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Research Paper

Use of remote sensing and GIS technique for groundwater potential zones delineation in Ilorin, SW Nigeria.

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Abstract
Groundwater is a major source of water supply used for domestic, agricultural and industrial need. However, there is poor level of its supply due to a high demand as a result of increased population, industrialization and urbanization. Therefore, in the present study remote sensing and geographic information systems techniques are collectively used to delineate groundwater potential zones in part of Ilorin metropolis (Sheet 223 NW). The conventional maps and DEM data have been used for preparation of a range of thematic maps like drainage distance, slope, elevation, lineament density, soil, depth to groundwater for demarcate groundwater potential zones.
As a results, each thematic map assigned weight on the basis of its contribution in groundwater potential. The features of each and every thematic map also assigned rank. GIS environment was used to integrate all the thematic maps for computing groundwater potential zones. The groundwater potential zones were classified as moderate to high with SE-NW, N-S and NE-SW flow directions. Groundwater potential zones were demarcated on basis of finishing ranking and weight. Accordingly, recognition of potential groundwater zones could be carried out by using combine approach involving remote sensing and geographic information systems.
Keywords: Groundwater potential zones, Remote Sensing, GIS, Ilorin, Nigeria

1. Introduction

Portable water is one of the major resources that a citizen of any nation can benefit (Alile et al., 2008). There is a high demand for table water to meet both domestic and industrial need (kinrinade et al.,2015). Water in the saturated zone is the only underground water that is available to supply wells and springs and is the only water to which the name groundwater is correctly applied. Groundwater is one of the most precious natural resources because of its availability, low cost of development and its reliable quality. Groundwater can be used for domestic water supply, agricultural irrigation, industries and cooling.

There has been a tremendous increase in the demand for groundwater due to increase in population, advanced irrigation practices, and industrial usages (Jha et al., 2007) (Jha et al., 2010). The occurrence and movement of groundwater in an area is governed by several factors such as lithology, geological structures, soil, lineament features, slope, drainage pattern, geomorphology, land use/land cover and interrelationship between these factors(Greenbaum, 1985)(Jha et al., 2010) (Chowdhury et al., 2010)(Jaiswal et al., 2003).

Several researchers (Saraf and Choudhury 1998; Jha, M.K., Peiffer 2006; Jaiswal and al., 2003a; Solomon and Quiel 2006;Jha and Chowdary 2007; Ganapuram and al., 2009; Saha et al., 2010; Saraf and Choudhury 1998b; Al-Adamat et al., 2003; Igboekwe., 2011; Nwachukwu et al., 2013; Hachem et al. 2015; Nag 2016;Bhange et al. 2016; Nejad et al. 2017; Oluwatobi et al. 2017;Kudamnya and Andongma 2017; Obimba et al., 2017;Bsr 2018; Gebrie and Getachew 2019; Adeyeye et al., 2019; Oyedele 2019; Arulbalaji et al., 2019)have utilized the GIS and remote sensing for delineation of groundwater potential zones in their areas of interest. Therefore, groundwater is not properly harnessed in some part of Nigeria because of inaccurate estimation of its availability and improper planning. The development of groundwater has been handled at several levels in Nigeria. Experience has shown that, the various schemes have generally failed to achieve the objective of providing reliable and dependable water to the intended beneficiaries. Adequate knowledge of groundwater is more important considering the fact that public water supply systems in major cities in Nigeria have not been successful in meeting the demand for water and sanitation for domestic, commercial and industrial purposes. For example, out of the 85 million people living in urban and semi-urban areas of Nigeria, less than half has reasonable access to reliable water supply(Federal Republic of Nigeria., 2000). Water supply services, where they exist, are unreliable, of low quality and not sustainable because of difficulties in management, operation, pricing and failure to recover costs. Currently, Nigeria's annual population growth rate of 2.86% has been projected to result in the doubling of its population of 150 million within 25 years; hence demographic pressures coupled with rising operational and maintenance cost of water infrastructure are affecting water supply particularly in urban centres like Ilorin.

The aim objectives of this research studies are: a.) to investigate groundwater potential and characterize aquifers in part of the Ilorin sheet 223 NW, South-western Nigeria, b.) to generate groundwater flow direction and potential maps, c.) delineate fracture zones and directions, d.) to demonstrate the capabilities of remote sensing and GIS in groundwater mapping.

2. Materials and Methods

Static Water Level (SWL) data from twenty-two (22) boreholes were collected from Lower River Niger Basin (2015-2016 boreholes project) and used to produce depth to groundwater map of the study area. Static water levels, geographic coordinates of 22 boreholes from the study area (**Table 1**) were used to produce a 3-D hydraulic head relief and groundwater flow directions map of the study are. The static water level values were subtracted from the ground elevation values for each borehole to obtain hydraulic head values. The hydraulic heads along with coordinates of the boreholes were then imported into Surfer 10 Golden software. The 3-D hydraulic head relief map was produced using 3-D Grid map. On the other hand, a vector map and contour map were produced with the same imported data and superimposed to produce the groundwater flow direction map of the study area.

Successful delineation of groundwater potential zones was achieved through the extraction of various data such as elevation, slope, drainage and lineament from a digital elevation model (DEM) satellite imagery which was downloaded from global land cover facility, University of Maryland (U.S.A.) website to produce thematic maps. The soil map was obtained from Geological Survey map of Nigeria, 2004. This soil map was scanned, georeferenced and digitized. Since these factors (soil, elevation, slope, static water level, drainage and lineament density) directly or indirectly affect groundwater, a thematic map for each was produced in layers with the use of ArcGIS software. Each layer produced was further sub-divided into different classes and weighting were assigned to these layers using the multi-criteria evaluation (MCE) technique. The layers that are more favourable to groundwater occurrence were assigned a higher weighting than layers less favourable to groundwater. Weighting for the different layers were calculated using analytical hierarchy procedure (AHP). Analytical hierarchy procedure is one of the multi-criteria evaluation technique (MCE) methods (Saaty., 1977). This technique provides a measure of the judgment consistency and simplifies preference rating among decision criteria using pair wise comparisons. For accuracy, consistency ratio was calculated. A consistency ratio of 0.1 and below was considered acceptable and any higher value will require re-examination.

Table 1: Borehole Data of the Study Area

S/N	Northing	Easting	Elevation (m)	SWL (m)	Hydraulic Head (m)
1	8.491111	4.597778	357	5.28	351.72
2	8.488056	4.588056	323	4.23	318.77
4	8.466389	4.538889	301	2.82	298.18
5	8.454167	4.593889	298	6.14	291.86
6	8.429444	4.575556	377	8.31	368.69
7	8.485278	4.611667	292	3.24	288.76
8	8.443056	4.541389	336	6.87	329.13
9	8.484167	4.555833	310	5.81	304.19
10	8.462778	4.519444	334	3.1	330.9
11	8.491389	4.540833	339	2.06	336.94
12	8.467778	4.571389	324	3.75	320.25
13	8.428889	4.583611	315	7.53	307.47
14	8.475	4.558611	304	3.03	300.97
15	8.499167	4.575833	298	3.45	294.55
16	8.458611	8.458611	366	5.31	360.69
17	8.493611	4.609444	338	3.54	334.46
18	8.450556	4.615556	331	6.31	324.69
19	8.438889	4.577778	311	6.32	304.68
20	8.438889	4.577778	426	4.82	421.18
21	8.43	4.605833	406	3.68	402.32
22	8.443889	4.561389	298	7.51	290.49

