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

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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 generation of 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 Ground Control Point 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 89.1km^{2,} while the least cover 0.1km^2 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 following 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 (Pimentel *et al.*, 2004). Water covers about three-quarter of

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the earth's surface (Loganathan, 2017) 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 (Hellbeck, 2009). Only a small fraction of about 0.015% is 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 agricultural activities are increasing the competition for water, hence causing civil unrest, mass migration, and conflicts between countries (WWDR, 2003, 2018). The previous conditions have increased the drive to create channels to further explore groundwater (Madan *et al.,* 2010).

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

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

Over the years, different methods of exploring groundwater have been developed. These methods include but not limited to test drilling and stratigraphy analysis, the use of geophysical methods of electrical resistivity. However, the integrated approach based on advanced application of geospatial technology offers an efficient and effective result-oriented method for identifying and managing water resources. The concept of geospatial technology integrates remote sensing and GIS in a novel manner, and it has proven to an efficient tool in groundwater studies (Kunda *et al.,* 2016; Gebrie *et al.,* 2018; Desalew *et al.,* 2019)

Population growth and infrastructural development in Keffi Local Government Area (LGA) of Nassarawa State, Nigeria has increased the competition for water usage and has resulted in the scarcity of water for various use. This condition has led to more individuals drilling boreholes and artisan wells to access groundwater. It is therefore important to thoroughly understand the potential areas where groundwater has a high recharge rate within this LGA to enhance its efficiency and performance in planning, utilization, and management. We must work with nature, instead of against it to increase the supply of water in a sustainable way that does not jeopardize future use and degradation of the ecosystem. In view of the situation, the ultimate goal of the study is to 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. The specific objectives aim to delineate and analyze the drainage characteristics and map out the groundwater potential zones.

2. DESCRIPTION OF THE STUDY AREA

The study area as shown in Figure 1 lies between $7^{0}46^{\prime}$ and $7^{0}55^{\prime}$E Latitude and $8^{0}46^{\prime}$ and $8^{0}54^{\prime}$N Longitude. 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.

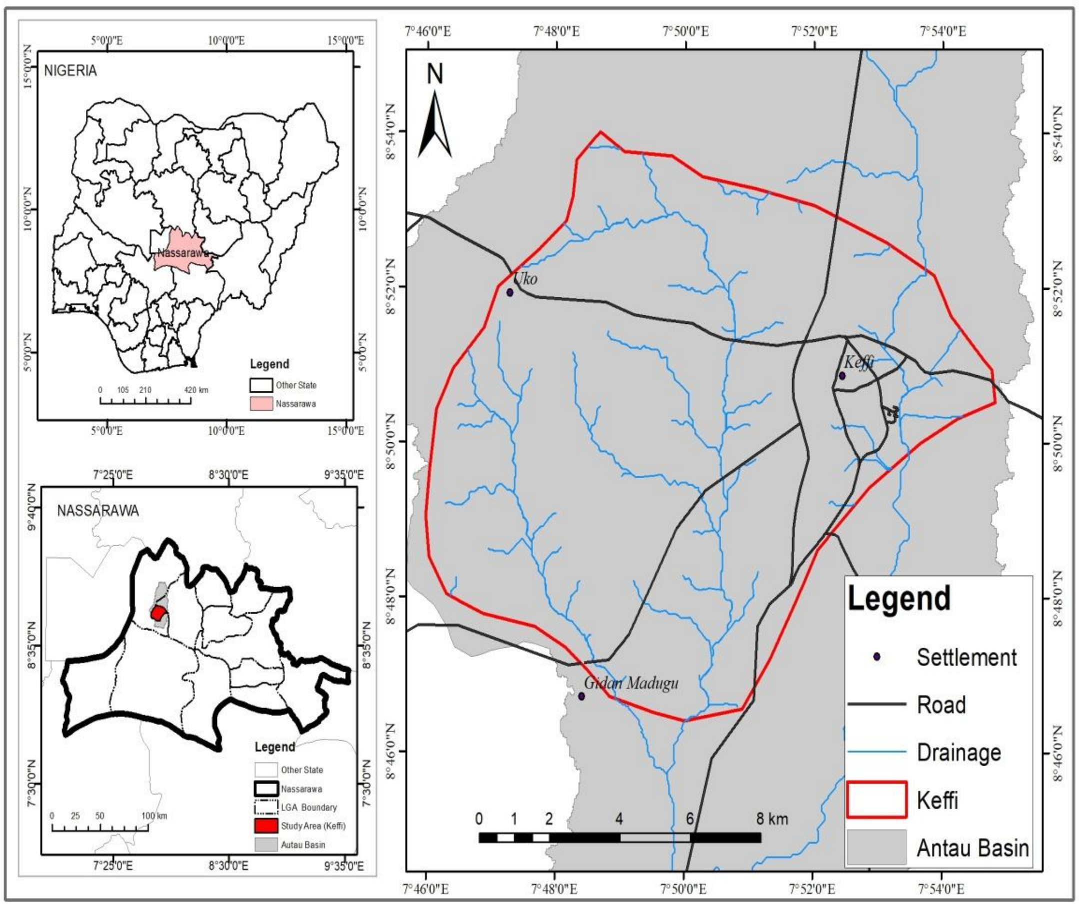

Figure 1: Map of the Study Area

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

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

Several rock outcrops are found all over the area and extrusions of the basement complex. These outcrops fall into the Lafia sandstone formation, consisting of siltstone and imbedded clays all of the Cretaceous characteristics. Laterite is well-developed in some areas. Weathering in the area has produced a gentle to almost flat topography (Ghosh and Guchhait, 2015; Adeola and Oyebola, 2016).

