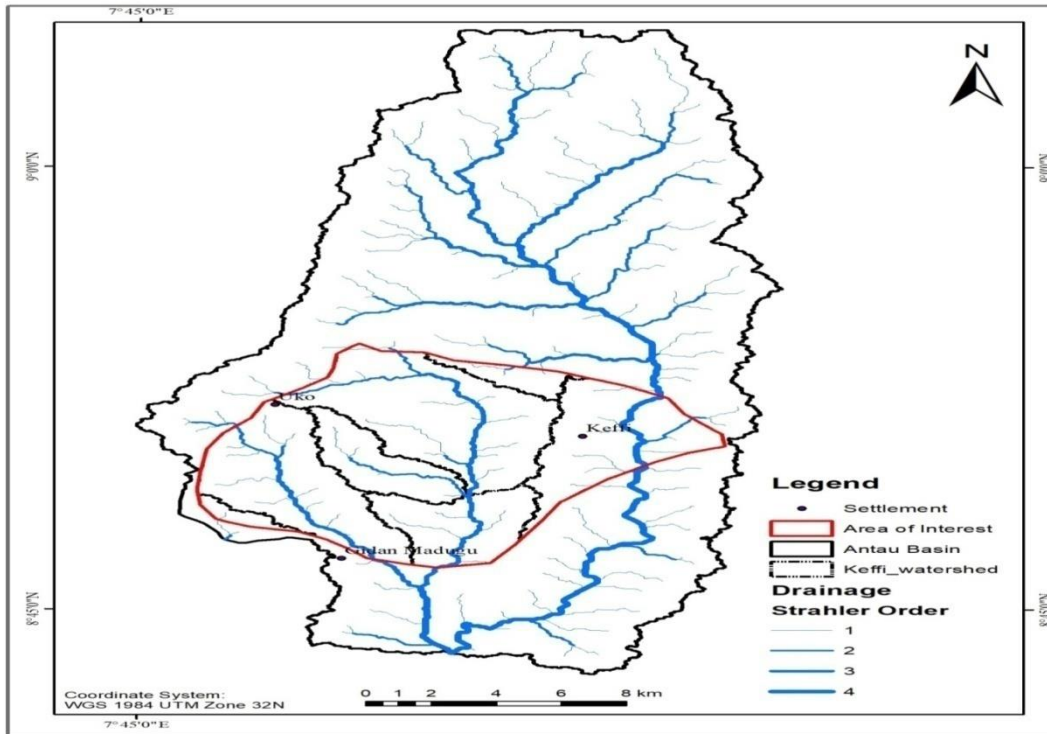
Figure 2: Methodology Flow Chart
Source: Authors Report

4. RESULTS AND DISCUSSION

4.1 **Drainage Delineation and Characteristics**

Antau Basin Drainage

The extracted Antau Basin from the study area is presented in Figure 3. The drainage network and its attendant hydrological attributes data were reclassified using Stralher Ordering to identify and differentiate streams into various order of magnitude using the length, width, and volume attributes.



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Figure 3: Antau Basin Drainage Network Map

Source: Authors Report

Table 2 summarizes the drainage characteristics of the Antua Basin based on the different Parameters and Stream Orders.

229 **Table 2:** Antau Basin Drainage Characteristics

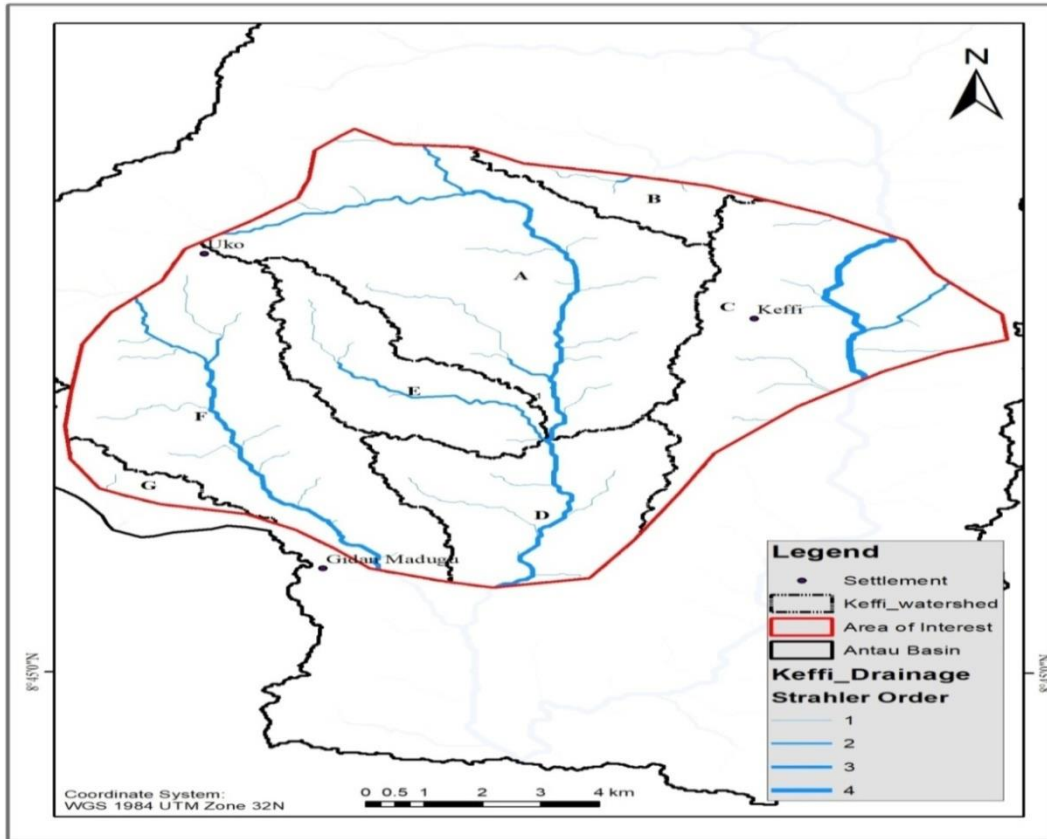
Drainage Characteristics				
Parameters	Order 1	Order 2	Order 3	Order 4
No. of Stream Segment	46	9	2	1
Stream Length (km)	53.11	19.12	22.54	5.5
Mean Stream Length (km)	1.5	2.12	11.27	5.5
Min. Stream Length (km)	0.07	0.04	7.71	5.5
Max. Stream Length (km)	4.05	5.13	14.82	5.5

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231 **Source:** Authors Report

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The drainage network of the study area extracted from the DEM covering Autau Basin is shown in Figure 4. The drainage network and its watershed characteristics were reclassified using Strahler Ordering technique to identify and differentiate streams of various order of magnitude using the length, width, and volume attributes.