2.1 Study area

The study area is within Ilorin metropolis, the capital city of Kwara state. By virtue of its location, Ilorin may be referred to as the gateway between the southwestern and Northern Nigeria. Since 1967, as a state capital, it has developed into an urban centre attracting people from different part of the country/world for greener pasture; this has therefore tremendously increased the population of the city. The National Population Census of 1991 put Kwara state at estimated figure of 1, 780, 269 by 1996 (Onokerhoraye., 2002). The city has grown into a full commercial and industrial status in the last twenty years and there would have been a simultaneous increase in water demands especially with the establishment of industries. The town is drained, principally, northward by the Asa and Oyun rivers. The area of study falls within Ilorin sheet 223 NW; and it is bounded by latitude 8º 25'N and 8º 30'N and longitude 4º 32'E and 4º 37'E with an area of 85 km^2 (**Figure 1**)

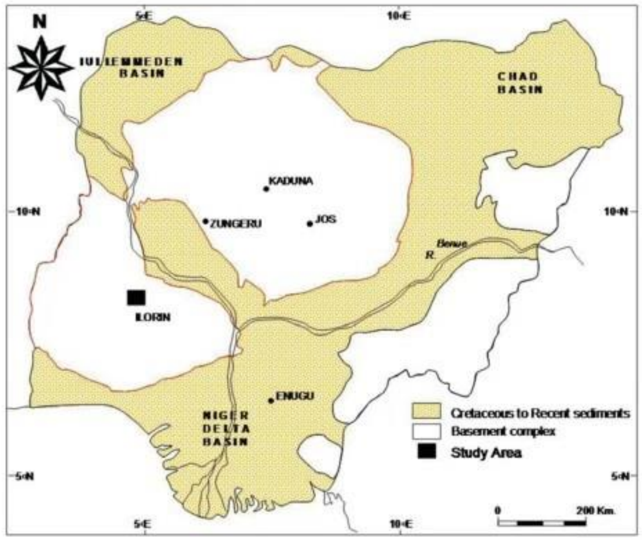

Figure 1: Generalized geological map of Nigeria showing the study area (Bolarinwa and Ibrahim 2015)

2.2 Geological setting

The geology of Nigeria is made up of three major rock types(Adelana et al., 2008), namely, Precambrian basement crystalline metamorphic-igneous-volcanic rocks; Mesozoic to Tertiary sediments, granites and volcanics; and Quaternary alluvial deposits as described by (Kogbe, 1989) (**Figure 2**). Precambrian Basement Complex rocks underlie three areas of Nigeria: North-central area including the Jos Plateau; Southwestern area adjacent to Benin Republic; and Southeastern area adjacent to Repulic of Cameroon (Oyawoye 1972; Rahaman 1989). The rocks of the North-central area are composed of gneisses, migmatites, granites, schists, phyllites and quartzites. The narrow, tightly folded north-south trending "schist belts" of northwestern and southwestern Nigeria include igneous rocks, pelitic schists, phyllites and banded ironstones. The migmatites-gneiss complex of amphibolites, diorites, gabbros, marbles and pegmatites form a transition zone between the schist belt of northwest Nigeria and the granites of the Jos Plateau to the east. They have been intruded by Jurassic age Younger Granites that are characteristic of ring complex structures (Oyawoye 1972). The Precambrian Basement rocks of southwestern Nigeria, as found in the Dahomeyan (Benin) Basin, consist of migmatites, banded gneisses and granite gneisses, with low grade metasedimentary and meta-volcanic schist, intruded by Pan-African age granites and charnockites (Oyawoye 1972). The migmatites and gneissic metasediments are often intruded by pegmatite veins and dykes(Oluyide et al., 1998). Older granites, granodiorites and syenites, with dolerite dykes, also form part of the Precambrian basement of southwest Nigeria. The Precambrian Basement rocks of Southeastern Nigeria occur in three blocks along the border with Cameroun (**Figure 2**). The crystalline basement rocks include biotite-hornblend gneiss, kyanite gneiss, migmatite gneiss and granites and are well fractured(Ekwueme., 1987). Tertiary age olivine basalts, trachytes, rhyolites and tuffs, overlying or interbedded with coarse grained alluvial sediments, occur in the Jos Plateau and adjacent plateau areas. The surfaces of these volcanic lava flows have been weathered to form succession of laterite paleosols on the Jos Plateau related to the uplift of the plateau(Farnbauer and Tietz., 2000).

The Mesozoic and Tertiary strata of the Sokoto part of the Iullemmeden Basin in northwest Nigeria comprise interbedded sandstones, clays and limestones that dip to the northwest. These formations are capped by laterite (MacDonald et al., 2008). The sedimentary sequence includes the Cretaceous Illo and Gundumi Formations, the Maastrichtian Rima Group, the late PaleoceneSokoto Group and the Eocene-Miocene GwanduFormation (**Figure 2**). These were deposited during a series of overlapping marine transgressions. Over 1250 m of sediments occur in the downwarpedSokoto Basin, unconformably overlying Precambrian Basement rocks. Quarternary age alluvial deposits occur along the course of the river Sokoto(MacDonald et al., 2008). In the Chad Basin of northeast Nigeria, Cretaceous sediments include the Albian-Cenomanian Bima Sandstone Formation, continental, poorly sorted and thickly bedded feldspathic sandstones and conglomerates to fluviatile and deltaic sediments. The early Turonian age Gongila Formation, up to 500 m thick, includes marine limestones, sandstones and shales. The Senonian Maastrichtian age Fika shale Formation, 100 to 500 m thick, consists of gypsiferous shales and limestones of marine and continental origin. The Maastrichtian age Gombe Sandstone Formation consists of estuarine and deltaic sediments, deposited upon marine shales with sandstone/shale intercalations. The lower deposits of siltstone, mudstone and ironstone are overlain by well bedded sandstones and siltstones. The upper formation contains coals and cross-bedded sandstones. The Cretaceous ended with a period of uplift and erosion.

The Paleocene age Kerri-Kerri Formation consists of lacustrine or fluvio-lacustrine loosely cemented cross-bedded coarse to fine grained sandstones, with locally occurring claystones, siltstones, lignites and conglomerates. The Kerri-Kerri Formation rests unconformably on the Gombe Sandstone Formation and thickens towards the basin centre where it is overlain by Chad Formation (**Figure 2**). The Pleistocene age Chad Formation (up to 840 m thick) consists of poorly sorted, fine to coarse-grained sand, with sandy clay, clay and diatomite (MacDonald et al., 2008). The Southern Nigeria sedimentary basin includes the Lagos-Osse and the Niger Delta Basins that are separated by the Benin hinge Line (the Okitipupa ridge). These basins have a common basal formation of marine Albian age, arkosic, gravelly, poorly sorted, cross-bedded sandstones and sandy limestones. The Lagos-Osse Basin, the eastern sector of the Benin Basin in Nigeria, underlies the western low-lying coastal zone, where rock exposures are poor due to thick soil cover. The Tertiary geology of the area comprises the basal Araromi/Ewekoro Formation, consisting of shelly and sandy black shale with thin sandstones and limestones that are overlain by the Paleocene age Imo Shale Formation. These are overlain by the Oshosun Formation of shales, clays and sandstones. The succeeding Miocene age Benin Formation consists of up to 200 m of sands with shales, clays and lignite (Okosun, 1998). The near surface Quaternary geology includes recent littoral sandy alluvium and coastal plain sands (Jones and Hockey., 1964; Longe et al., 1987). In the Niger Delta Basin, Quaternary age sediments underlying the delta Plain consists of coarse to medium grained unconsolidated sands and gravel with thin peat, silts, clays and shales, forming units of old deltas. The underlying Miocene age Benin Formation is composed of gravels and sands with shales and clays. This multi-aquifer system formation crops out to the northeast of the coastal belt(MacDonald et al., 2008).