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

3. METHODOLOGY

3.1 Data Type and Sources

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

Table 1: Spatial Data Characteristics

S/N	Type	Format	Scale/ Resolution	Path/Row	Date	Source
1.	LandSat 8	Digital	30 m	Path 188 Row 54	2018	Earth Explorer
2.	Soil	Analogue	1:1,300,000	-	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

Source: Authors Report

3.1 Methods

Area of Interest (AOI) Delineation

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

Spatial Analysis of Morphometric Parameters

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

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

In general, suppose we define an MCDA problem on m alternatives and n decision criteria. Then, we denote wj as the relative weight of importance of the criterion Cj and aij is the performance value of alternative Ai when evaluated in terms of criterion Cj. Then, when all criteria are considered simultaneously, the total importance of alternative Ai, denoted as AiWSM-score, is defined as follows:

$$\sum_{j=1}^{n} w_{\mathrm{j}} a_{\mathrm{ij}}, \text{for } i = 1, 2, 3, \ldots, \mathrm{m}$$

Where:

WSM = weight sum model,
W = relative weight, and
a = performance value (Fishburn, 1967; Triantaphyllou, 2000)

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

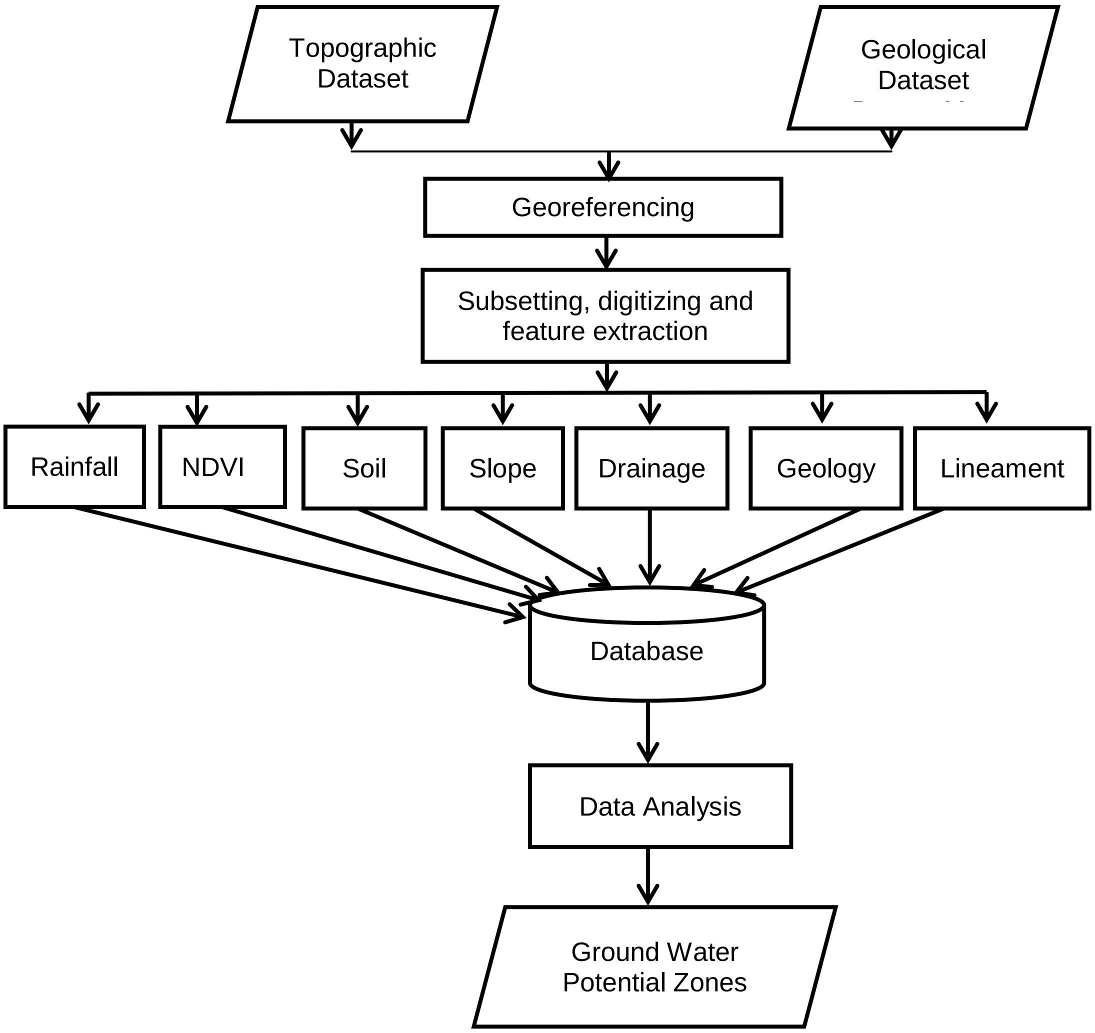

Figure 2: Methodology Flow Chart
Source: Authors Report

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.