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Figure 4: Drainage Network of Keffi Local Government Area
Source: Authors Report

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Table 3 analyzes the study area watershed characteristics into various segments from A through G. The higher the drainage density, the higher the degree of wetness, and it ranges between 0.2 to 1.6 sq.km drainage density. From the result displayed, Segment D has the highest degree of wetness represented with 1.6 sq.km drainage density, while Segment G has the lowest with 0.2 sq.km drainage density. Keffi metropolis falls within the Segment C of 0.7 sq.km drainage density. This signifies having moderate extent of groundwater potentials.

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Table 3: Keffi Watershed Characteristics

Keffi Watershed Characteristics				
Watershed	Basin Perimeter	Basin Area	Stream Length	Drainage Density
A	42.2	42.2	38.4	0.9
B	4.9	4.9	2.6	0.5
C	26.5	26.5	18.1	0.7
D	17.3	17.3	27.5	1.6
E	13.4	13.4	9.0	0.7
F	31.6	31.6	24.2	0.8
G	2.4	2.4	0.5	0.2

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Source: Authors Report

4.2 Groundwater Potential Factors

The thematic maps of the hydro-geological influencing groundwater potential factors are displayed in Figure 5 to Figure 11. The consideration for the selection of these factors depends on personal judgment and expert's opinion. These are summarized and outlined in the remarks shown in Table 4.

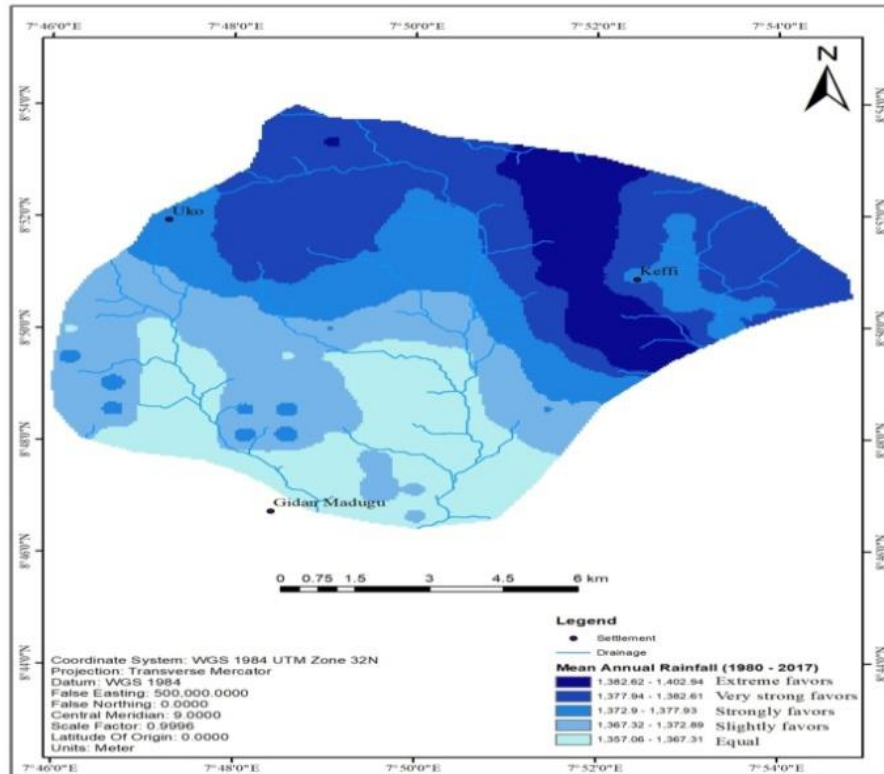
Table 4: Multi-factors for Groundwater Potentials

Factor	Remark
Rainfall	Higher rainfall recharge the Aquifer
NDVI	Vegetation cover reduces runoff
Soil	Soils with voids allow infiltration
Slope	Flat surfaces accumulate water
Drainage Density	Coarse drainage influences water availability
Geology	Migmatite vertical infiltration
Lineament Density	Possible water seepage into the aquifer

