International Journal of Geosciences, 2022, 13, 33-53
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Groundwater Exploration Using Multi Criteria Decision Analysis and Analytic Hierarchy Process in Federal Capital Territory, Abuja, Central Nigeria

Jude Steven Ejepu*, Muftau Owolabi Jimoh, Suleiman Abdullahi, Marrietta Adaobi Mba

Department of Geology, School of Physical Sciences, Federal University of Technology, Minna, Nigeria
Email: *ejepu.jude@futminna.edu.ng

How to cite this paper: Ejepu, J.S., Jimoh, M.O., Abdullahi, S. and Mba, M.A. (2022) Groundwater Exploration Using Multi Criteria Decision Analysis and Analytic Hierarchy Process in Federal Capital Territory, Abuja, Central Nigeria. *International Journal of Geosciences*, **13**, 33-53.
https://doi.org/10.4236/ijg.2022.131003

Received: December 22, 2021
Accepted: January 21, 2022
Published: January 24, 2022

Abstract

There exists a growing demand for potable water resources to fill the abysmally insufficient water needs for domestic and industrial especially in the Basement Complex terrains of Nigeria. This situation is attributable to its complex hydrogeologic character. The present challenge has worsened due to the non-incorporation of integrated methods in groundwater exploration campaigns. To effectively combat the challenge of unacceptable failure rates in drilled water well development, there is a need for innovative scientific principles and quantitative assessment of groundwater resources to enhance sustainable and proper utilisation of these resources. Hence, it is the objective of this research to exploit the potential application of remote sensing, Geographic Information System (GIS), and Multi-Criteria Decision Analysis (MCDA) techniques and freely open datasets in mapping groundwater potential zones. Seven thematic maps have been produced based on factors that are deemed to influence and deemed to have significant control on the occurrence and movement of groundwater. These factors are geology, lineament density, slope, drainage density, rainfall, land-use/land cover, and soil class. Analytic Hierarchy Process (AHP) was used to assign normalised weights to the thematic maps based on the various relative contributions to groundwater occurrence and movement. These thematic maps were then processed in a GIS environment using the Weighted Overlay tool which implements the MCDA. The resulting Groundwater Potential Zones (GPZ) of the area gave rise to Five classes viz: Very good, Good, Moderate, Poor and Very Poor representing 19%, 8%, 14%, 47% and 13% respectively. It is recommended that the GPZ map should be used as a reconnaissance tool for selecting prospective sites for detailed groundwater resource exploitation.

Keywords

Groundwater Potential Zones, Multi-Criteria Decision Analysis, Analytic Hierarchy Process, Geographic Information System, Remote Sensing

1. Introduction

Groundwater is an important resource. It is a known fact that without water, life as we know it will not exist. However, due to increase in civilisation and industrialisation, fresh water especially those from surface water resources have been greatly impacted [1]. More so, they are more susceptible to pollution. Another challenge of fresh surface water resource is that it may be in areas that are far from inhabitants, leading to the challenge of going very long distances to obtain this resource [2].

On the other hand, groundwater has the capacity to circumvent these challenges because it is less susceptible to pollution and may be readily available in areas where it is needed the most. However, its availability varies from one place to another [3]. In fact, it is a known fact that communities located within the Basement Complex terrains have the greatest water needs. This is arising from the fact that the hydrogeology of such terrains is complex [4].

Delineating areas where groundwater can successfully be extracted demand that an in-depth knowledge on the nature of occurrence and anomaly interpretation are done in an integrated manner [5] [6] [7] [8]. Poor success rates in water borehole development in Basement Complex regions have been attributed to the non-integration of hydrogeological concepts into anomaly interpretations in borehole sitting [9].

Regional groundwater exploration campaigns in the Basement Complex terrains often target areas where there is considerable thick weathered residuum and densely fractured and jointed subsurface zones [10]. Technological advancements in the sphere of geospatial technologies and its corresponding increase in spatial accuracy have led to the explosion of implementing groundwater research using this tool. Remote sensing and Geographic Information System (GIS) offer integrated and result-oriented platform capable of managing and integrating disparate datasets that have influence on the availability and movement of groundwater [11] [12] [13]. This integration is often done using the Multi-Criteria Decision Analysis (MCDA).

Several techniques have been adopted by various researchers that do not require fieldwork in mapping groundwater potential sites. These include the decision-tree model [14], Principal Component Analysis (PCA) [15], and the logistic-regression model [16]. Most of these methods are based on multivariate statistical techniques [17]. In contrast, the analytical hierarchy process (AHP) is a simple, effective, transparent, and reliable technique [18]. The AHP method is easy to identify in a useful way by integrating geographic information system

(GIS) and remote sensing (RS) data. Groundwater parameters such as precipitation, aquifers, land use, and soil type can easily be defined as spatial data in a GIS environment. Analytical hierarchy process (AHP) is the most used MCDA method. AHP has recently found application in several fields of geology and more importantly in groundwater-related studies and has performed satisfactorily, especially in delineating groundwater potential zones [4] [7] [19] [20] [21] [22] [23].

Groundwater forms the major source of domestic and industrial water for the inhabitants of the Federal Capital Territory (FCT), Abuja. A lot of the inhabitants of the territory especially those in the suburbs lack sustainable access to this resource [24]. These areas show a rapidly growing population trend because of urban migration which has exacerbated the shortages in supply in the area. This situation has necessitated the need to explore groundwater resources to solve this menace.

In this research, the GIS-based AHP-MCDA method was used to produce groundwater potential zone map of the Federal Capital Territory, Abuja using meteorological, hydrological, and hydrogeological characteristics without drilling water wells (test drilling) in the area. In this study, the ArcGIS 10.8.1 program and extensions such as spatial analyst and Archydro tools were used to define groundwater potential. Seven criteria that affect groundwater discharge, namely geology, lineament density, slope, drainage density, rainfall, land-use/land cover, and soil class were considered. The relative weights of each criterion were determined by the AHP-MCDA method in a GIS environment. Groundwater Potential Zones (GWPZ) map of the area was produced as an outcome of the result of this study. This map would form a significant source of information database that can help water-resource managers to make accurate management plans and much better use of groundwater resources.