The Cretaceous sediments of the down faulted and failed rift that is the Benue Trough occur in a series of sedimentary basins that extend north east of the confluence of the Niger and Benue rivers, bounded by the

Basement Complex rocks to the north and south of the Benue River (**Figure 2**)(Reyment., 1965). The Lower Benue Basin consists of shales, silts and silty shales with subordinate sandstones and limestones intruded by dolerite dykes. The Upper Benue Basin consists of a thick succession of continental sandstones overlain by marine and estuarine deposits. The basal formation is the Bima Sandstone (Carter et al., 1963). The Bida Basin runs northwest from the confluence of Niger and Benue Rivers towards the Sokoto Basin (**Figure 2**). The basin contains Cretaceous age sandstones, siltsones, claystones and conglomerates, mainly of continental origin. The Middle Niger Basin at the confluence of the Niger and Benue rivers, contains 500 to 100 m of alluvial to deltaic coarse to medium-grained cross-bedded to massive sandstones with subordinate siltstones, kaoliniticclaystones and shales indicate(Adelana et al., 2008).

Quarternary to Recent age alluvial deposits occur along main river valleys. These deposits range from thin discontinuous sands to thick alluvial deposits up to 15 Km wide and 15 to 30 m thick along the Niger and Benue rivers(Adelana et al., 2008). The alluvial deposits include gravel, coarse and fine sand, silt and clay. Thin beds of unconsolidated and mixed sands and gravel occur along the courses of ephemeral “fadamas” in northern Nigeria.

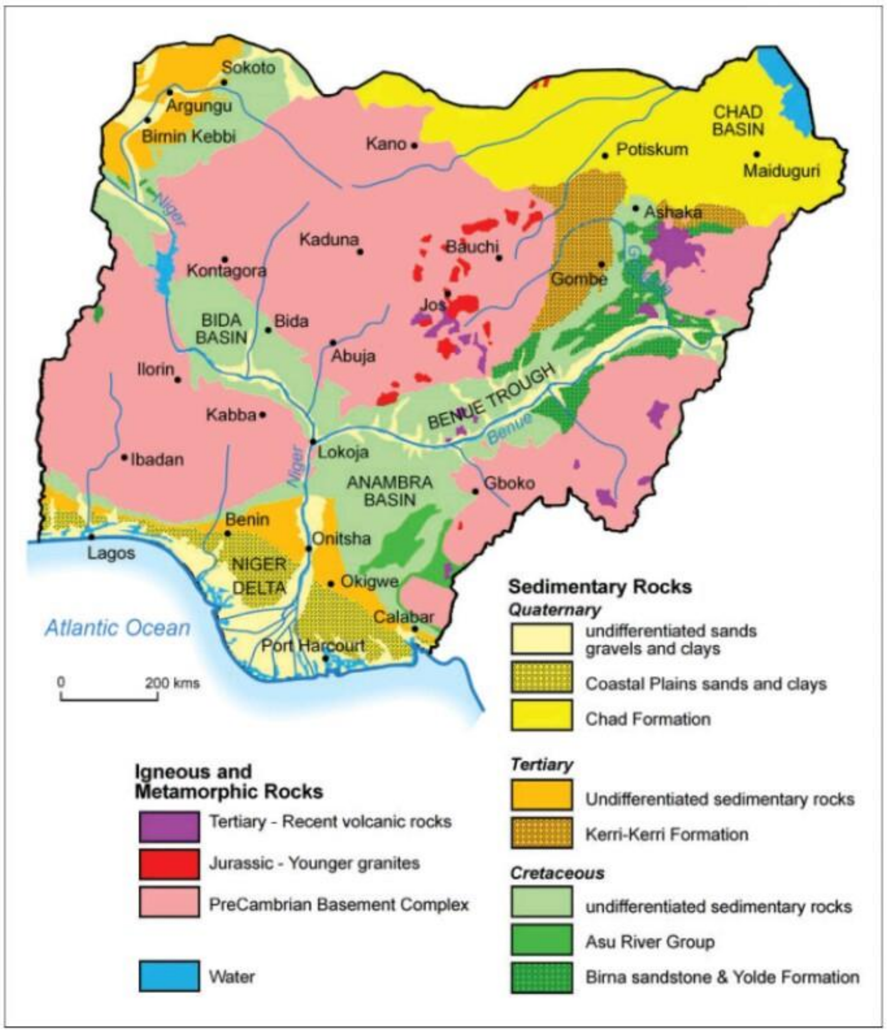

Figure 2: Simplified geological map of Nigeria (MacDonald et al., 2008)

2.3 Local Geology

Ilorin metropolis is underlain by Precambrian basement complex rocks represented basically by migmatite-gneisses, granite gneisses and metasediments such as quartzite. Younger materials derived from weathering of these rocks constitute the major superficial deposits Migmatite-gneiss is the most extensive of the rocks in Ilorin occupying of the study area (**Figure 3**). Classification of theses rocks is however difficult. It is generally believed that the Pan African Orogeny has a homogenizing effect of the rocks. The combination of metasomatism, dynamic metamorphism and eventual regional metamorphism must have produced different rock types, depending on their original composition, for example rocks like migmatite-gneisses, porphyroblastic-gneisses and granite gneisses.

The rocks generally belong to those chased as lit-par lit migmatite, which are conventional migmatite with their components disposed in parallel order encompassing banded migmatite and banded gneiss. They are found around Oko-Erin, Odota, Sobi area and along Jebba road. They are noted for their high colour index being dominted by dark coloured minerals. They have granitic composition and well-developed foliation plane. They generally occur or exposed around Offa-garage Daniel, Daniahi and Basin areas. They occur as isolated domes low ridges. The mineral composition in hand specimen includes mainly feldspar, quartz, biotite and muscrovite. Quartzites are found around the Police road and G.R.A area. They are essentially made up of quartz mica.

The result of intense chemical weathering which caused dearth of outcrop in the study area led to the preponderance of laterites and lateritic cappings. These are derived mostly from weathering of granite gneisses, migmatite-gneisses and quartzites. Laterite and bauxite are residual deposits formed under special climatic conditions in tropical regions. Laterite consists essentially of hydrated iron oxides, while bauxite consists of hydrated aluminium oxides. The most common impurities in both are silica, aluminous laterites and ferruginous bauxites. Lateritization is a chemical process concentring the geo-chemical mobile elements (Al, Fe, Si) in near surface horizons while leaching away alkalis which are more mobile.

The migmatite –gneiss group is striking almost North-South and dipping mostly easterly. They are several joints in the area trending N-S, E-W, NW-SE and NE-SW direction. The NE-SW joints are commonly in the southeast of the study area. The fracture filled quartz and pegmatite in Migmatite and Quartzite and Granite-gneiss of Ilorin are generally NS and NW-SW, and NE-SW (Bolarinwa and Ibrahim 2015) (**Figure 3**).