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Source: Authors Report

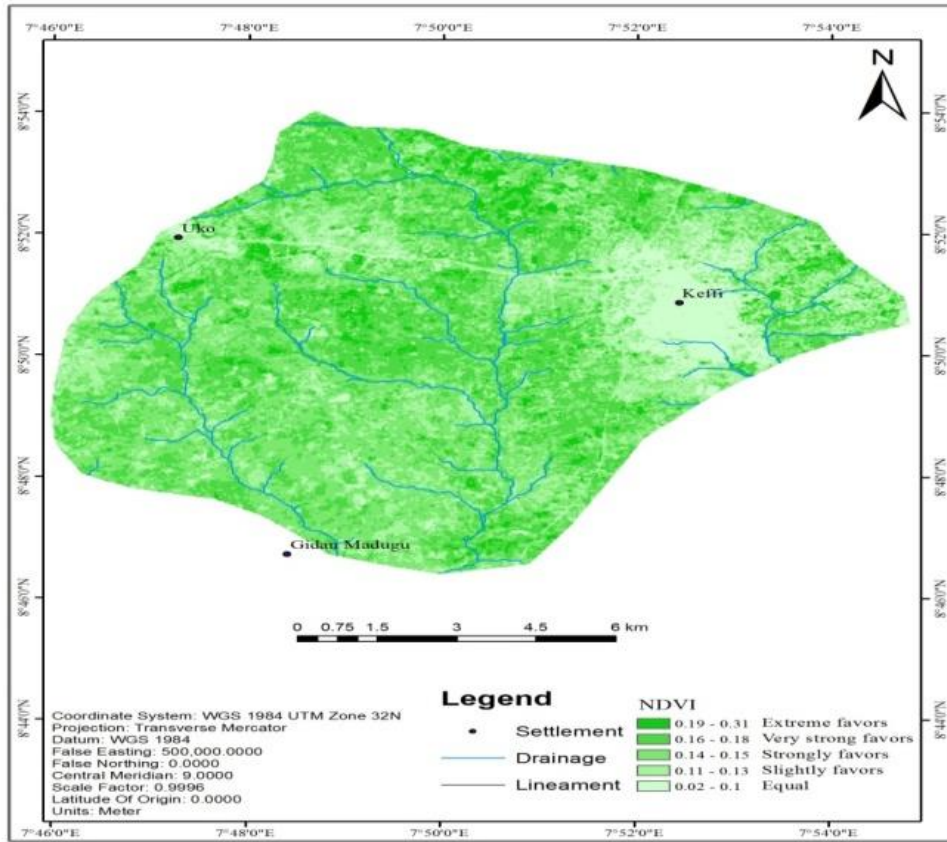
- **RAINFALL:** The mean annual rainfall of the study area from 1980 to 2017 ranges from 1357 to 1402 ml. The more the rainfall, the more the groundwater potential of an area. As shown in Figure 5, the intensity of rainfall within the study area increases towards the north-eastern parts, and less towards the south.



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Figure 5: Mean Annual Rainfall Map
Source: Authors Report

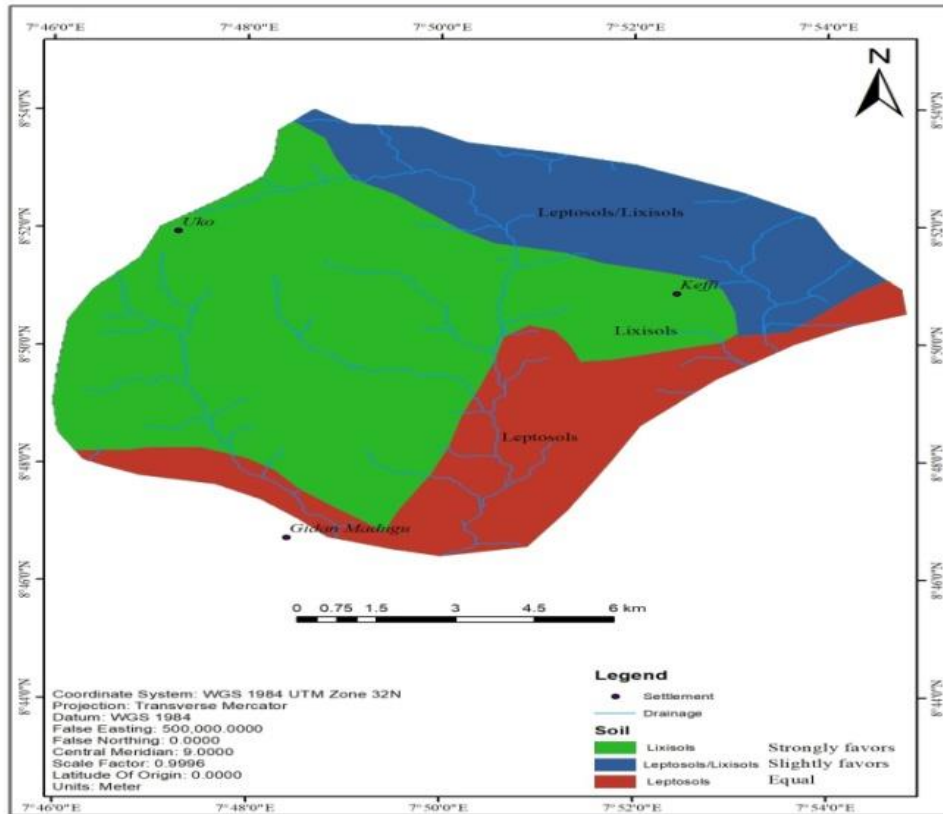
- **NDVI:** The greater the vigor of green vegetation has displayed using the Normalized Difference Vegetation Index (NDVI) map, the larger the contrast between the Near Infrared (NIR) and red reflectance. This gives a higher result of NIR/red ratio values, but a reduced spectral contrast would be attributed to lower vegetation quantity (sensing vegetation under stress). Thus, as shown in Figure 6, the areas with lower green reflectance representing the bare surfaces and built-up areas have little contribution to groundwater recharge potentials observed towards the north-eastern parts of the study area.



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Figure 6: NDVI Map
Source: Authors Report