2. Materials and Methods

2.1. Study Area

The Federal Capital Territory (Abuja) is bounded by Latitudes 8˚25'N and 9˚20'N and Longitudes 6˚45'E and 7˚39'E. It is strategically located at the central portion of the Nigeria landmass and covers an area of approximately 7,315 km^2. The study area is characterized by two major seasons; the rainy season with an onset around April and lasts till October and a dry season that begins around November and terminates around March [25]. The prevailing weather conditions of the study area are chiefly governed by its undulating topography and the high altitude. The lowest elevation of 76 m (above sea level) which marks its floodplains is located at the extreme south-west. The highest elevation is in the north-western portion of the territory and is marked by peaks with elevation of 760 m (above sea level) (**Figure 1**). The dry season peaks in March with recorded average temperatures in the range of 30˚C-37˚C, while lower temperatures are recorded in the rainy season because of dense cloud cover. FCT records relatively low humidity during the dry seasons usually in the afternoon at higher

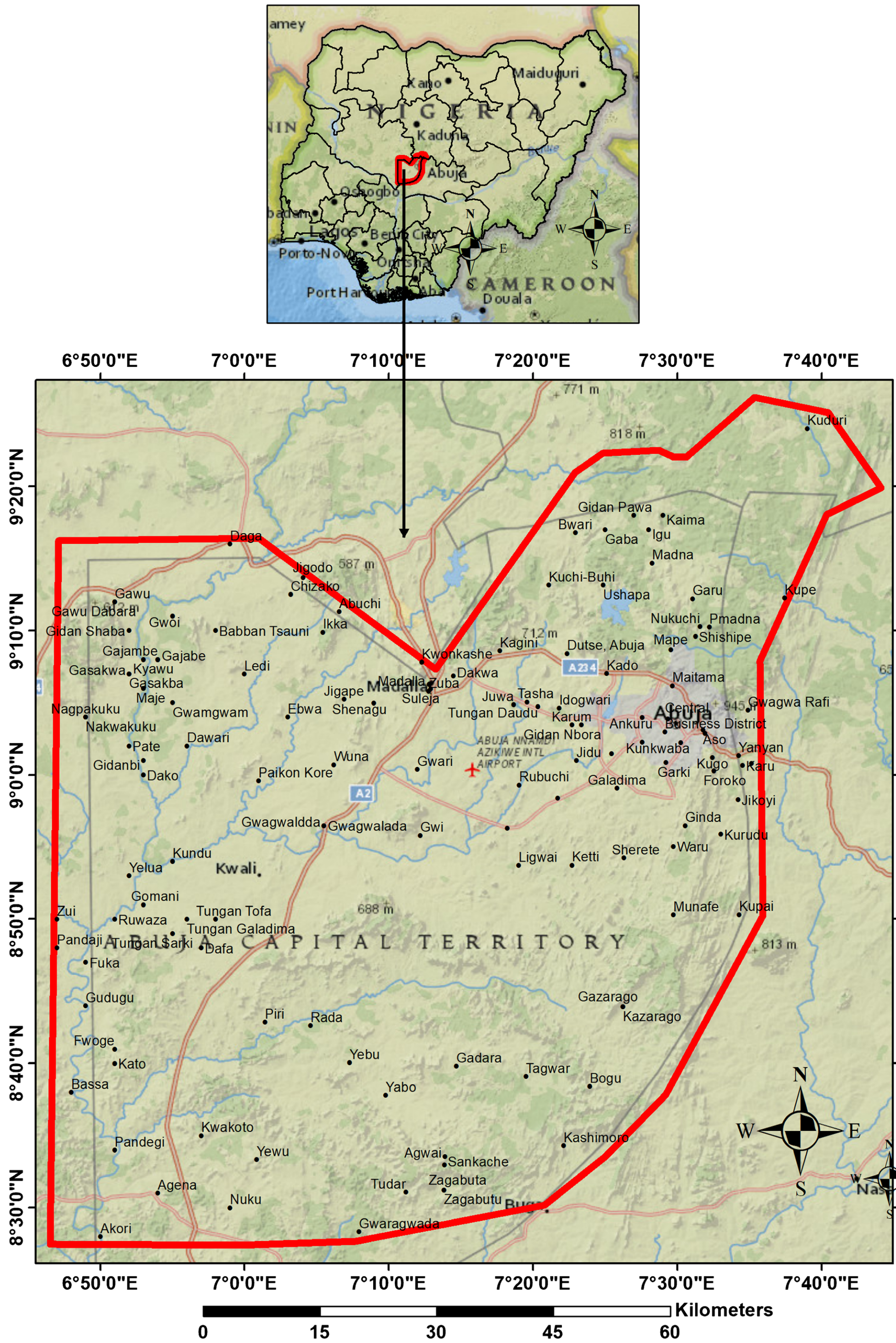

Figure 1. Location map of the study area.

elevations.

2.2. Geology

The study area lies within the Basement Complex Terrain of Nigeria. It forms part of reworked West African Craton which underlies about 60% of Nigeria's land mass [26]. The Basement complex has been described by [27], as a heterogeneous assemblage, which includes migmatites, gneisses, schists, and a series of basic to ultrabasic metamorphosed rocks. Pan African Granites and other minor intrusions such as pegmatite and Aplites dykes and quartz veins have intruded these rocks [28]. Four major lithologic units are recognisable in the area. These include the Nupe sandstones of the Bida Basin, the Older Granites, the Metasediments/Metavolcanics, and the Migmatite-Gneiss Complex [29] [30] [31].

The older granites are pre-, syn- and post tectonic rocks that cut across and have intruded the Migmatite-Gneiss Complex. Their age ranges from 750 - 450 Ma and display magmatic cycles which are associated with the Pan-African Orogeny [32]. The older granite rocks include coarse porphyritic biotite and hornblende granite with sharp contacts with pegmatite and gneiss where they are exposed.

The metasediments/metavolcanics consist of quartzite, amphibolite, schist and phyllite considered to be Upper Proterozoic in age. They display a series of textures ranging from fine to coarse grains clastics, pelitic schist, dolomitic marbles and mafic metavolcanics consisting mainly of the amphibolites.

The Migmatite-Gneiss Complex comprises of the most varied rocks in the basement complex. The group of rocks are referred to as Basement Complex *sensu stricto* comprising of migmatites, orthogneisses, paragneisses, clac-silicate rocks and biotite hornblende schist [27] [28]. These rocks have assigned ages ranging from Pan African to eburnean [29]. The south-western portion of the FCT is composed of the Bida Sandstone Formation it consists of arkoses, feldspathic sandstone, and sandy siltstone [30]. A braided stream environment was described as the environment of deposition. Alluvial deposits of gravel, coarse and fine sand, silt, and clay can be found in some areas around south-western portion of the territory. The sandstone units are frequently cross stratified, generally poorly sorted and composed mainly of quartz and feldspars displaying textural and mineralogical immaturity. The general characteristic of this sequence is fining upward character, compositional and textural immaturity and unidirectional paleocurrent trend which suggest a fluvial depositional environment dominated by braided streams with sands deposited as channel bars consequent to fluctuating flow velocity.