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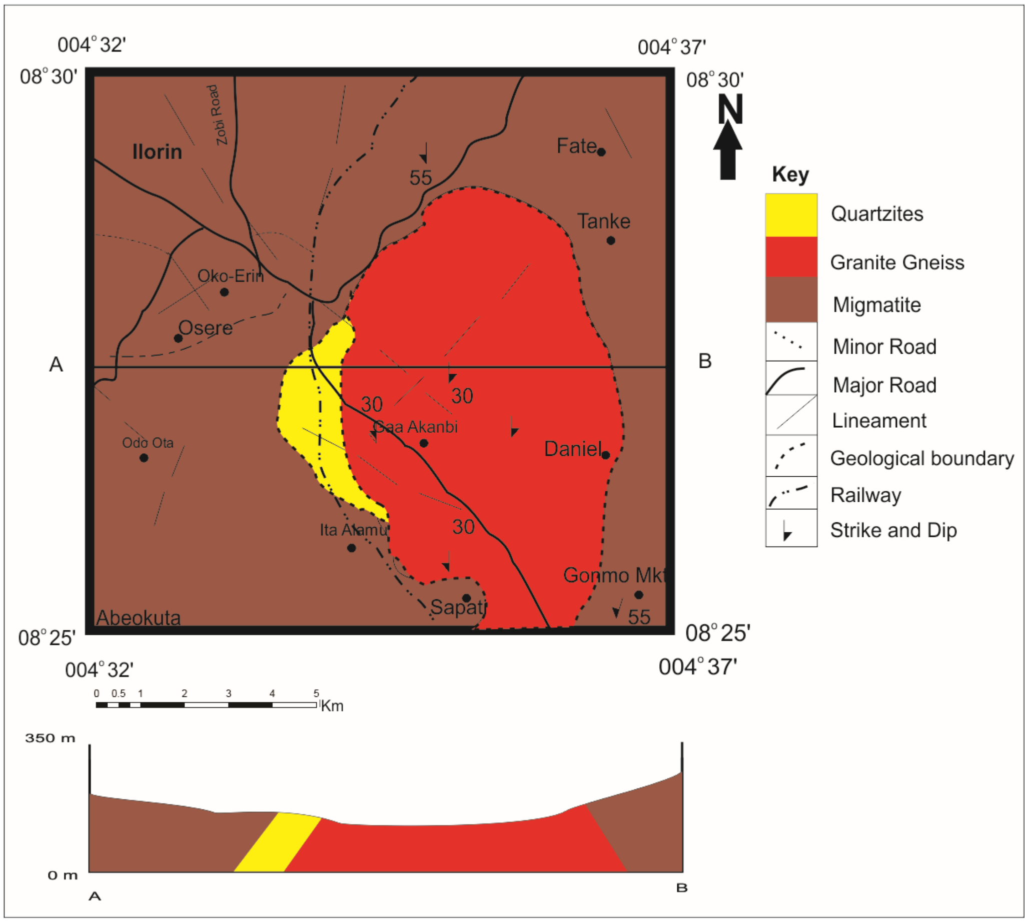

Figure 3: Geological and Cross Section Map of Ilorin Modified from (Bolarinwa and Ibrahim 2015)

3. Results

3.1 Geology

Hydraulic heads were computed by subtracting Static Water Levels from elevations of 22 boreholes from the study area to generate groundwater flow direction map. The boreholes data are here hereby presented in table 4 while the 3-D hydraulic head and groundwater flow direction maps are presented in figure 4 and 5 respectively.

3.2 Drainage Distance

The drainage network for the study area was extracted from digital elevation model (DEM) using Arc-GIS software. The drainage distance in the area has been calculated after digitization of the entire drainage pattern of the study area. Buffering was performed to create distance layers away from the stream. Regions close to the drainage were given higher weighting than those further away. The drainage distance was then classified into; very close, close, far and very far (**Figure 4**), while weightings for different layers are presented in **Table 2**.

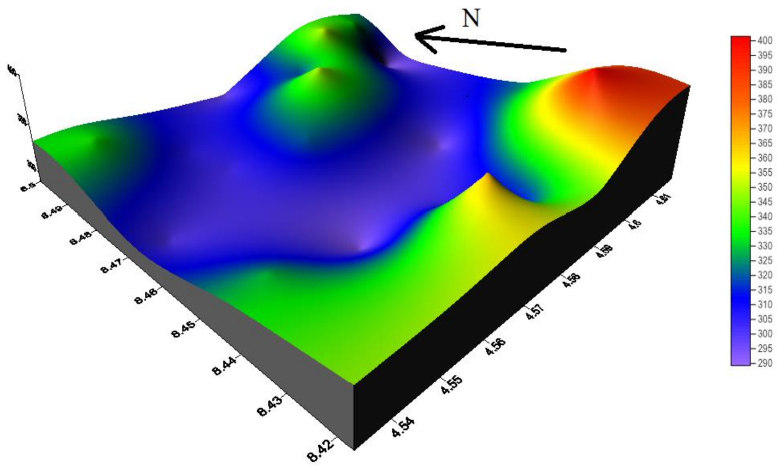

Figure 4: 3-D Hydraulic Head Map of the Study Area

Table 2: Weighting for Drainage Distances

S/N	Drainage Distance	Weight
1	Very Close	49
2	Close	30
3	Far	14
4	Very Far	7
		Consistency Ratio (CR)=0.04

3.3 Slope

The Slope data was extracted from digital elevation model (DEM) and classified into; steep, moderate/gentle and flat (**Figure 4**). Weighting for different layers was carried out (**Table 3**). Flat slope followed by gentle slope generally promote an appreciable groundwater infiltration hence areas indicating flat slope are favourable for round water infiltration and areas indicating steep slope especially in the south-western part of the study area are not favourable for groundwater infiltration (**Figure 5**).

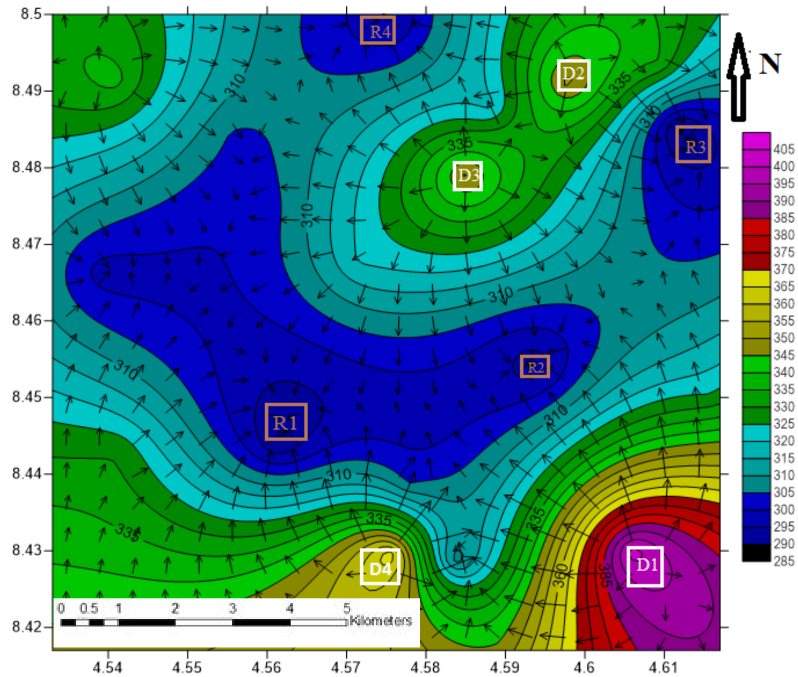

Figure 5: Groundwater Flow Direction Map of the Study Area

Table 3: Weighting for Slope Classes of the Study Area

S/N	Slope	Weight
1	Flat	54
2	Gentle	30
3	Steep	16
		CR = 0.008

3.4 Elevation

Elevation data for the study area was extracted from digital elevation model (DEM) and classified into very low, low, high, very high and extremely high (**Figure 6**). Weighting were assigned for the different layers (**Table 4**).