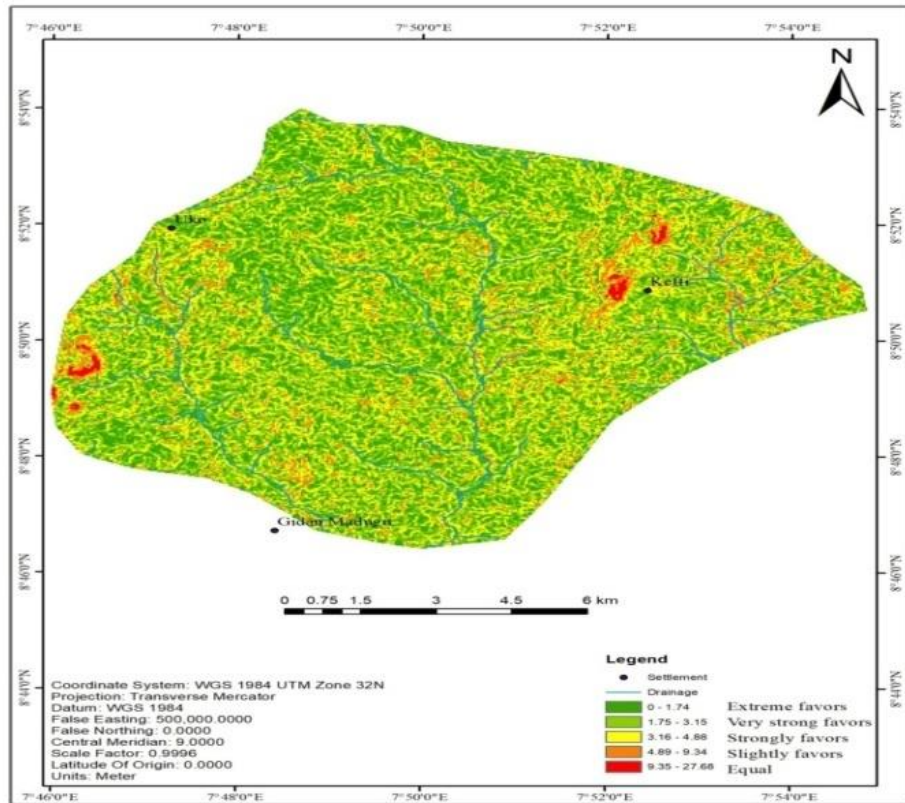
- **SOIL:** Various soil type influences the occurrence of groundwater availability. Generally, permeability is directly proportional to the effective porosity of the soil. Grain size, shape, structural arrangement and stratification of grains, properties of the pore fluid, voids ratio, entrapped air (degree of saturation) and other foreign matters influence factors of soil permeability. In the area of interest as shown in Figure 7, three types of soil were classified: Lixisols (strongly favours groundwater), Leptosol/lixisols (slightly favours groundwater), and leptosols (equally favours groundwater).



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Figure 7: Soil Map
Source: Authors Report

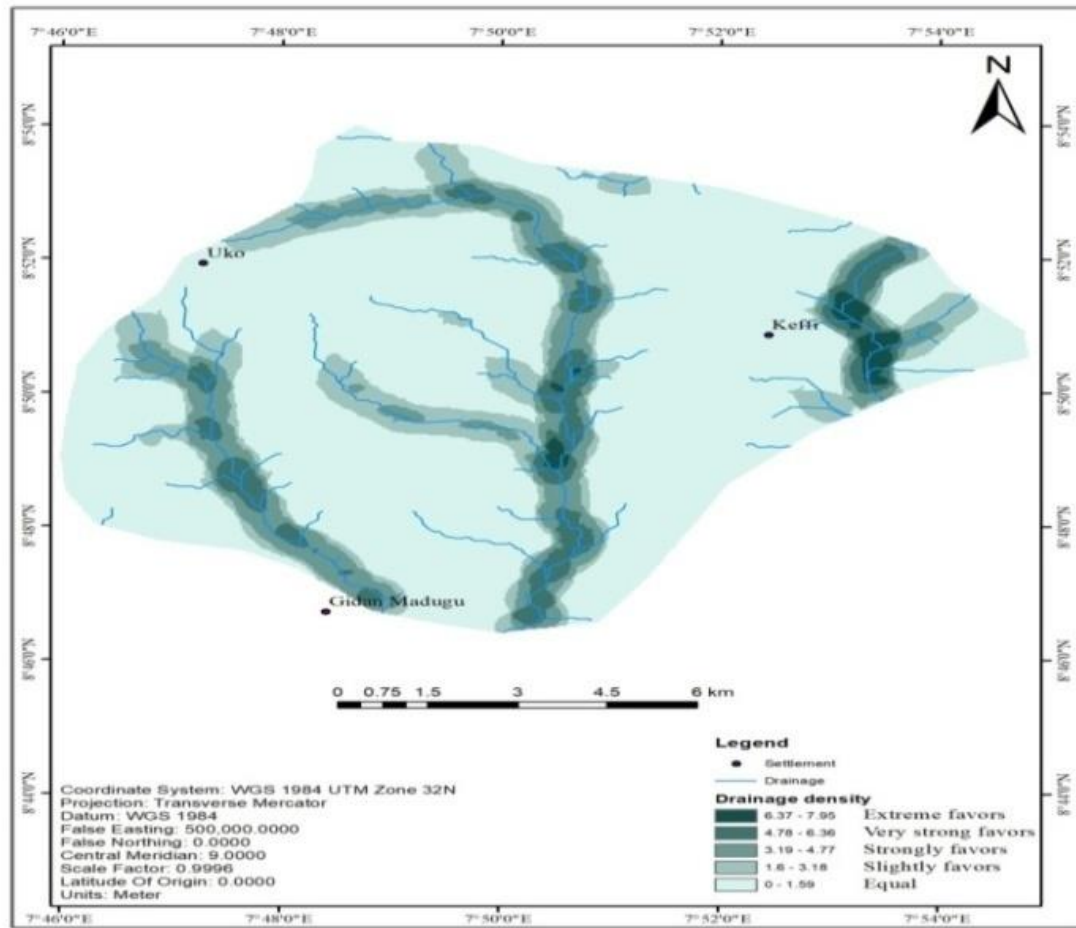
- **SLOPE:** This determines the hydrological characteristics of a catchment. Lower slope values show lower hydraulic gradients. This tends to enhance infiltration and recharge by reducing the speed of the surface runoff. Therefore, the slope values ranging from 0 to 1.74 as observed within the study area in Figure 8 is characterized as areas strongly favoring groundwater whereas those between 4.09 – 9.34 and above, slightly and equally favours groundwater potential respectively.



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Figure 8: Slope Map
Source: Authors Report

- **DRAINAGE DENSITY:** This is a measure of permeability, and we can observe a noticeable concentration of streams within the study area. As shown in Figure 9, areas within the low-lands have high drainage density. This is an indication of favorable condition for vertical infiltration of runoff from surrounding hills, and thus, enhancing groundwater occurrence. However, low drainage density implies low infiltration and recharge potentials.