The lithologic units in the area are characterised by two major fracture orientations: the NE-SW and NW-SE [32]. These sets of fractures are parallel to the Schist Belts of Nigeria and the Cretaceous Bida Basin, controlling the drainage and flow directions of surface water sources in the area. The presence of these sets of fractures in the crystalline rocks have been attributed to act as good indicators of groundwater sources where hand-dug wells, tube wells and drilled wells can be exploited for the supply of potable water and for agricultural and industrial purposes [33] [34]. The dominance of and orientation of these structures imply a good indication for a high potential for the availability of groundwater resources. However, is important to note that the width of the fractures seems to decrease with increasing depth, with accompanying deeply weathered and unconsolidated regolith materials containing numerous pore spaces that serve as conduits for rainfall infiltration. The thick regolith materials are capped by laterites and alluvial deposits in some locations. Water from torrential rains during the wet season usually infiltrates into the deeply weathered regolith, which in turn stores and transmits it to deeper reservoirs [35] [36].

2.3. The Hydrogeological Setting of the Study Area

Crystalline basement rocks only become aquiferous after weathering and fracturing of the rock units. This is because they lack intrinsic primary porosity and permeability. The ancient land, when exposed to prolonged weathering could result in the formation of a mantle of alteration products. This regolith includes both the residual soil and the saprolite [37].

There exists a large variation in the occurrence, movement, distribution, recharge-discharge mechanisms, and quality of groundwater in these aquifers. In some cases, even boreholes situated at very close proximity, having same lithology, exhibit these variations [38].

These variations are caused by a complex interplay of independent and interrelated factors both on local and regional scales [39] [40]. These factors include geomorphological, lithological, climatological, hydrogeological and hydrogeochemical [37] [41] [42].

Literature review have revealed that the weathered regolith in the area varies in thickness from 2 m or less to as deep as about 45 m in places [43]. Similar characteristics have been reported by [36] [44] [45]. Some workers have reported that the basement complex portion of the study area have static water levels between 2 m and 15 m. Hand-dug wells usually exploit the top 5 to 20 m of the upper horizon within the weathered overburden, producing water with moderate yields, especially during the wet seasons. Furthermore, analysis of up to 184 boreholes drilled during a rural water supply drilling programme under the China-Nigeria co-operation shows that yields from these boreholes vary between 0.7 and 3.2 m^3/h [46].

Several of these wells either dry up or produce extremely low yields in the dry season. While the yields of drilled wells may produce variable yields, the lower aquifer horizon usually produces comparatively more prolific yields, this is due to the interconnection of the fracture systems that serves as transmission pathways on a regional scale. However, in borehole drilling campaigns in the Basement complex terrains, the ultimate target remains the fractured bedrock [47] [48]. The lithologic units in the Bida sandstone formation of the study area range from conglomerates, fine to coarse grained sandstones and siltstones. However, aquiferous zones are delineated between 60 m and 120 m within the sands and sandstone beds.

2.4. Data Acquisition

The GIS-MCDA is an important evaluation tool implemented in a GIS environment that is capable of handling different and disparate criteria, simplifying the process of solving problems involving multiple criteria [4] [49]. The Spatial Analyst extension of the ArcGIS 10.8.1 [50] was utilised for the implementation of the model. The analysis was performed using the Spatial Analysis and Weighted Overlay tools considering the relative values and weights that were derived from the AHP computations using a template by [51] and finally interpolating the reclassified thematic maps, thus producing the final GPZ map.

To produce the groundwater potential map of the study area, the parameters were taken into account and their relative weights were determined by the AHP method. Geologic map of the area was digitised from the geologic map of Nigeria as produced by the Nigeria Geological Survey Agency using the coverage shapefile of the FCT. This was followed by conversion of this layer to a raster format with their respective geological units, these were then reclassified according to their relative importance in groundwater holding capacities.

Shuttle Radar topography Mission (SRTM) Digital Elevation Model (DEM) was downloaded from https://dwtkns.com/srtm30m/. It is a web interface that attempts to ease the pain of downloading 30-meter resolution elevation data from the Shuttle Radar Topography Mission. The data are in form tiles which come as zipped SRTM HGT files at 1-arcsecond resolution (3601 × 3601 pixels) in a latitude/longitude projection (EPSG:4326), downloaded from NASA servers.

This SRTM DEM was used to extract parameters that have a relation to groundwater availability. These are the drainage, slope, and surface lineaments. Drainage lines were extracted using the ArcHydro tools of ArcGIS and subsequently used to produce the drainage density thematic map using the line density tool of ArcGIS. Drainage density was determined using:

$$\mathrm{DD} = \sum_{i=1}^{n} \frac{D_i}{A} \quad (1)$$

where DD = Drainage density, D_i = drainage length, i = lineament number, and A = area.

The ArcHydro tool consists of a data model, toolset, and workflows developed to support specific GIS implementations in water resources. It helps to build a foundational dataset that can be used in water resources analyses and for integration with water resource models. It standardizes water data structures so that data can be used consistently and efficiently to solve water resource problems at any spatial scale [52].

To extract lineaments from SRTM DEM, shaded relief maps were created using different sun azimuth values and elevation angles. The LINE module of PCI Geomatica software was used to automatically extract lineaments in various shaded relief maps. LINE extracts linear features from an image and records the polylines in a vector layer. Although this module is designed for extracting lineaments from radar images, it can also be used on optical images to extract curve-linear features [53]. The value used for sun elevation angle was 25˚, while for azimuths 45˚, 135˚, 225˚, 270˚, 315˚. The extracted lineaments were subsequently combined to form a composite of lineaments for the study area. Further analysis on the lineaments involved presentation of results as statistical and spatial plots. Lineament density thematic map was produced using the line density tool of ArcGIS. Lineament density was determined using:

$$\mathrm{LD} = \sum_{i=1}^{n} \frac{L_i}{A} \tag{2}$$

where LD = lineament density, L_i = lineament length, i = lineament number, and A = area.

Slope which is an indication of the topographic setting of an area, defines the relationship between local and regional relief conditions of the area. Slope governs the effect of gravity on the movement of water, hence, gives an idea about the general direction of groundwater flow and its influence on groundwater recharge and discharge [54]. The slope amount map (in degrees) was prepared using SRTM DEM data.