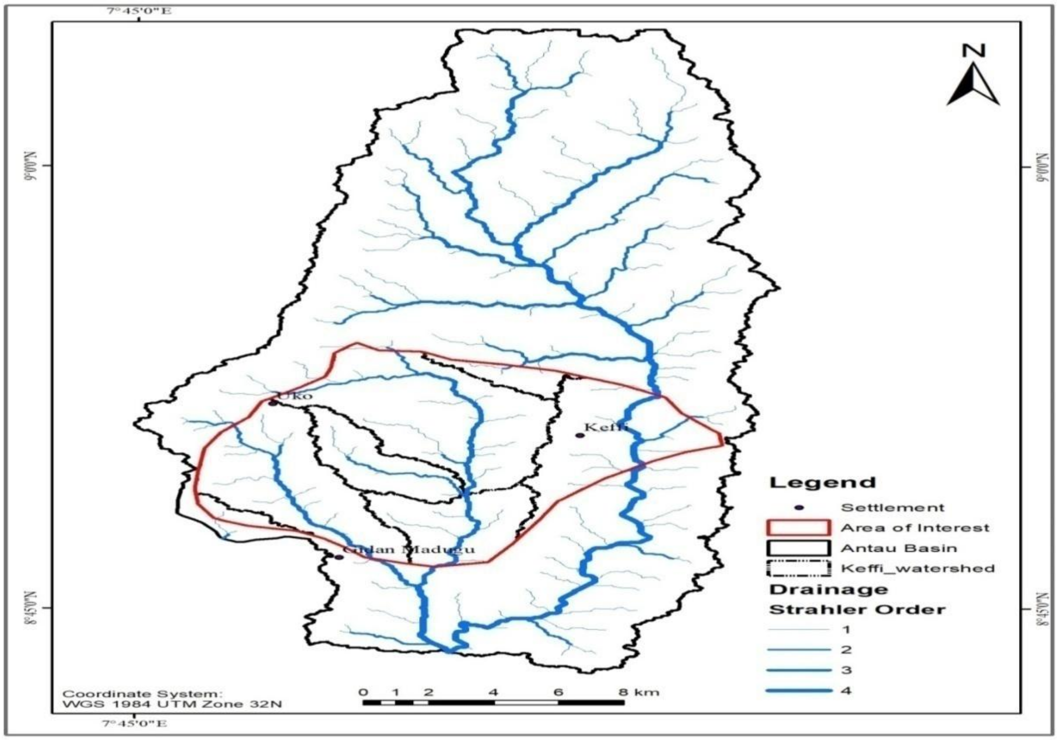

Figure 3: Antau Basin Drainage Network Map
Source: Authors Report

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

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

Source: Authors Report

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.

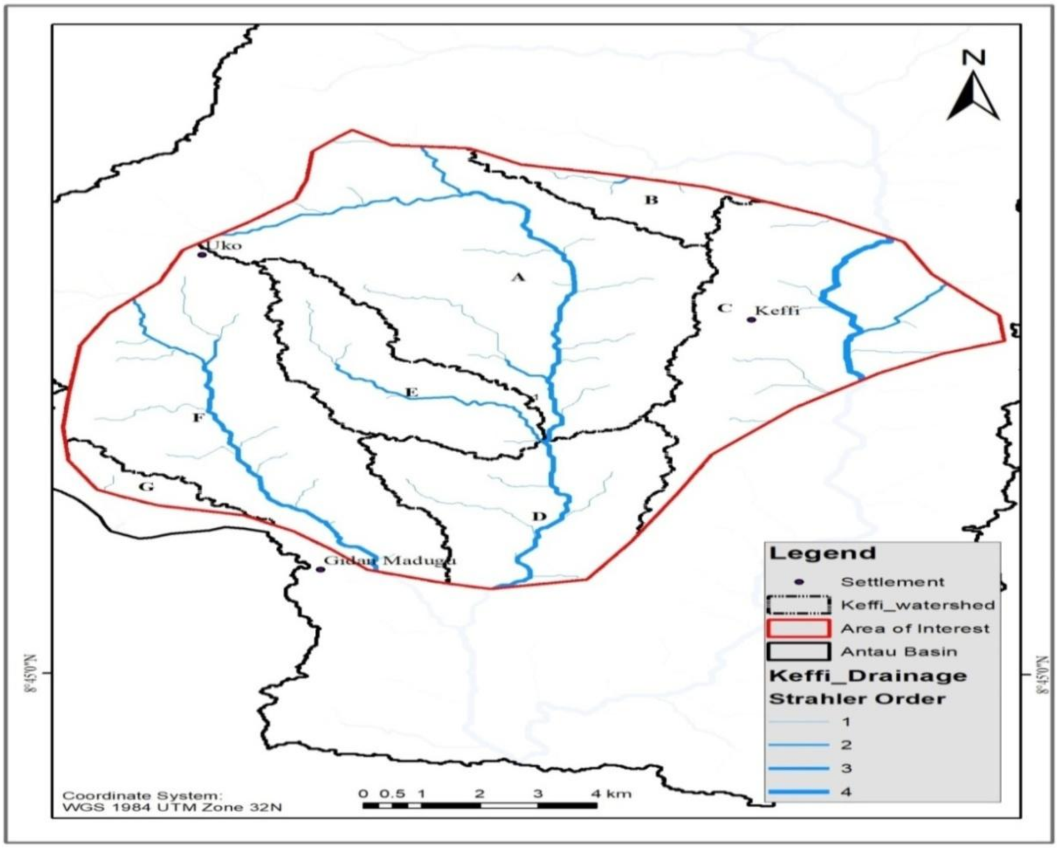

Figure 4: Drainage Network of Keffi Local Government Area
Source: Authors Report

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.

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

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 are 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

Source: Authors Report

- **RAINFALL:** This factor serves as the rechargeability for the groundwater. 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.

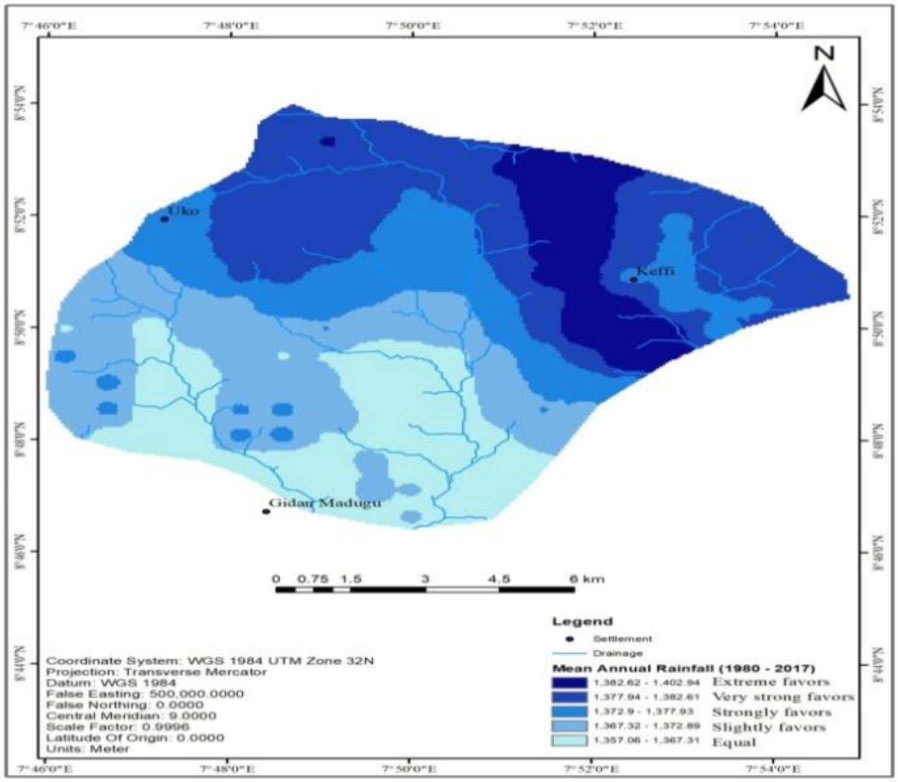

Figure 5: Mean Annual Rainfall Map
Source: Authors Report

- **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.