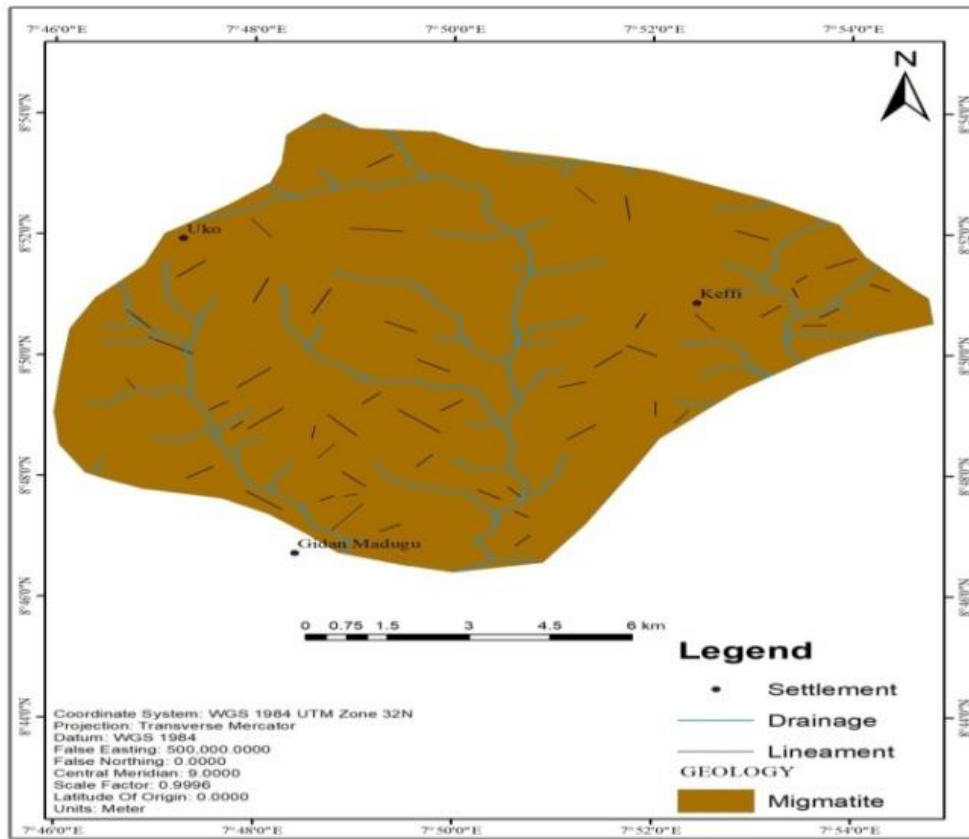


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Figure 9: Drainage Density Map
Source: Authors Report

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- **GEOLOGY:** This has a great influence on the primary porosity and permeability of rocks (Christensen *et al.*, 1996). Higher groundwater storage contributes to higher porosity, and higher permeability contributes to higher groundwater yields. As displayed on the map in Figure 10, the study area has the migmatite rock type, thickness of weathering, fracture density, etc. The rock has a sympathetic character for groundwater accumulation owing to their primary porosities and permeability. The Cretaceous rock formations were assumed to have better groundwater accumulation than other rock types due to the secondary structures, joints, and secondary porosity.




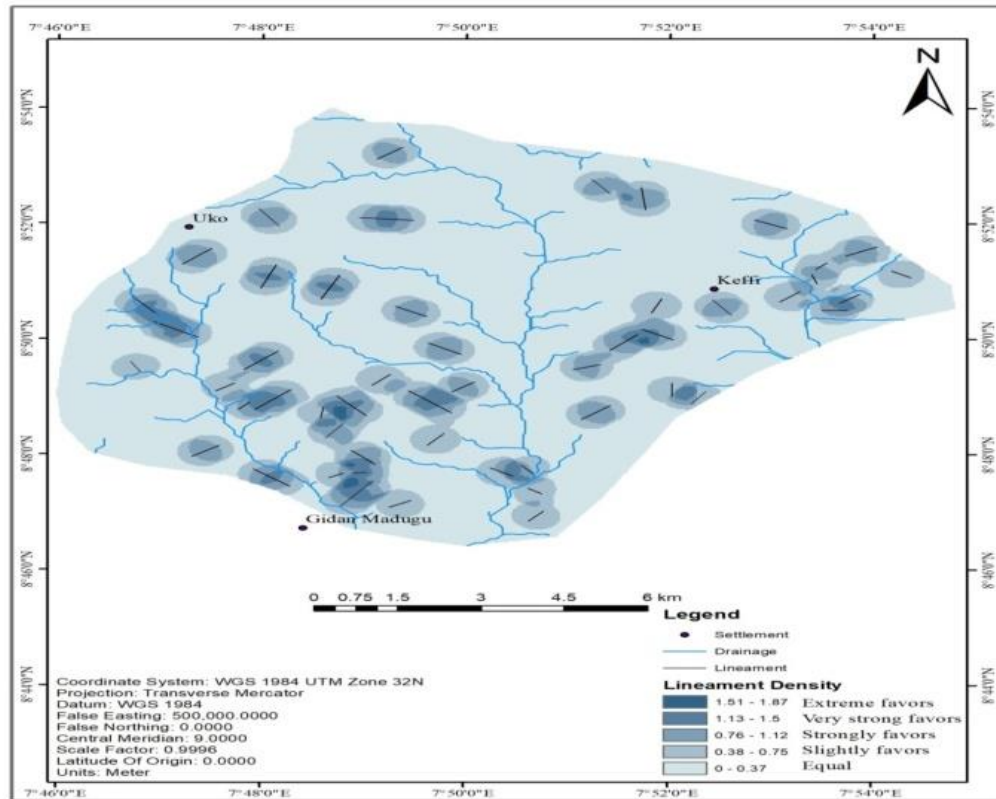
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340 **Figure 10:** Geology Map341 **Source:** Authors Report

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- 343 • **LINEAMENTS DENSITY:** s often represents zones of fracturing and increased
 344 secondary porosity and permeability. Therefore, it enhances groundwater occurrence
 345 and movement. The displayed lineament density map in Figure 11 shows lines of
 346 weakness in the study area, and these indicate areas of possible water seepage into the
 347 aquifer (underground reservoir of water) which extends across the area. Thus, areas
 348 good for groundwater development are regarded as having high lineament density.