Fifteen (15) years monthly rainfall data (ISO 90001:2015 certified) of the FCT from 2006 to 2020 was acquired from Nigerian Meteorological Agency (NIMET). This data was interpolated using the Inverse Distance Weighting (IDW) and subsequently producing the precipitation map of the area. In partnership with Microsoft AI for Earth and ESRI, Impact Observatory released a new and the first 10-m high-resolution Land Use/ Land Cover (LULC) map for the whole world. The data uses imagery from Sentinel-2 in the year 2020 which was freely downloaded from the ESRI portal. It was clipped to the study area and used for this research (http://www.livingatlas.arcgis.com/landcover).

The newest digitized version of the "Soil Map of the World" (SMW) is classified according to the "World Reference Base for Soil Resources" (WRB). The WRB is the international standard taxonomy soil classification system, developed by the "International Soil Reference and Information Centre" (ISRIC), the "International Union of Soil Sciences" (IUSS) and the "Food and Agricultural Organization" (FAO) for the first Soil Map of the World in 1988. The vector data set is based on the FAO-UNESCO "Soil Map of the World" [55]. The soil map of the study area was extracted from this dataset.

2.5. Criteria Weight Assignment

Implementation of AHP in MCDA is a very popular method used in assigning weights to different influential factors according to their relative importance. Saaty's scale [56] of 1 - 9 of comparative rating was adopted for relative comparison (**Table 1**). To assign meaningful weights to the different parameters, other sources of information such as previously published research were analysed, and personal consultations were made to further constrain the information acquired.

Subsequently, all the parameters were compared on Saaty's scale, and relative weights/scores were given accordingly using a template developed by [51]. It is a free web based AHP solution supporting tool for complex decision-making

Table 1. Saaty's scale for pairwise comparison [56].

Intensity of influence	Explanation
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6 and 8 are the intermediate values	

processes. A pairwise comparison matrix is generated to compute further eigenvector, consistency ratio, and normalized weight. The consistency index and consistency ratio are computed by using the Equations (3) & (4) since according to Saaty's pairwise comparisons are consistent with the value < 0.10 [57].

$$\text{CI} = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \tag{4}$$

where, CI is the consistency index, $\lambda_{\max}$ is an eigenvalue, n is the number of influencing criteria, CR is the consistency ratio, and RI is the random index with value of 7%.

$$\text{GWPZ} = \sum_{i=1}^{m} \sum_{j=1}^{n} M_i \times R_j \tag{5}$$

where, M_i = normalized weight of the ith criteria layer, R_j = normalized weight of the jth class of criteria layer, m & n = total number of criteria selected and the total number of classes in each criteria layer respectively.

3. Result and Discussion

3.1. Results

3.1.1. Geology

Lithologic composition of an area is an important factor in the occurrence and distribution of groundwater. This is because it controls infiltration rate and flow of precipitation [31] [58] [59]. The geological map (**Figure 2**) of the study area shows a range of lithologic units spanning the geological timescale from the Cretaceous to Upper Proterozoic, Precambrian, Liberian (ca 2800 Ma) to Pan African (ca 600 Ma). These rocks have been grouped into five classes namely: schist, migmatite, gneiss, granite, and sandstone. They occupy an approximate area of 16%, 24%, 19%, 27% and 14% respectively. Precambrian lithologies that underlie the study area are characterised by low to moderate yielding aquifers [31]. However, regolith and fractures are the main aquifers which can store and transmitting groundwaters in a metamorphic terrain [4].

Cretaceous sediments have better productivity due to their possession of intergranular permeability and sometimes may produce extensive aquifers [31].

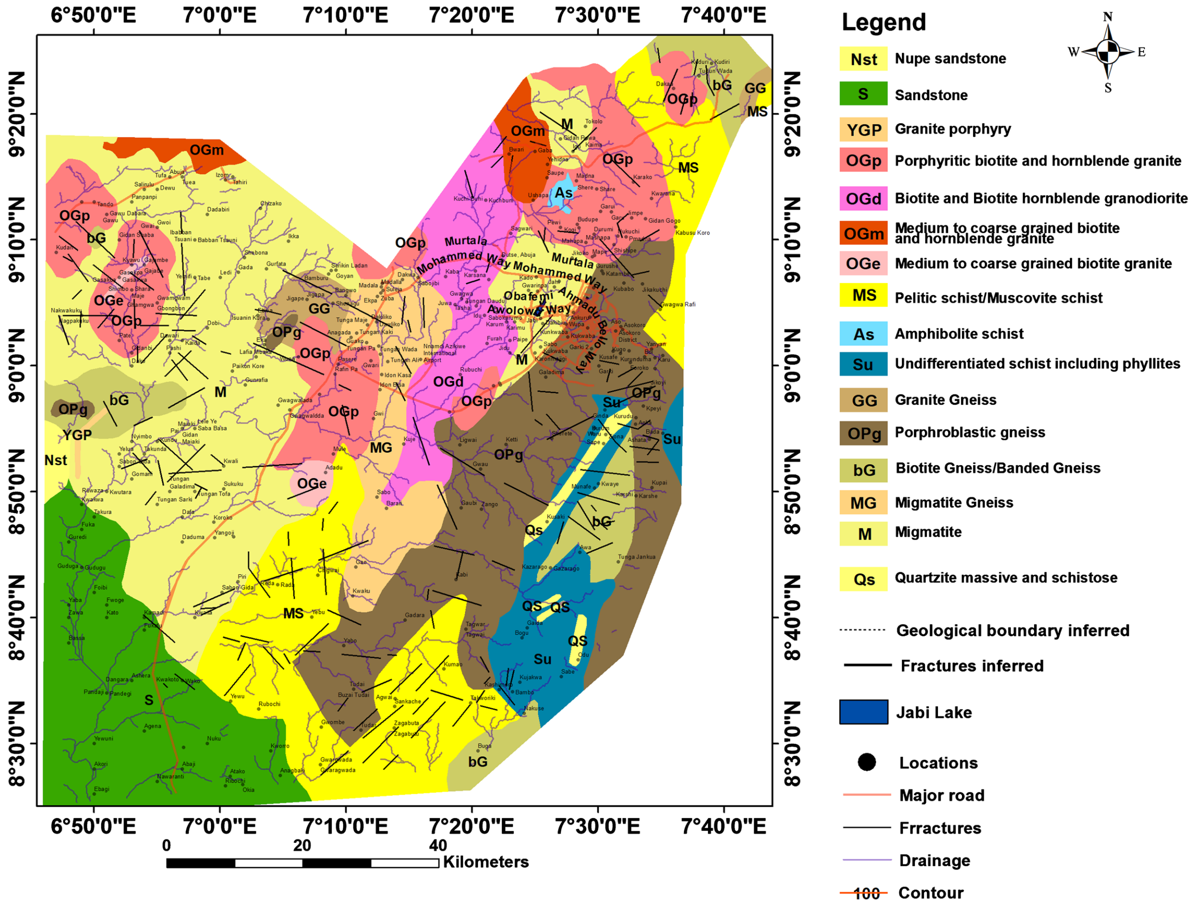

Figure 2. Geologic map of the Federal Capital Territory, Abuja (NGSA, 2010).