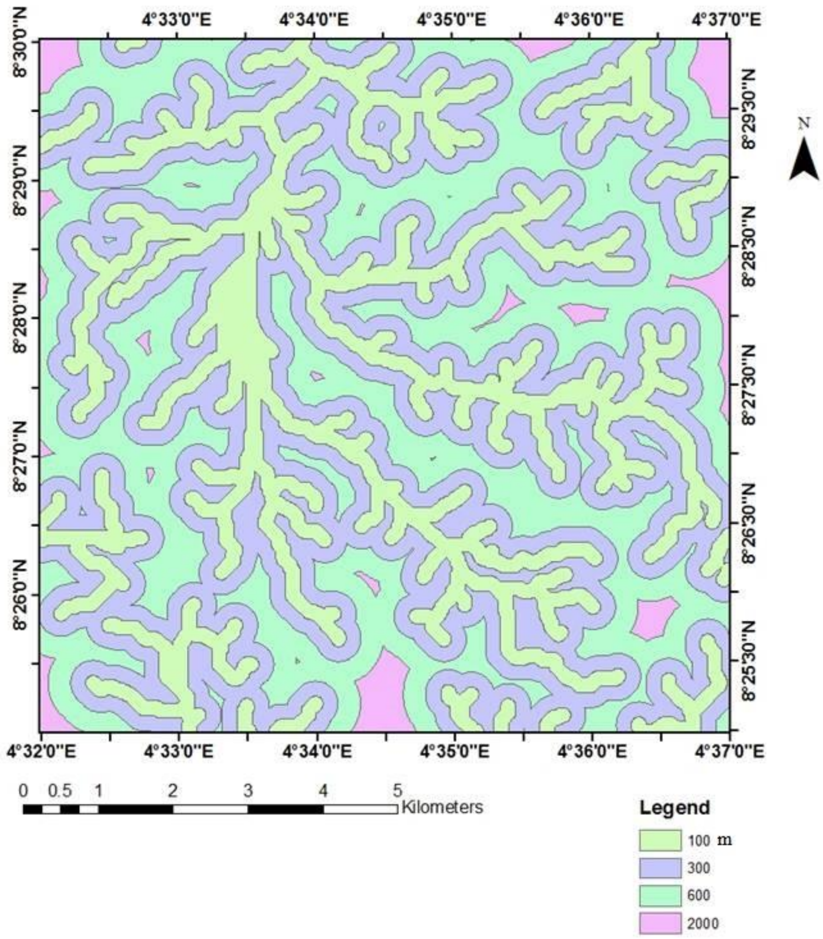

Figure 6: Drainage Distance Classes Map of the Study Area

Table 4: Weighting for Elevation Classes of the Study Area

S/N	Elevation	Weight
1	Very Low	42
2	Low	31
3	High	15
4	Very High	8
5	Extremely High	4
		CR = 0.03

3.5 Lineaments density

The lineaments present in the study area have varying dimensions. Based on the concentration and length of lineaments, a lineament density map was prepared. Lineament delineated were extracted from the DEM and classified into zones of different lineament density, very low, low, moderate and high using spatial density analysis in ArcGIS domain (**Figure 7**). Weighting for the different lineament layers is given on **Table 5**.

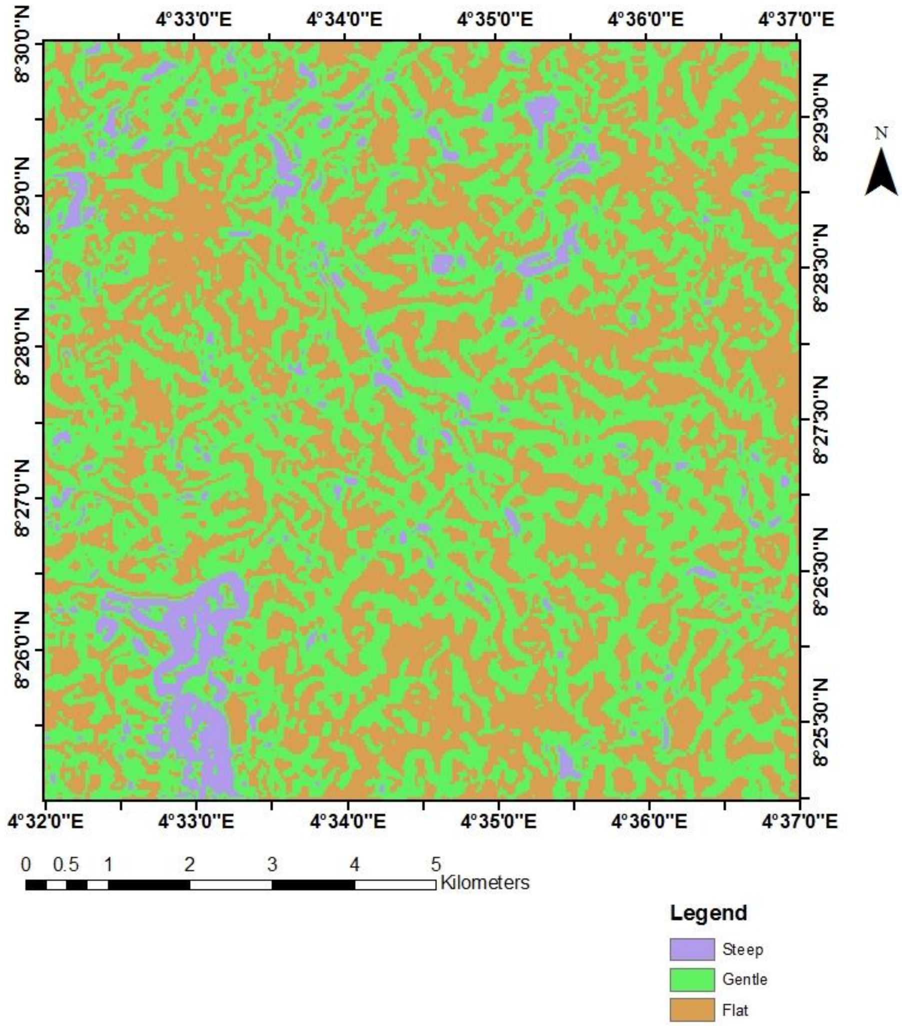

Figure 7: Slope Classes Map of the Study Area.

Table 5: Weighting for Lineament Density Classes of the Study Area

S/N	Density of Lineaments	Weight
1	Very low	8
2	Low	15
3	Moderate	27
4	High	50
		CR = 0.0039

3.6 Soil

Soil map for the study area was produced from Geological Survey soil map of Nigeria. Soil cover-type within the study area consists of luvisols and lixisols (**Figure 8**). The weighting assigned to each soil class is presented on **Table 6**.