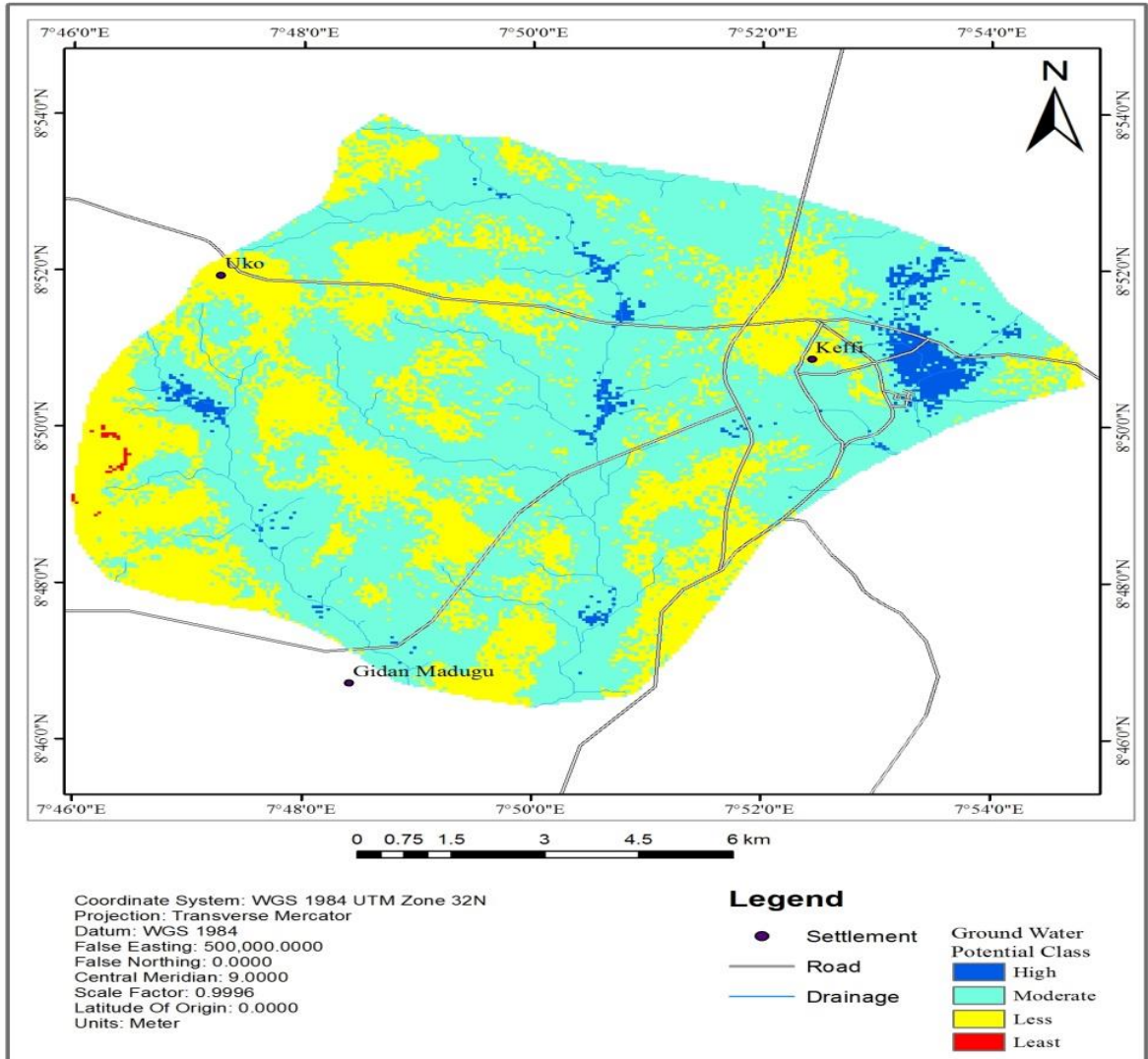
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Figure 11: Lineament Density Map

Source: Authors Report

354 **4.3 Groundwater Potential Map**

355 The result of the weighted overlay ranking assigned to the groundwater potential factors is
356 presented in Figure 12 and grouped into various levels of potentiality.