The granites have moderate to poor groundwater potential because they lack primary porosities to make them good aquifers. However, if fractured and weathered to some considerable extent, they could yield good amounts of water [7]. The weights assigned during the reclassification of the thematic maps considered the characteristics of the hydrogeological units.

3.1.2. Lineament Density

In the prediction of groundwater potential zones in Basement Complex terrains, lineaments play huge roles in that regard. The presence of these linear features and fractures on crystalline rocks usually indicative of the presence of good groundwater storage. Lineaments may also be used to delineate areas having thick weathered horizons. Therefore, high lineament densities have been given relatively higher groundwater potential scores. The varying density values are grouped into five categories from very low to very high density using the Equation (2). The distribution of lineament densities has been classified into five viz: 0 - 1, 1.1 - 3, 3.1 - 5, 5.1 - 7 and 7.1 - 12.2 km/km^2 (**Figure 3**).

3.1.3. Rainfall

The chief source of groundwater is from rainfall (precipitation). Hence, it is one of the most important groundwater parameters. As shown in **Figure 4**, the mean

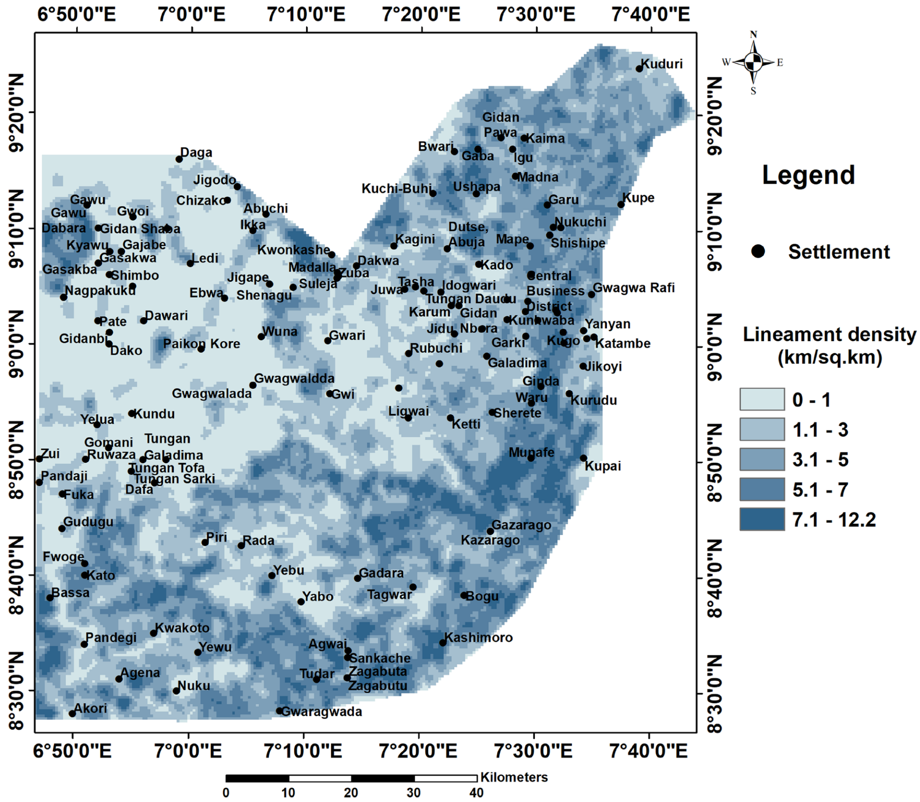

Figure 3. Lineament density of the Federal Capital territory, Abuja.

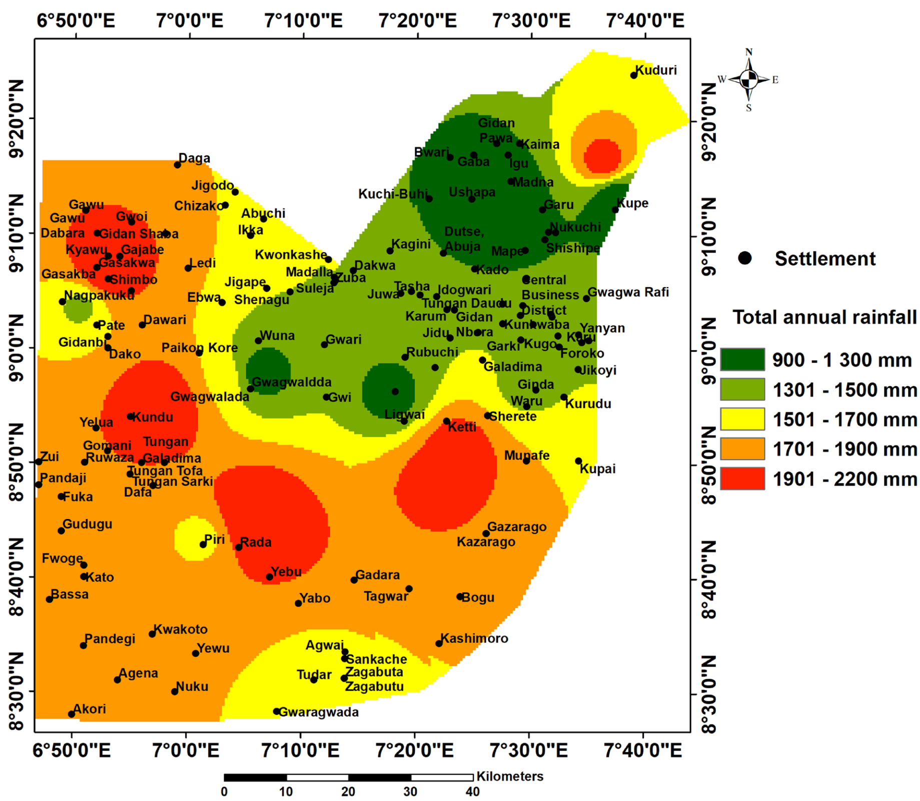

Figure 4. Total annual rainfall distribution of the Federal Capital territory, Abuja (NIMET, 2020).

annual rainfall ranges from 900 - 2200 mm/year. Since the amount of rainfall is an important hydrogeological parameter, playing a significant role in infiltration, a higher weight was given to higher rainfall rate classes [60].