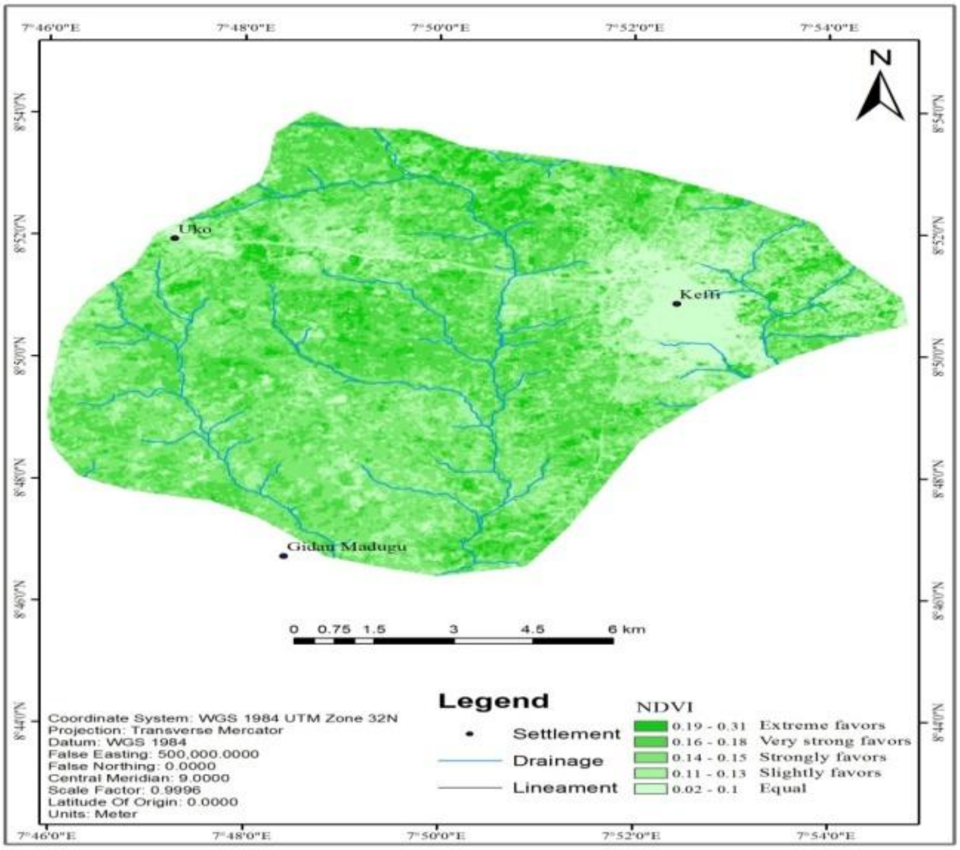

Figure 6: NDVI Map
Source: Authors Report

- **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).

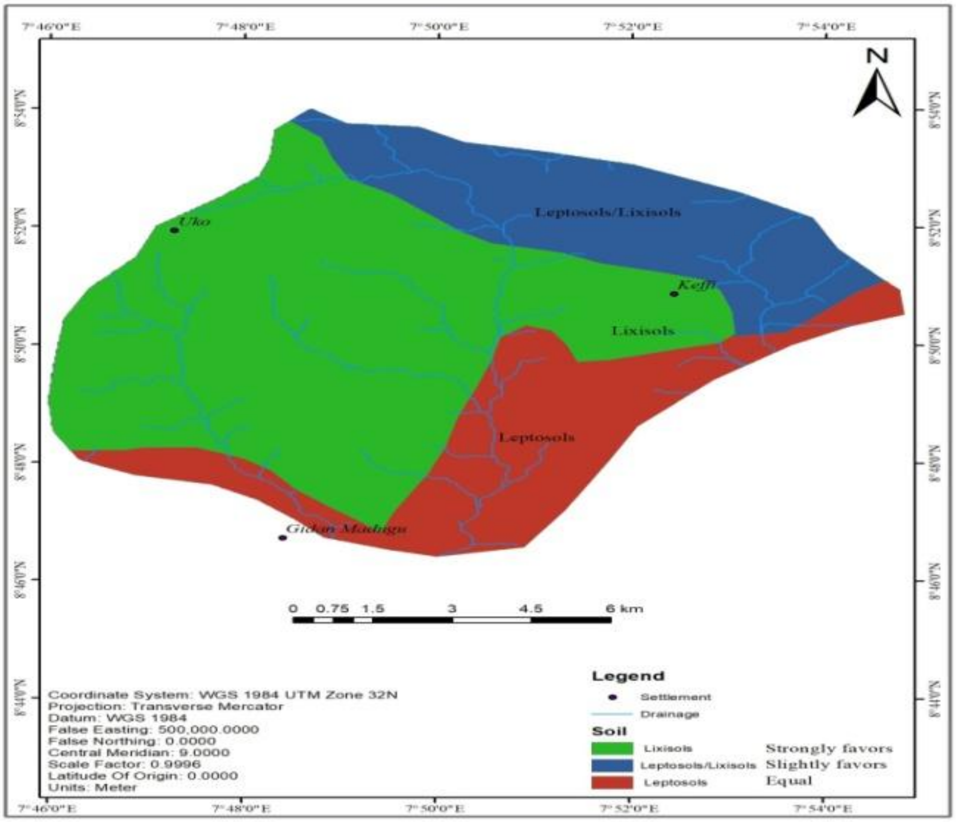

Figure 7: Soil Map
Source: Authors Report

- **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.