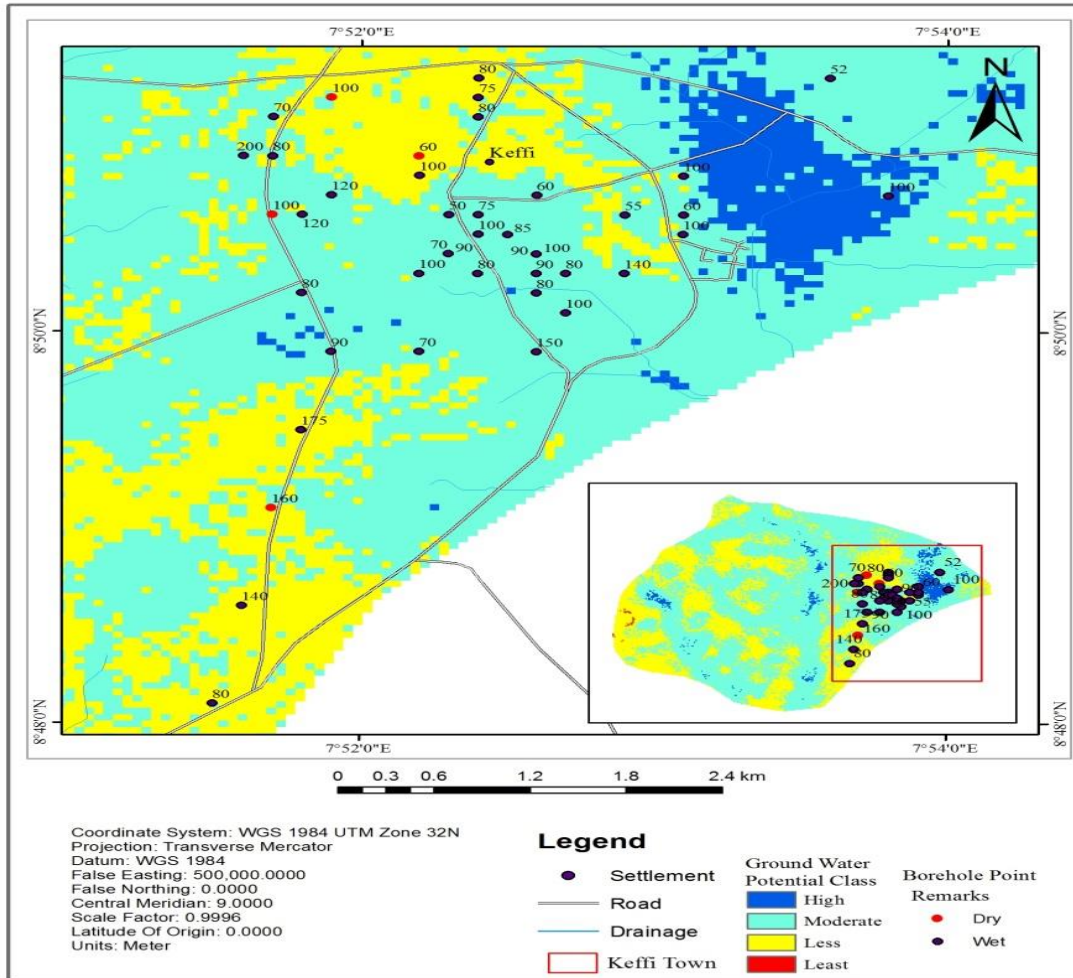
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 358 **Figure 12: Groundwater Potential Map**
 359 **Source:** Authors Report
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361 Going by the research location, areas represented with the blue colour represents the high
 362 groundwater potential zones. This area covers about 2.6% of the total study area. Those in
 363 cyan colour depicts the moderate groundwater potential classes, covering about 89.1 km²
 364 (64.7%) of the area. The less groundwater potential classes cover 44.8 km² (32.6%) and the
 365 least groundwater potential classes cover 0.1 km² (0.1%) of the total study area.
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 368 **4.4 Groundwater Potential Classes and Borehole Locations**
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370 The GIS-based output validating the result of the analyzed groundwater potential classes
 371 was done using ground-truthing by selecting the boreholes with their depth attributes
 372 randomly at different locations within the study area as shown in Figure 13. The boreholes
 373 represented with red colour signifies dry points and these mostly fall within the less

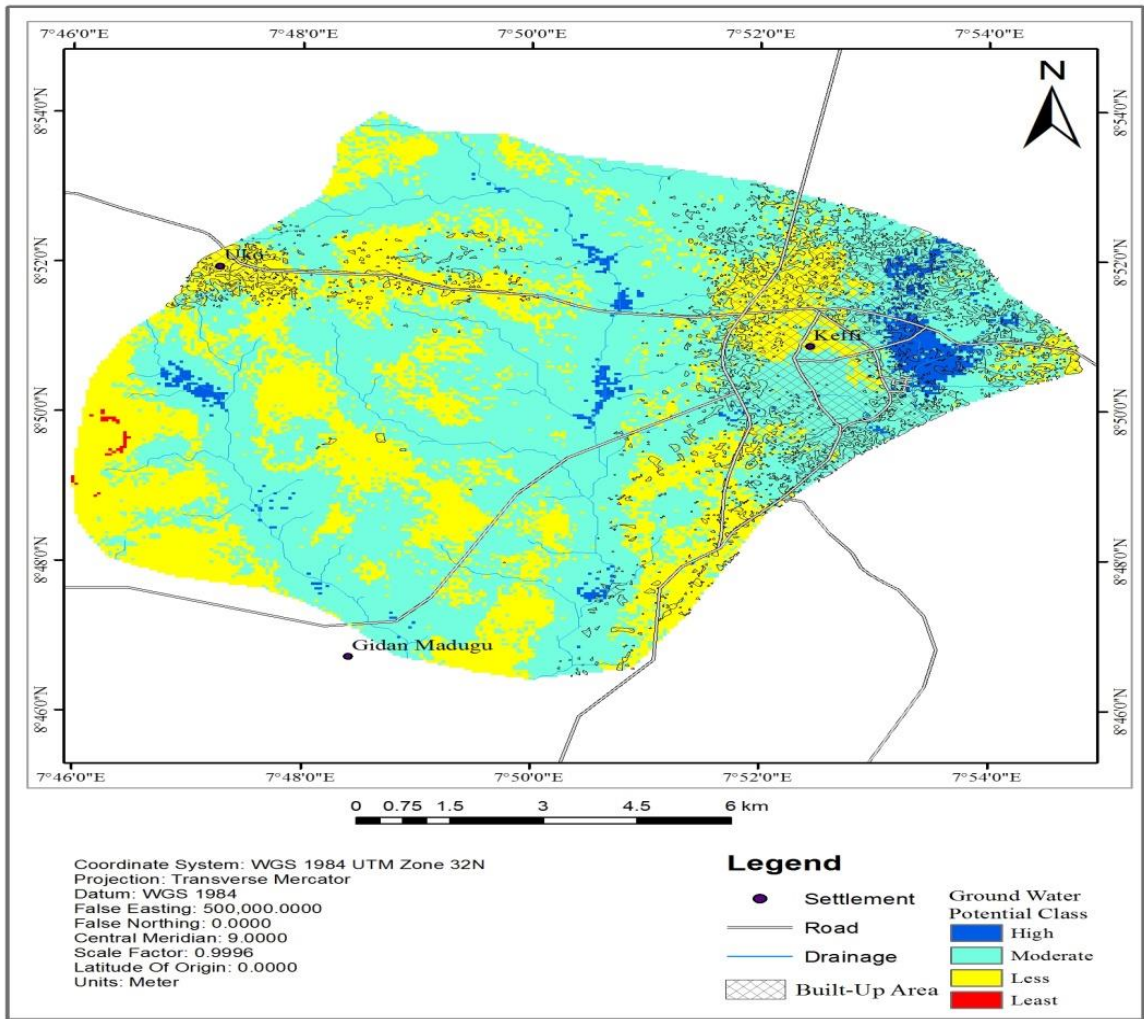
374 groundwater potential classes. The black colour represent the wet points and are mostly
 375 found within the moderate groundwater potential classes. These signifies that the boreholes
 376 are dug based on the availability of water in accordance with the groundwater potentials in
 377 the study area.
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 380 **Figure 13: Borehole Locations**
 381 **Source:** Authors Report