3.1.4. Drainage Density

Drainage density plays a role in groundwater infiltration and accumulation. It is an inverse function of permeability [61]. Areas having higher drainage densities are associated with less infiltration of water to the ground, which consequently leads to higher surface runoff [62]. This is evident from Figure 5 as hilly regions and closely spaced streams have higher drainage densities as compared to other areas. Hence, areas having lower drainage densities can allow more infiltration of water to the ground. This consequently leads to lower run off. Evaluating the drainage system of the area revealed that the drainage system of the area may be structurally controlled as many drainage lines followed lineament orientations.

3.1.5. Slope

Slope of an area is a major factor controlling infiltration of precipitation. Hence, it is an important hydrological parameter in delineating groundwater potential zones [63]. Areas having low slope amounts are deemed to have more infiltration into the ground because of less surface flow. Increase in slope amounts in the area leads to an increase in surface flow resulting into less ground infiltration. Figure 6 show that the slope amounts range from 3 degrees to 70 degrees.

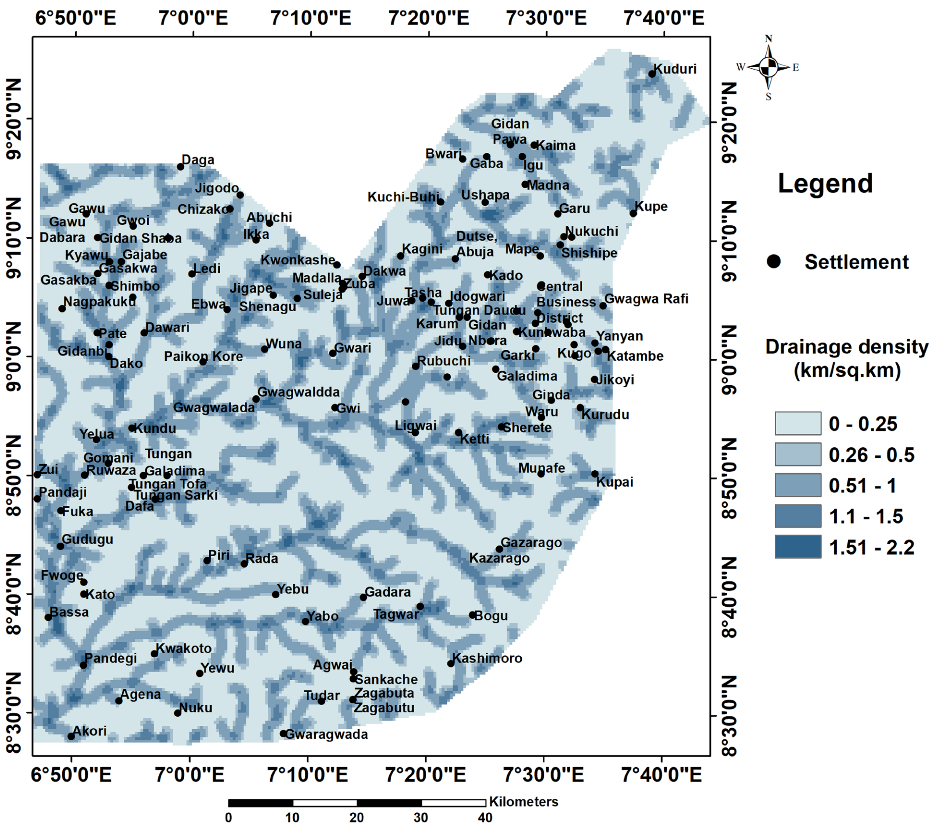

Figure 5. Drainage density of the Federal Capital territory, Abuja.

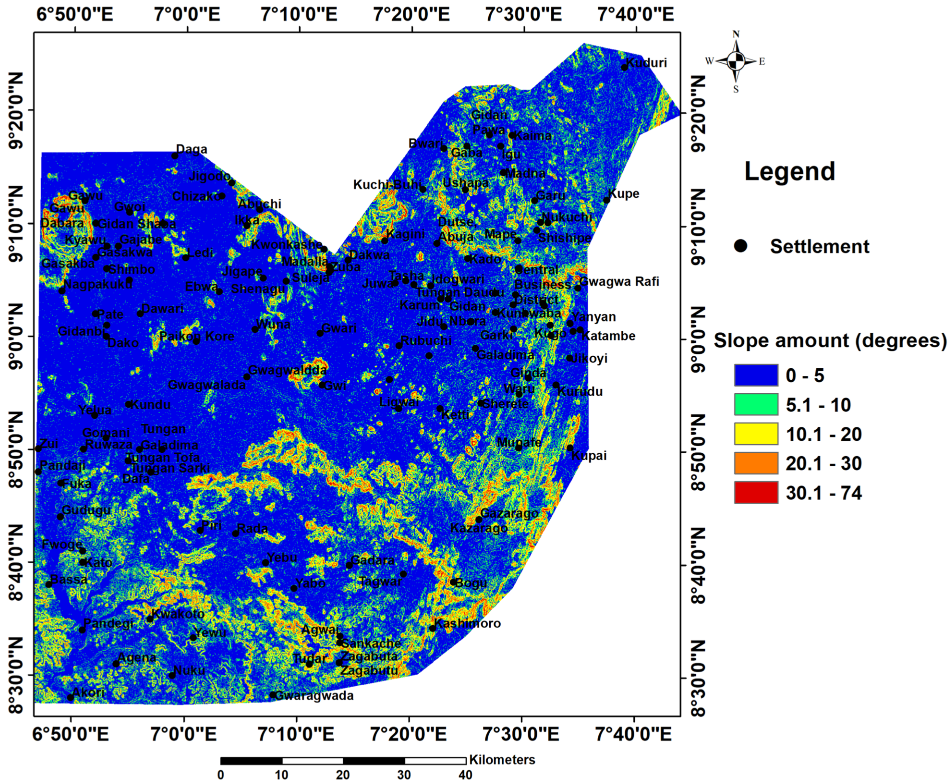

Figure 6. Slope amount (degrees) of the Federal Capital territory, Abuja.