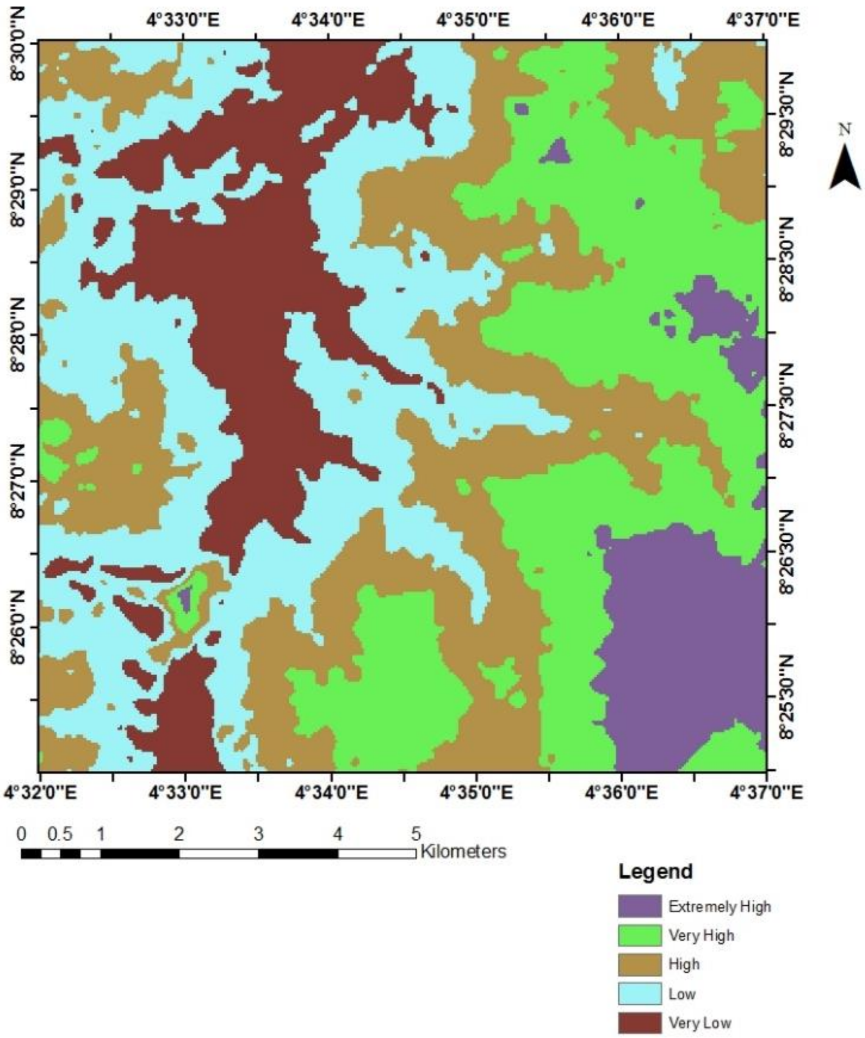

Figure 8: Elevation Classes map of the study area

Table 6: Weighting for Soil Classes of the Study Area

S/N	Soil Type	Weight
1	Lixisols	59
2	Luvisols	42
		CR = 0

3.7 Depth to Groundwater

Static Water Levels (SWL) and ground elevation data of the twenty-two boreholes collected from Lower River Niger Basin borehole projects were used to produce depth to ground water map of the study area.

The pattern of the SWL in the study area was used to produce depth to ground water map of the study area using ArcGIS software (**Figure 9**).

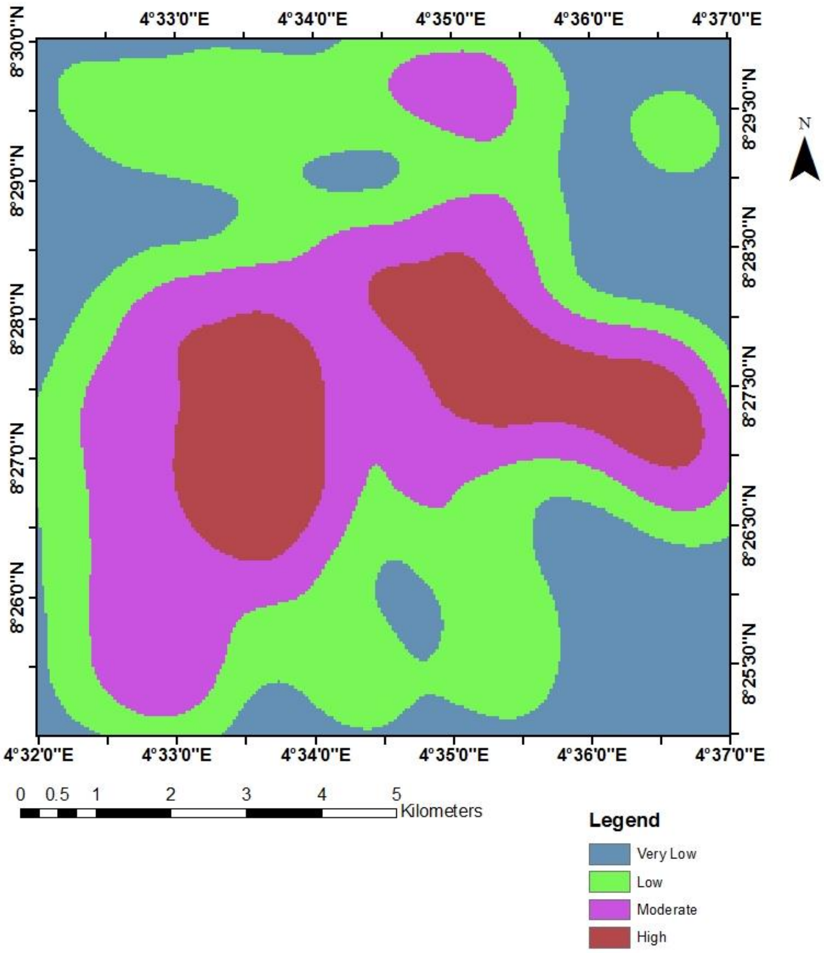

Figure 9: Lineament Density Classes Map of the Study Area.

Table 7: Weighting for Depth to Groundwater of the Study Area

	Ground Water Depth	Weight
1	Very Shallow	38
2	Shallow	31
3	Deep	22
4	Very Deep	9
		CR = 0.01

3.8 Groundwater Potential Zones

The extraction of various data and subsequent production of different thematic maps for factors that determine groundwater occurrence was followed by combining the different layers using Arc-GIS Spatial analysis tools. With this, the different thematic layers were combined using the weight-sum in the manner represented below:

GROUNDWATER POTENTIAL MAP (GWPM) = Soil + Drainage Distance + Elevation +Elope + Lineament Density + Depth to Basement.

Thus, a groundwater potential map for the study area was produced by combining all thematic layers acquired from remotely sensed satellite imageries. It was then re-classified into four classes showing the favourable areas for groundwater occurrence. The classes are; very low, low, high and vey high (**Table 8**). Statistical analysis of the groundwater potential map (**Figure 10**).