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 383 **4.5 Groundwater Potential Classes and Settlements**
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385 The groundwater potential classes with the settlement locations as shown in Figure 14
 386 revealed that 59.8% (12 sq.km) of the settlement areas fall within the areas demarcated as
 387 having moderate groundwater potential classes. This covers the largest extent of the study
 388 area. This is followed by areas having less groundwater potential classes having 36.3 % (7.3
 389 sq.km) and the high groundwater potential classes having 4 % (0.8 sq.km) of settlements.
 390 There are no settlements located within the least groundwater potential classes.



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Figure 14: Concentration of Settlements within the Groundwater Potential Classes
Source: Authors Report

395 **5. CONCLUSION**

396 The environmental and edaphic properties of Keffi LGA with the application of geospatial
397 technology has been useful in this study to delineate the groundwater potential zones.
398 Remote sensing and GIS have proven to be an efficient tool in predicting groundwater
399 potential and sustainable management of watershed. The hydrology map gave an insight
400 into watershed management and areas with high water recharge rate. More areas in Keffi
401 metropolis falls under the moderate groundwater potential classes. In addition, more than
402 half of the study area are within the high and moderate groundwater potentials. This shows
403 the area has adequate capacity for water supply. Therefore, only those within the high
404 groundwater potential classes can access groundwater throughout the year.

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406 This study has illuminated the need for strict legislation that promotes optimal resource use
407 through communal water utilization. This will control multiple and situations where every
408 household sink borehole to get water. Series and multiple holes clustered within an area
409 causes distortion and weakness to the rock formation which invariably increases the
410 intensity of tremor.

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412 It is also important that legislation be taken seriously since all borehole draws water from a
413 common source (underground water). If left uncontrolled, the chances of pollutant getting to
414 the underground water increases in the accidental spill of a pollutant through a borehole
415 source.

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References 

417 Ariyo, S. O., and Adeyemi, G. O. (2009). Role of electrical sensitivity method for
418 groundwater exploration in hard rock areas: A case study from Fidiwo/Ajebo areas
419 of southwestern Nigeria. *Pacific J. Sci. & Tech*, 10(1), 483-486.

420 Christensen, B.J., Mason, T.O. and Jennings, H.M.: 1996, Comparison of measured and
421 calculated permeabilities for hardened cement pastes. *Cement and Concrete*
422 *Research*, Vol. 26, No. 9, 1325-1334.

423 Diary, A. M. M., and Lanja, F. R. (2016). Groundwater potential mapping using remote
424 sensing and GIS-based, in Halabja City, Kurdistan, Iraq. *Arab J Geosci*, 9, 357.
425 doi:10.1007/s12517-016-2385.

426 Fashae, O.A., Tijani, M.N., Talabi, A.O. and Adedeji, O.I. (2014). Delineation of Groundwater
427 Potential ZONES in The Crystalline Basement Terrain of SW-Nigeria: An Integrated
428 GIS and Remote Sensing Approach. *Applied Water Science*, Volume 4, Issue 1, pp
429 19-38.

430 Fishburn, P.C. (1967). Additive Utilities with Incomplete Product Set. Applications to
431 Priorities and Assignments. ORSA Publication, Baltimore.

432 Todd, D.K. and Mays, L.W. (2005). Groundwater Hydrology. Willey International Edition.

433 Greenbaum, D. (1992). Structural Influences on the Occurrence of Groundwater in SE
434 Zimbabwe. Geological Society, London, Special Publications, 66, 77-85.

435 Gustafsson, P. (1993). High resolution satellite data and GIS as a tool for assessment of
436 groundwater potential of a semi-arid area. IXth Thematic Conference on Geologic
437 Remote Sensing, Pasadena, California, U.S.A. 8-11 February 1993.

438 Madan, K.J., Chowdary, V.M. and Chowdhury, A. (2010). Groundwater Assessment in
439 Salboni Block, West Bengal (India) Using Remote Sensing, Geographical
440 Information System and Multi-criteria Decision Analysis Techniques. *Hydrogeology*
441 *Journal*, Volume 18, Issue 7, pp 1713-1728.

442 Roy, B. (1996). Multicriteria Methodology Goes Decision Aiding. Kluwer Academic
443 Publishers, Berlin.

444 Saraf, A. K., Gupta, R. P., Jain, S. K., and Srivastava, N. K. (1994). GIS based processing
445 and interpretation of groundwater quality data. In Proceedings of the Regional

446 Workshop on Environmental Aspects of Groundwater Development, 17-19 October,
447 1994, Kurukshetra, India, pp. II-9-II-4.
448 Subbarao, C., Subbarao, S.N. and Chandu, S.N. (1996). Characterization of Groundwater
449 Contamination using Factor Analysis. Environmental Geology, Volume 28, Issue 4,
450 pp 175-180.
451

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