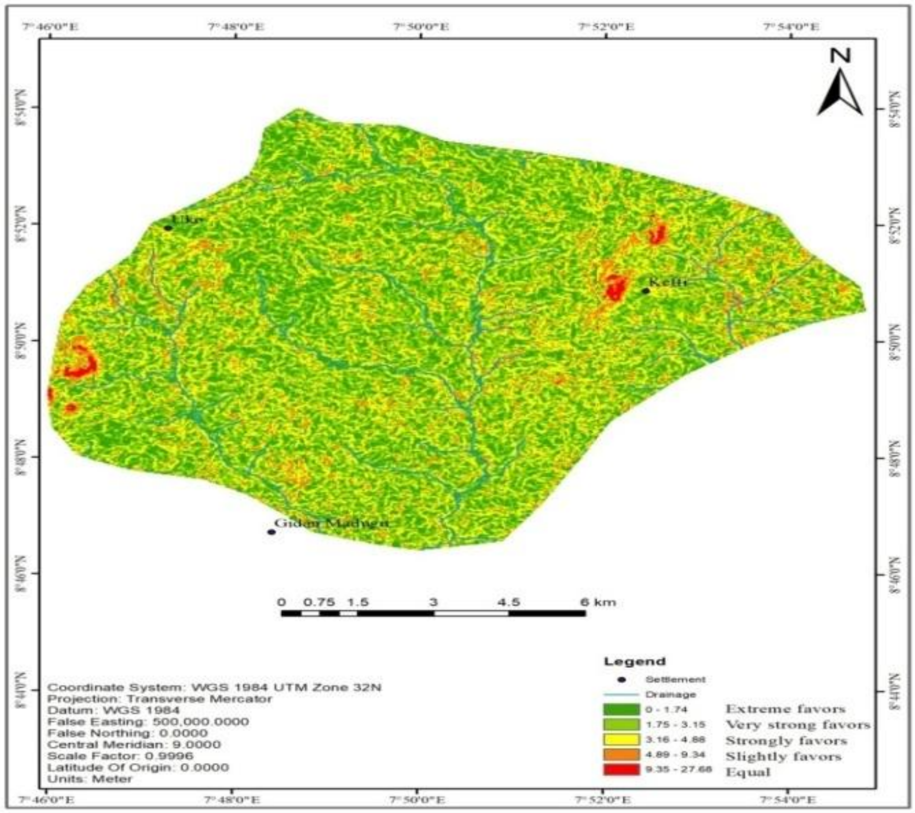

Figure 8: Slope Map
Source: Authors Report

- **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.

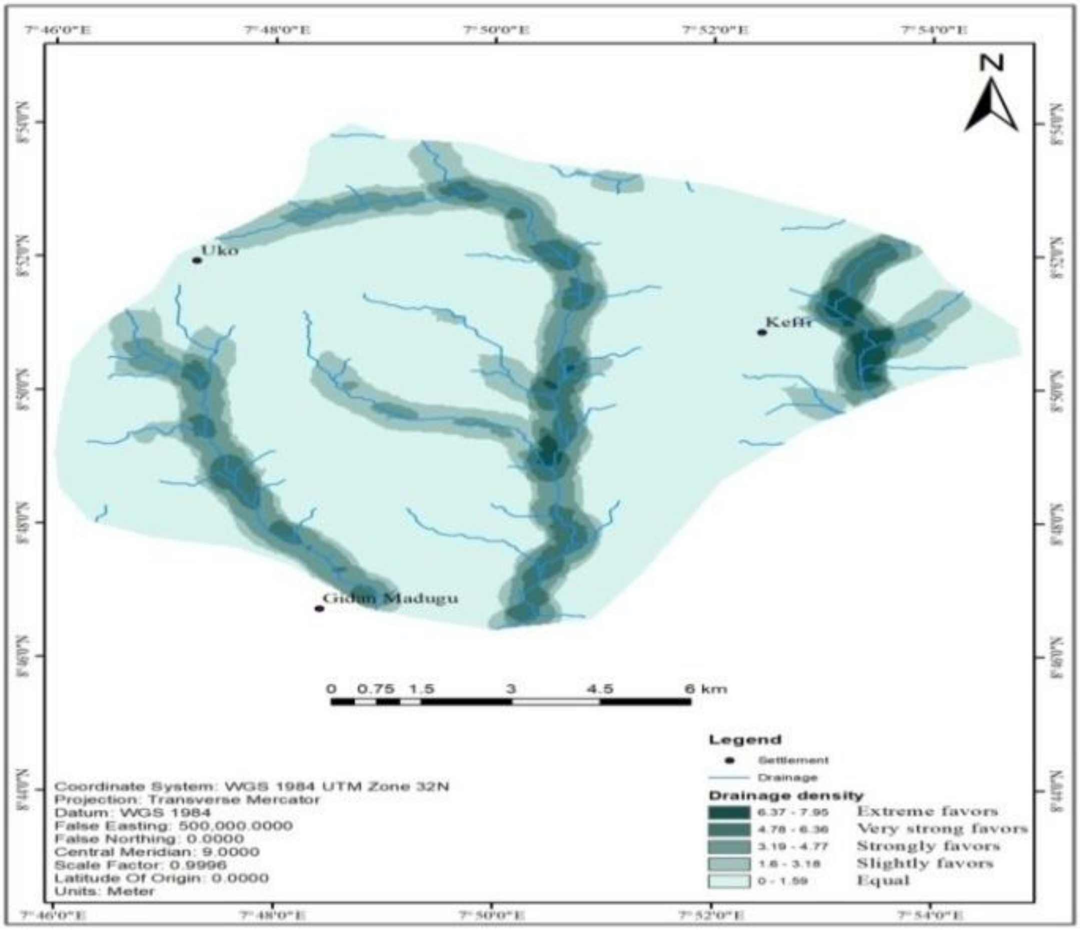

Figure 9: Drainage Density Map
Source: Authors Report

- **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.