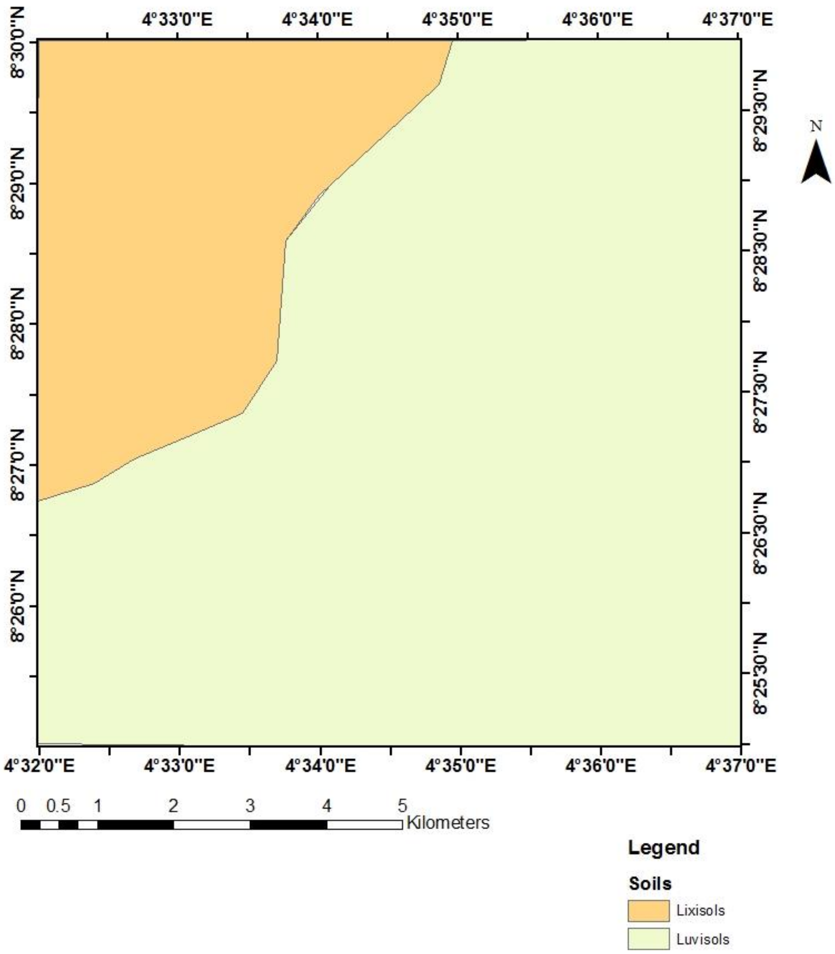

Figure 10: Soil Map of the Study Area

Table 8: Area and Percentage of Groundwater Potential Zones of the Study Area

S/N	Count	%	Area (km^2)
Very Low	7716	25.11800514	21.4141041
Low	8757	28.50678733	24.30317647
High	9026	29.38246688	25.04972831

4. Discussion

The hydraulic heads range from 285 m to 400 m (**Figure 4**). Groundwater flows in SE-NW, N-S, NE-SW and E-W directions (**Figure 5**) which agrees with the structural trend of the study area except that of E-W.

Four recharge areas are found: two in the central, one in the northern and one in the north-eastern part of the study area. This implies that these zones are zones of high groundwater potential. Four discharge areas are also found (**Figure 5**): two in the north-eastern and southern part of the study area respectively. This indicates zones of poor groundwater potential. The drainage density (km/km2) expresses the closeness of spacing of stream channels, thus providing a quantitative measurement of the average length of stream channels of the whole area (Strahler 1964; Singh et al., 2017; Bhange et al. 2016). The presence of drainage has a great effect on the groundwater level of any given area. Regions close to the drainage are likely to have high ground water potential than those further away from it. This is so because percolation of water into the ground from a drainage system is greater in areas nearer to the drainages than farther away. The drainage density of the study area varies from 100 m to 2000 m (**Figure 6**). The very far drainage area suggest very low-infiltration rate whereas the very close density area suggests very high-infiltration rate. Slope is one of the factors controlling the infiltration of groundwater into the subsurface; hence an indicator for suitability for groundwater prospect (Mondal et al., 2009; Dinesan, Gopinath, and Ashitha 2015; Bhange et al. 2016). In the very gentle slope area the surface runoff is slow allowing more time for rainwater to percolate, whereas high slope area facilitate high runoff allowing less residence time for water hence comparatively less in filtration (**Figure 7**).

Elevation played an important role in determining the infiltration rate of the rainfall, flow accumulation, transit and dissipation zone, areas with low relief was closed associated with groundwater accumulation (Liu et al., 2015; Argaz et al. 2019). The water infiltration increases with the decrease in value in altitude (Elmahdy et al., 2014). However, it is believed that as ground water tends to move down gradient surface water tends to flow from higher to lower lands; hence there will be less percolation of groundwater in elevated areas than in low land areas. The lowland areas will therefore have a high groundwater potential than elevated areas. However, in the present study very low followed by low elevation areas especially in the western part of the study area suggest high groundwater potential since there will be high percolation of groundwater in those areas. On the contrary areas indicating high to extremely high elevation especially the eastern part of the study area suggests low groundwater potential zones (**Figure 8**).

Lineaments are linear topographical or tonal features on the ground representing zones of structural weakness [(William.,1983]; Argaz et al. 2019; Gebrie and Getachew 2019). These zones of structural weakness can actually serve as pathways for percolation of surface water into the subsurface. According to Yeh et al., 2016,lineaments represent the total length of lineaments in a unit area and is expressed as in Equation below:

$$L_d = \frac{\sum_{i=1}^{i=n} Li}{A} \quad (1)$$

Where; $\sum_{i=1}^{i=n} Li$ represents the total length of lineaments (L) and A represents a unit area (L^2).

Lineament density gives an idea about underground faults and fractures, indicative of the happening of groundwater and performs as space for groundwater flow(Todd and May., 2005; Bhange et al. 2016; Oluwatobi et al. 2017; Argaz et al. 2019). Since lineaments are path for percolation of water into the subsurface, the higher the number of lineaments per unit area the greater the percolation of groundwater will be; thus areas with moderate to high lineament density especially the central part of the study area are favourable for high groundwater potential hence higher wells yield. Areas indicating low to very low density (at the corner of the study area) might suggest low groundwater potential (**Figure 9**).

Soil is the most important parameter that determines the infiltration capacity of the region, it's one of the natural resources, which is an important factor to delineate potential groundwater zones and it plays a critical role in groundwater recharge(Savita et al., 2018; Argaz et al. 2019). According to (Jasrotia and Majhi., 2009;Dinesan, Gopinath, and Ashitha 2015), the infiltration rate depends on the soil texture of the area. The types of soil present in an area have a great impact on the availability of groundwater. Highly porous soils allow easy percolation and infiltration of surface water into the subsurface, and this is ideal for a favourable groundwater potential. The luvisols dominate the study area the lixisols is found in the north-western part of the study area (**Figure 10**).

The northern part and south-eastern corner of the study area account for very shallow to shallow depth to ground water whereas the southern part account for deep to very deep depth to groundwater. Depth to groundwater gives information on whether to site a hand dug well or a borehole. Areas with very shallow depth to groundwater are favorable for hand-dug wells since ground water will be closer to the surface than those with very deeper depth to groundwater. The northern part and south-eastern corner of the study area account for shallow to very shallow depth to groundwater whereas the southern part account for deep to very deep depth to groundwater (**Table 7**). This also implies that shallow wells in areas with shallow depth to ground water might be vulnerable to contamination since depths to groundwater are closer to very close to the surface. It should also be noted that hand-dug wells in areas with shallow depth to groundwater may not be productive during the dry season. Deep wells (boreholes)should be of choice to avoid seasonality of groundwater (**Figure 11**).

From the **Figure 12**, the potential map reveals that high groundwater potential zone dominates the area and occupies29.38% of the total area. The next dominating zone is the low zone which occupies 28.51 %of the study area; this is followed by the very low zone occupying 25.12% of the study area.The very high prospect zone is only marked with 16.99% of the total area. The high to veryhigh groundwater potential zones account for 46.37% of the total area that is nearly half of also indicates that groundwater in the study flows in SE-NW, N-S and NE-SW directionwhich also strongly agrees with the structural trend and groundwater flow direction map ofthe study area. The study area; hence groundwater potential of the study area can be said to be moderately high. This agrees with the result of Bolarinwa and Ibrahim, 2015 for the same study area. Areas with low to very low groundwater potential should be taken up for water resources management with development of water harvesting structures.