The slope classes of 0 - 5, 5 - 10, 10 - 20, 20 - 30 and above 30 degrees have been used to classify the slope of the study area Areas having the ideal slopes amounts necessary for groundwater accumulation occupy about 70.86% of the area.

3.1.6. Land Use/Land Cover

Land use and land cover are directly linked to percolation and infiltration of rainfall into the subsurface. Hence, the availability and movement of groundwater depends on the nature of land use and land cover in the area [64] [65]. One of the major factors of urbanisation is construction of houses, roads, and other engineering structures, these have the consequence of blocking the paths of groundwater percolation and infiltration. Wetlands and water bodies on the other hand, are considered to have enhance the process of percolation and infiltration. Hence, the highest evaluation scores were assigned to these features. Land use classes delineated from the study are water, trees, grass, flooded vegetation and crops. Others include scrub/shrub, built area and bare ground (**Figure 7**).

3.1.7. Soils

Four soil classes are distributed across the study area. These include Lithosols, Ferric Luvisols, Plinithic Luvisols and Distric Nitosols (**Figure 8**). Weights assignment for the soil class was made subjectively to each soil class its water-holding capacity. Soils, such as Lithosols have good water-holding capacities and have been assigned higher weightings. Distric Nitosols have moderate water

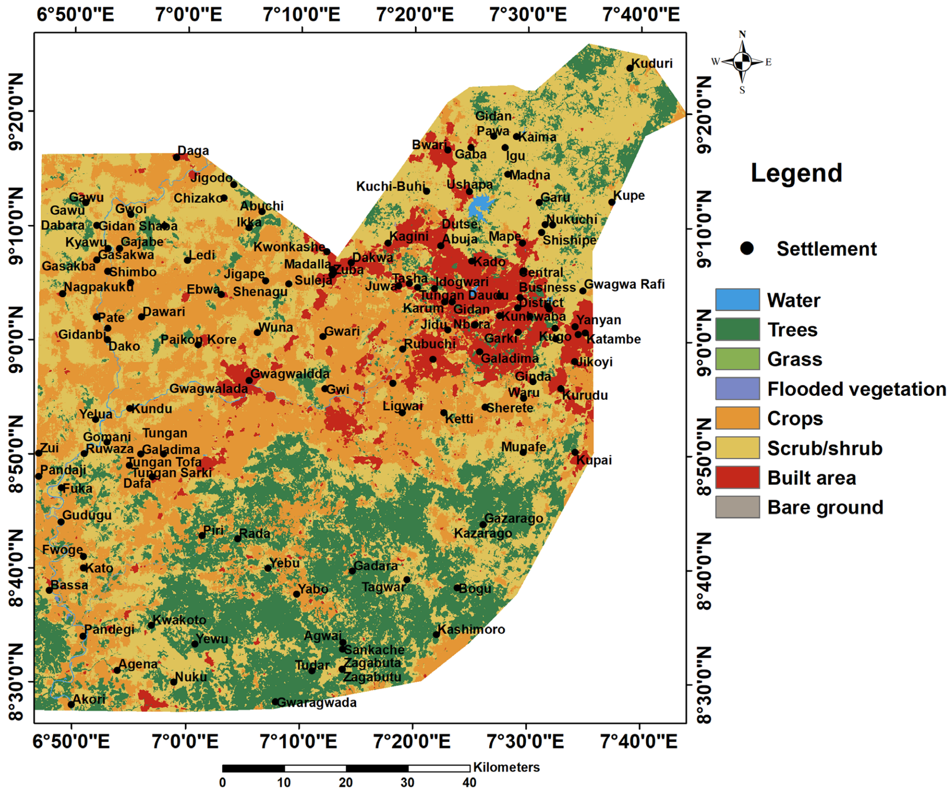

Figure 7. Land use/Land cover classes of the Federal Capital Territory, Abuja.

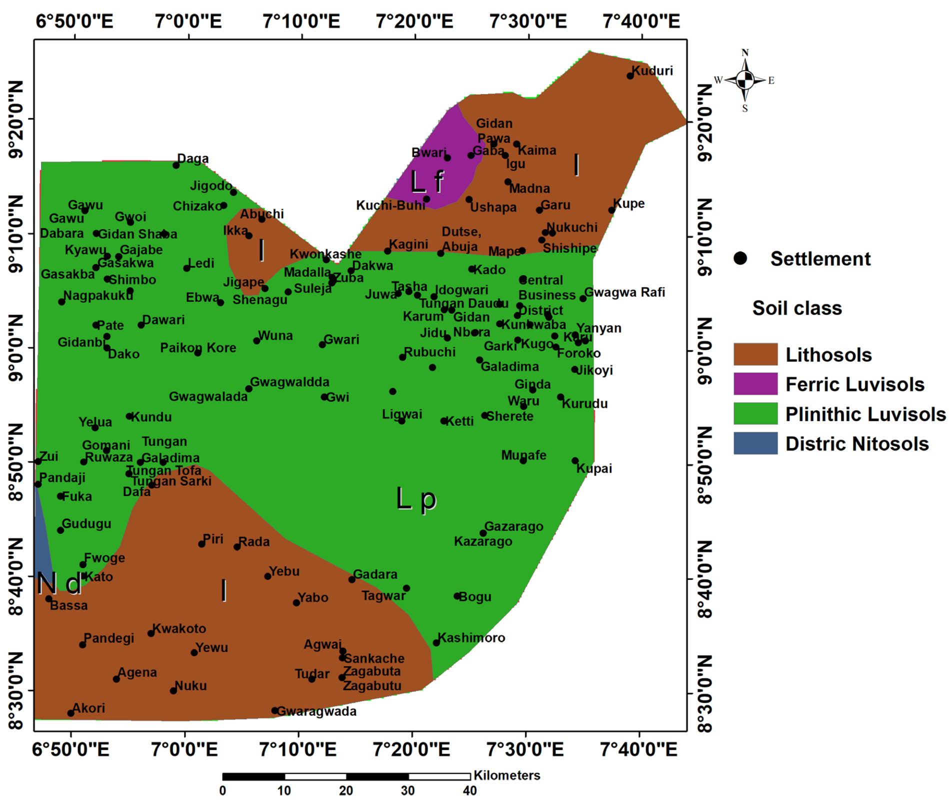

Figure 8. Soil map of the study area (Source: http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/).

holding capacity. Both Plinithic and Distric Luvisols were considered to have poor water holding capacities. These were consequently assigned comparatively lower weights.