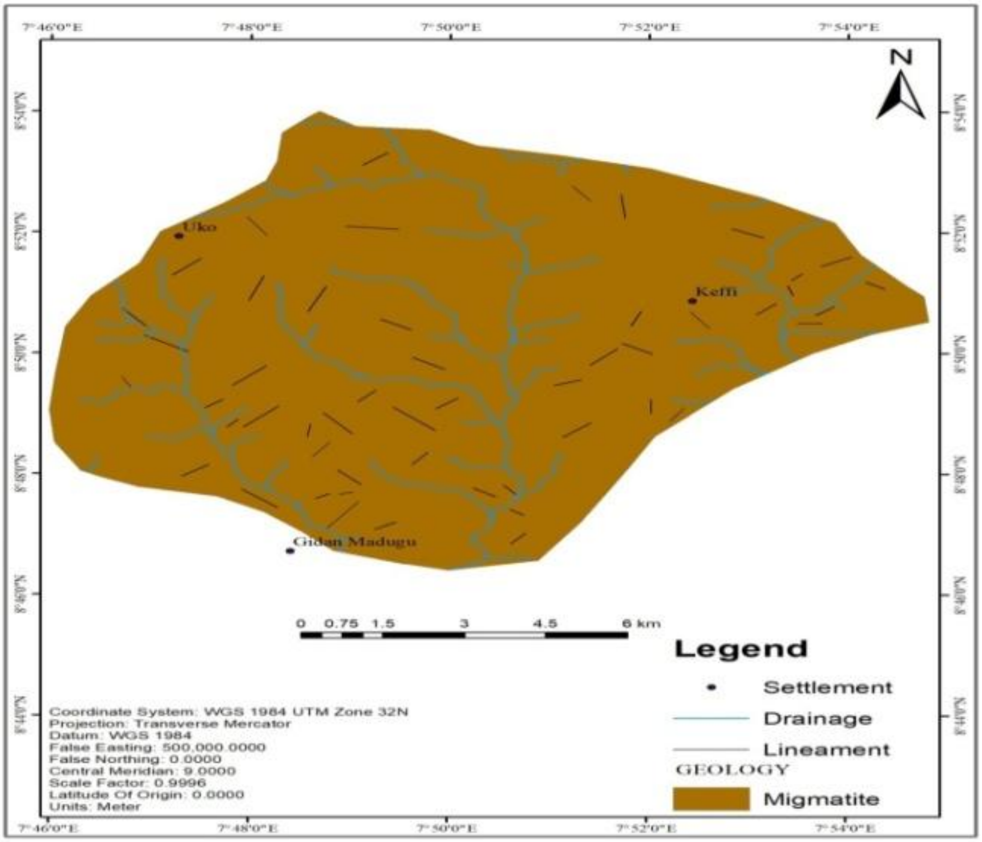

Figure 10: Geology Map
Source: Authors Report

- **LINEAMENTS DENSITY**: This often represents zones of fracturing and increased secondary porosity and permeability. Lineaments are indicative of secondary porosity in the form of fractures and if intersected by a well at depth, have the potential to supply large and reliable quantities of water (Meijerink *et al.,* 2007; Kann and Glenn, 2006). Therefore, it enhances groundwater occurrence and movement. The displayed lineament density map in Figure 11 shows lines of weakness in the study area, and these indicate areas of possible water seepage into the aquifer (underground reservoir of water) which extends across the area. Thus, areas good for groundwater development are regarded as having high lineament density.

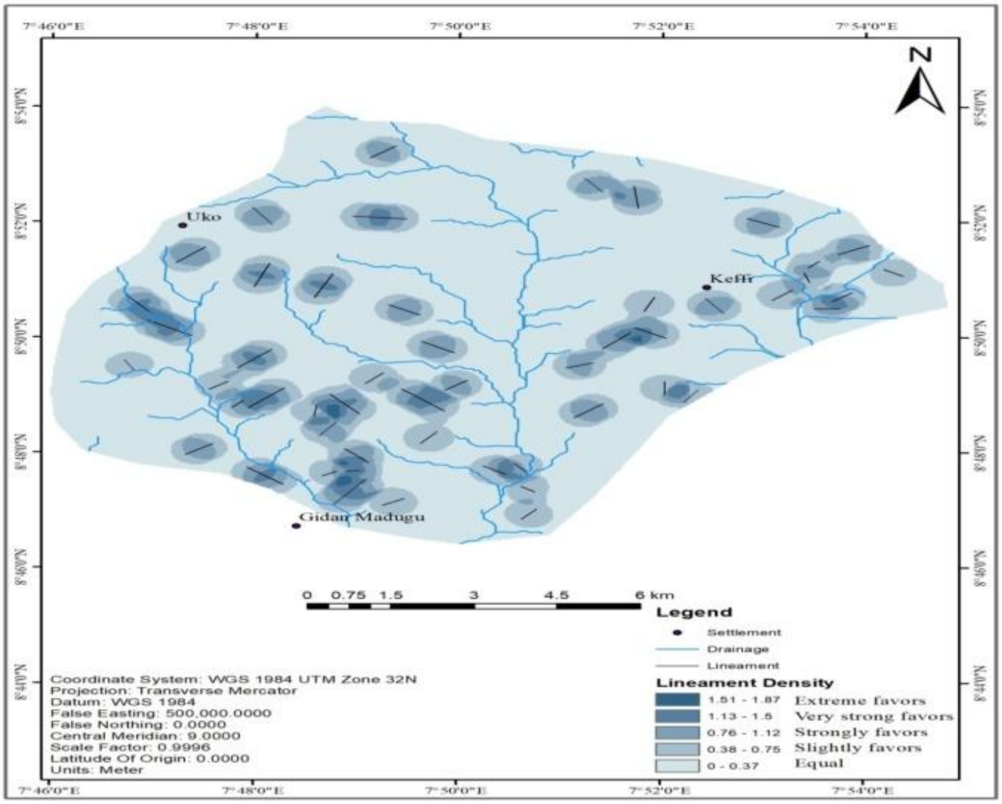

Figure 11: Lineament Density Map
Source: Authors Report

4.3 Groundwater Potential Map

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

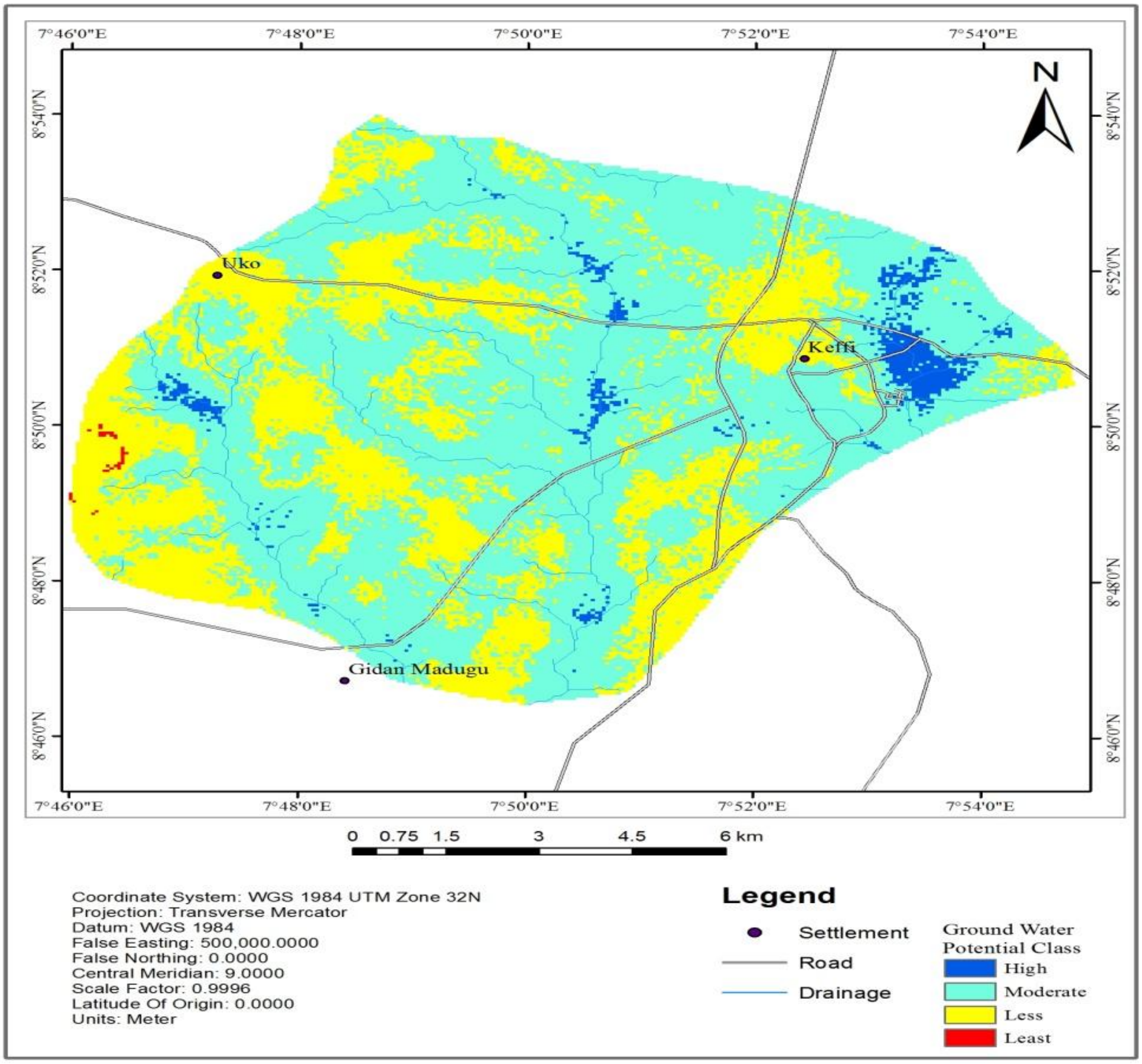

Figure 12: Groundwater Potential Map
Source: Authors Report

Going by the research location, areas represented with the blue colour represents the high groundwater potential zones. This area covers about 2.6% of the total study area. Those in cyan colour depicts the moderate groundwater potential classes, covering about 89.1 km^2 (64.7%) of the area. The less groundwater potential classes cover 44.8 km^2 (32.6%) and the least groundwater potential classes cover 0.1 km^2 (0.1%) of the total study area.

4.4 Groundwater Potential Classes and Borehole Locations

The GIS-based output validating the result of the analyzed groundwater potential classes was done using ground-truthing by selecting the boreholes with their depth attributes randomly at different locations within the study area as shown in Figure 13. The boreholes represented with red colour signifies dry points and these mostly fall within the less groundwater potential classes. The black colour represents the wet points and are mostly found within the moderate groundwater potential classes. These signify that the boreholes are dug based on the availability of water in accordance with the groundwater potentials in the study area.