3.2. Discussion

MCDA implemented using GIS provides the necessary flexibility and objectivity in delineating groundwater potential zones. However, there exist some level of subjectivity in selecting appropriate thematic criteria that is deemed to have different levels of controls in the availability and movement of groundwater. This subjectivity may come from experience, knowledge of the local hydrogeology and expertise in choosing and assigning different weights to different criteria. The final map product is a direct reflection of both the number of criteria choses and the weights assigned to different thematic maps.

However, the application of AHP before using the GIS-based MCDA tool allows for a technically correct and acceptable weight assignment by ensuring that the consistency ratio of the various assigned weight is less than 10% [57]. The AHP tool used in this study [51], allowed for accurate weight assignment of different criteria, and enhanced the use of this tool in terms of theoretical structure, clarity, and ease of use [59]. It is important that verification of the GPZ map is field checked and corrected for inconsistencies before the final map is produced (**Table 2**).

In this research, five groundwater potential zones have been delineated. These are "Very Good", "Good", "Moderate", "Poor" and "Very Poor" (**Figure 9**). "Very Good" to "Good" zones are spatially distributed in the south and to a very small extent, in the NNE side of the study area. These areas are strongly correlated to lithology where it exhibits a higher level of primary porosity and due mainly to the availability of sandstones in the region. Also, areas of high lineament

Table 2. Pairwise comparisons used to calculate thematic priorities using the Analytic Hierarchy Process tool [51].

Priorities					**Decision Matrix**							
Criteria	**Priority**	**Rank**	**(+)**	**(−)**		1	2	3	4	5	6	7
Geology	44.1%	**1**	13.1%	13.1%	1	1	3.00	7.00	9.00	3.00	9.00	9.00
Lineament density	21.1%	**2**	6.8%	6.8%	2	0.3	1	3.00	5.00	2.00	3.00	9.00
Slope	6.4%	**5**	2.7%	2.7%	5	0.1	0.3	1	1.00	1.00	1.00	1.00
Drainage density	7.3%	**4**	2.9%	2.9%	4	0.1	0.2	1	1	1.00	2.00	3.00
Rainfall	12.5%	**3**	6.2%	6.2%	3	0.3	0.5	1	1	1	3.00	9.00
Land Use/Landcover	5.7%	**6**	2.4%	2.4%	6	0.1	0.3	1	0.5	0.3	1	4.00
Soil	2.9%	**7**	1.7%	1.7%	7	0.1	0.1	1	0.3	0.1	0.3	1
Number of comparisons = 21					**Principal eigen value = 7.561**							
Consistency Ratio (CR) = 0.07					**Eigenvector solution: 6 iterations, delta = 1.4E−9**							

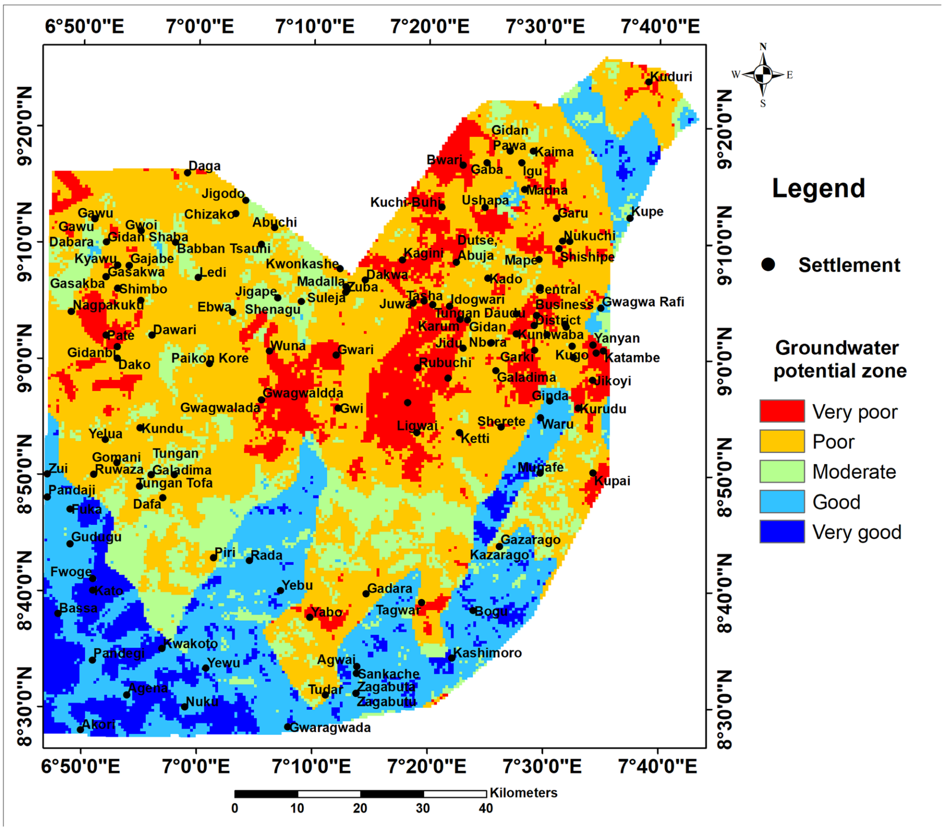

Figure 9. Groundwater potential zone map of the study area.

and low drainage densities have shown to occupy the "Good" to "Moderate" classes. This reflects the importance of lithology, lineaments and other geomorphological factors that govern groundwater accumulation in an area [66].

4. Conclusions

Groundwater exploration of the Federal Capital Territory, Abuja, Nigeria has been successfully implemented using MCDA and AHP techniques using ArcGIS 10.8.1 as the GIS platform. This was done by applying normalised weights and ranks for groundwater controlling parameters such as Geology, Lineament density, rainfall, and Drainage density. Other factors that were incorporated in the analysis include slope, land use and landcover and soil class. The weighted overlay tool of ArcGIS was used to produce groundwater potential zone map. These were classified into five classes viz: "Very Good", "Good", "Moderate", "Poor" and "Very Poor" classes. This represents 19%, 8%, 14%, 47% and 13% respectively

It should be noted that this work has been done on a regional scale. The complex hydrogeology of Basement Complex should be considered when making use of these maps. However, it has the advantage of being used as a tool to determine the potentiality of an area as a first pass reconnaissance database. This map is therefore recommended to groundwater planners for government agencies, private sector water developers, researchers in institutions of higher learning and individuals who wish to investigate groundwater potential in the area. An additional advantage of the method implemented in this study is that it is scalable, where this method can be applied even at continental scales. Hence, it can be adopted and used in different geologic terrains and have confidence in obtaining similar results.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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