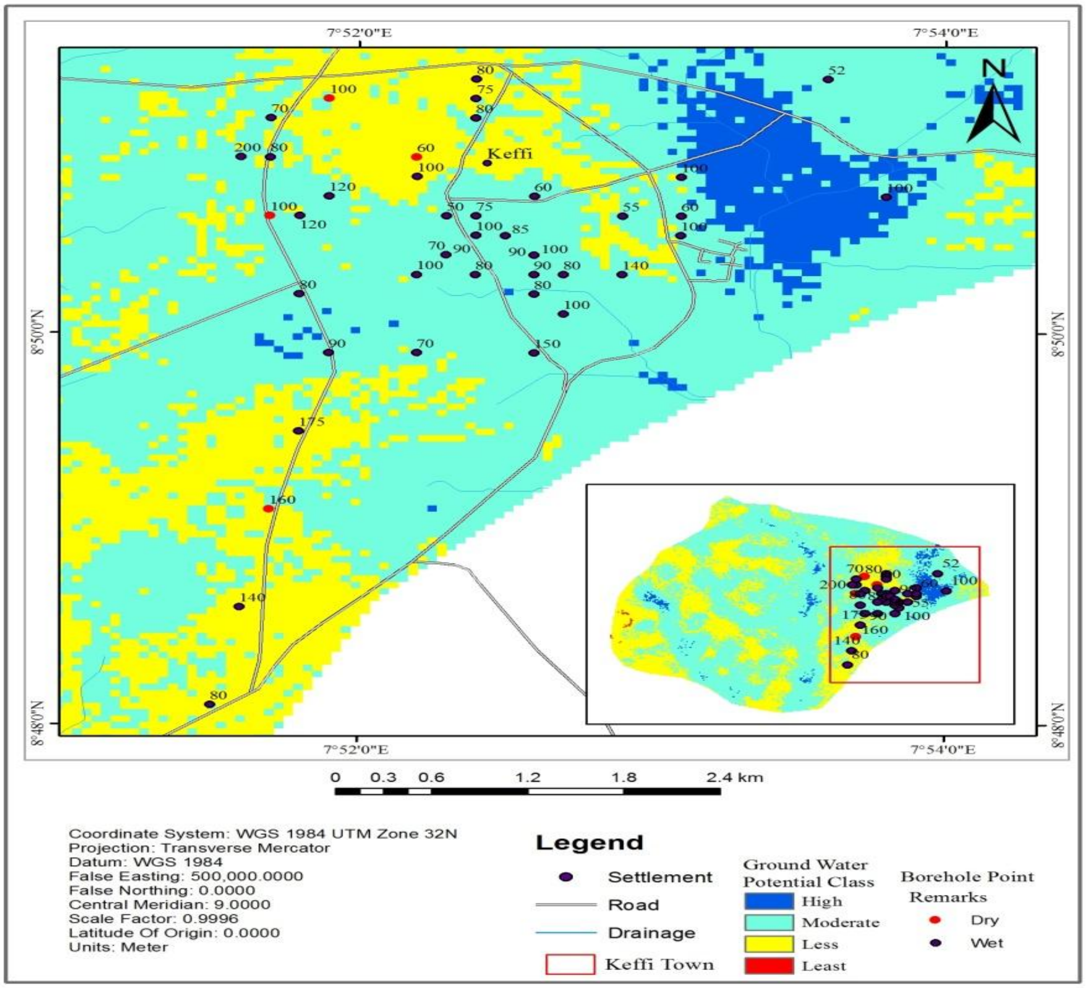

Figure 13: Borehole Locations
Source: Authors Report

4.5 Groundwater Potential Classes and Settlements

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

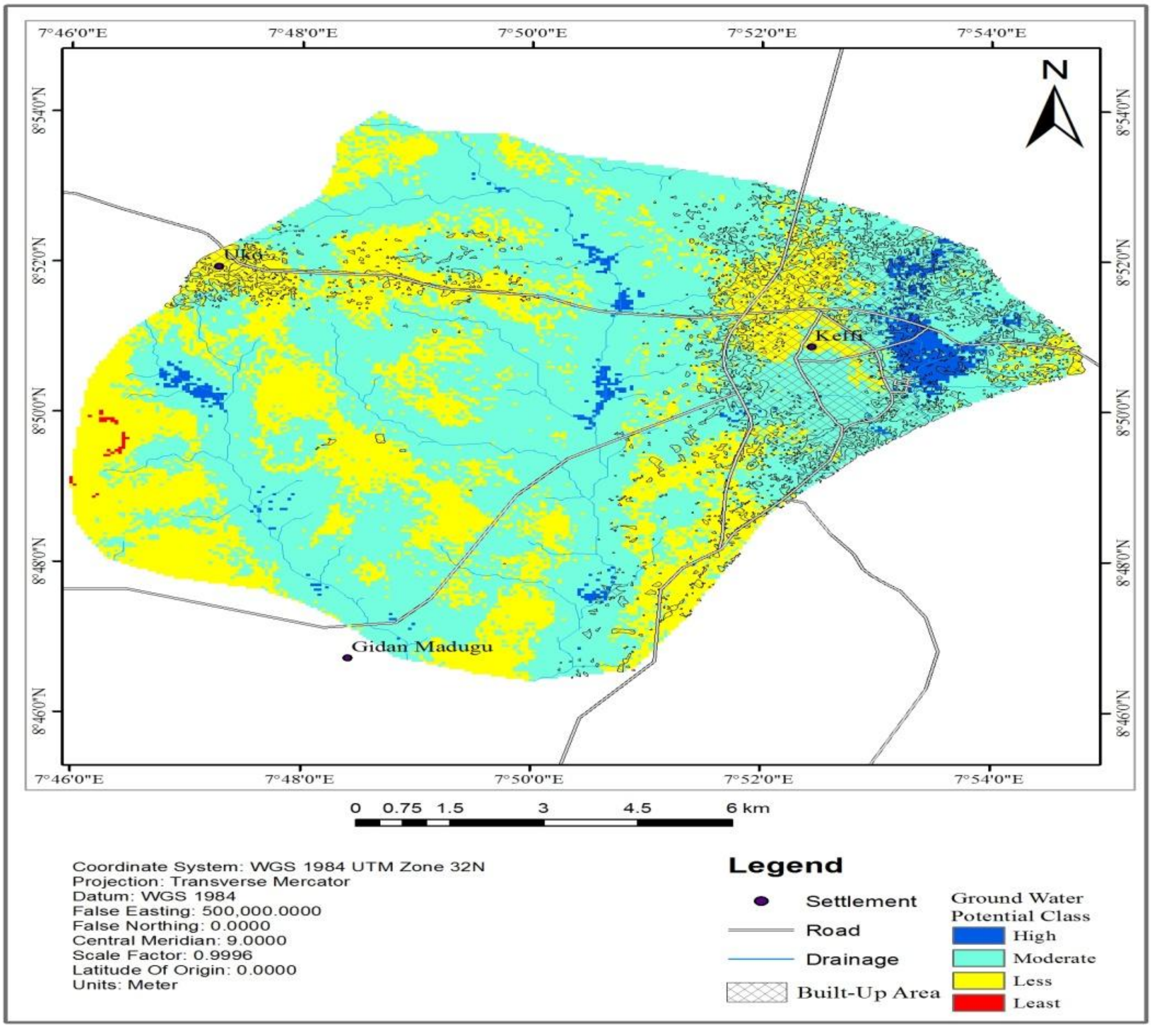

Figure 14: Concentration of Settlements within the Groundwater Potential Classes
Source: Authors Report

5. CONCLUSION

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

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

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

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