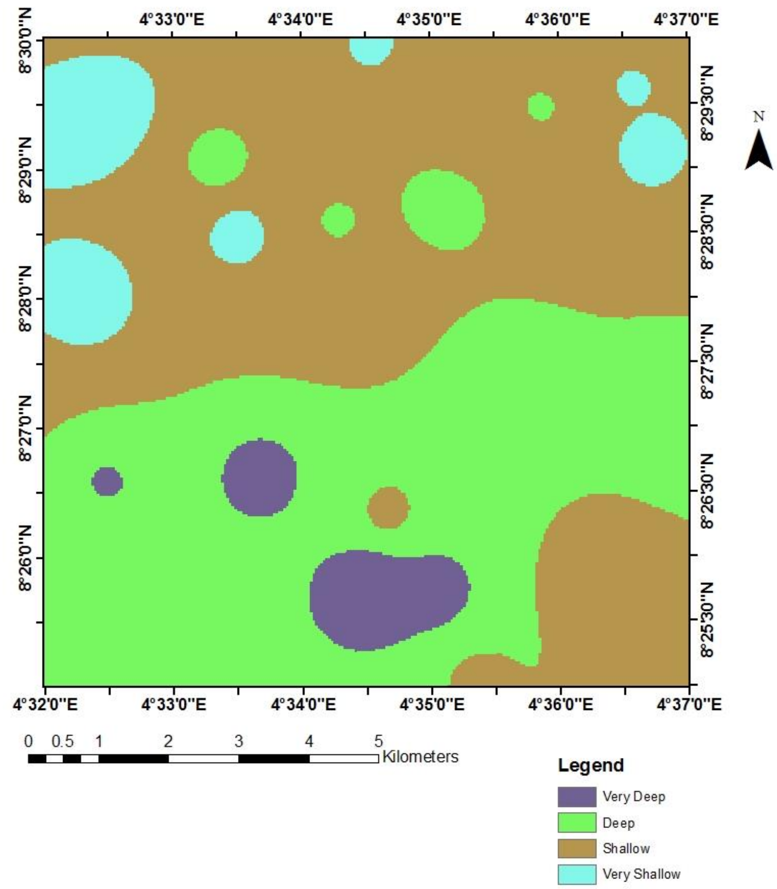

Figure 11: Depth to Groundwater Map of the Study Area

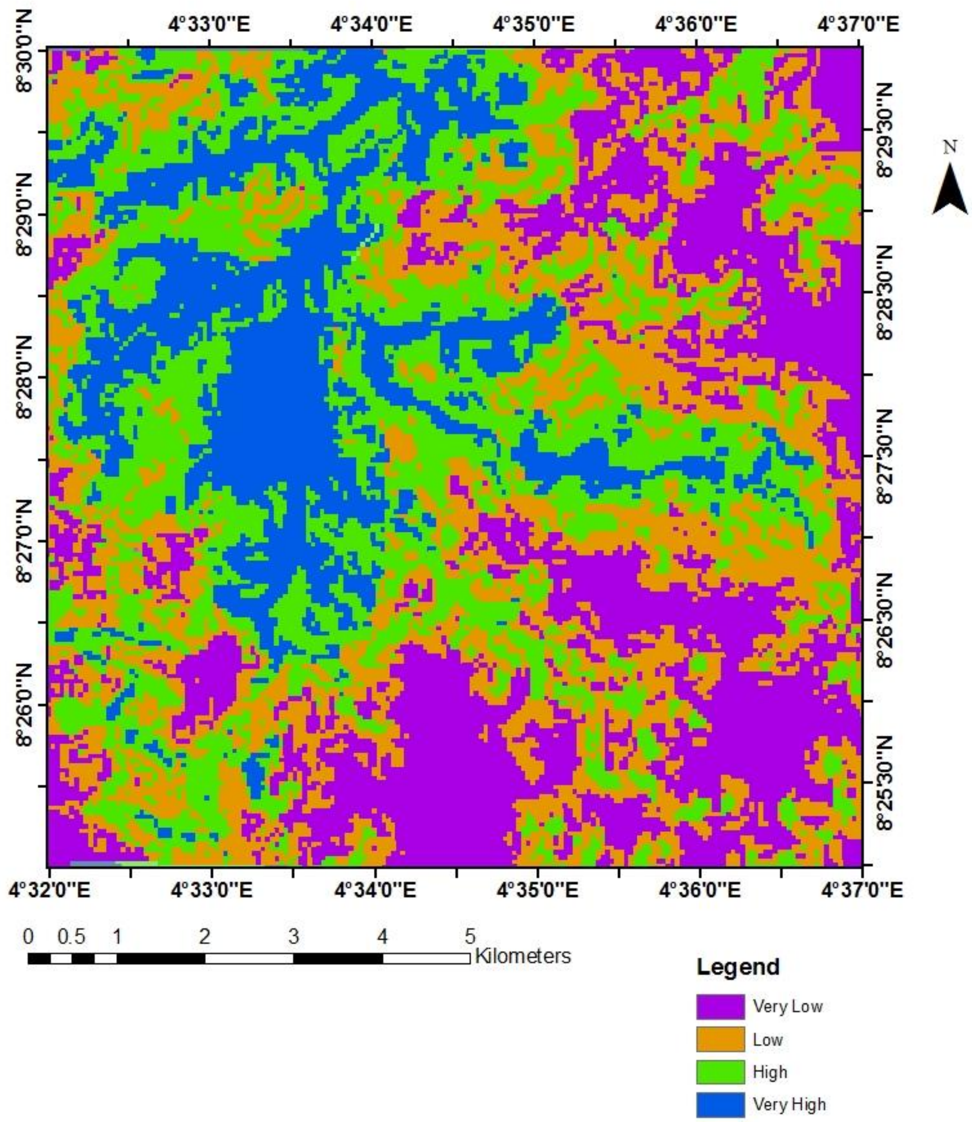

Figure 12: Groundwater potential map of the study area

5. Conclusion

Groundwater is the major source of drinking water and also it is an important source of water for the agricultural and the industrial sector. In this paper, remote sensing and geographic information system have been successfully used for evaluation and delineation of groundwater potential zones by combination of eight parameters related to land and water resources with different weights include geology, drainage distance, slope, elevation, lineaments density, soil, elevation and depth to groundwater. All thematic maps were assigned different ranks and their classes assigned different weight according to their importance for groundwater occurrences. The resulted potential groundwater map of the study area showed areas with moderately to high; and also high to very high groundwater potential zones mainly in the central, northern and western with direction flow dominantly in N-S, NE-SW, E-W and SE-NW. Therefore, groundwater development activities can be performed in such high to very high groundwater prospect zones of Illorin metroplis for increasing the productivity of supplementary irrigation and domestic use and for further hydro-geophysical investigations.

Significance Statement

This study discovers the possible use of integrated GIS and remote sensing that can be beneficial for geologists to quickly identify the prospective groundwater zones for conducting site specific investigations and reasonably thus, significantly scaling down scope of search. This study will help the researcher to uncover the critical areas of borehole drilling that many researchers were not able to explore. Thus a new theory on remote sensing and geographic information system combination, and other combinations may be arrived at.

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Authors Contribution

All authors on the list have contributed adequately to the research studies to be listed as authors, and all qualified individuals are listed as authors in the author's subtitle.

Conflicts of Interest

The authors have not declared any conflict of interests.

6. References

Adelana, S. M. A., Olasehinde, P. I., Vrbka, P., Edet, A. G. and Goni, I.B. (2008) 'An overview of the Geology and Hydrogeology of Nigeria', *Applied groundwater studies in Africa Leiden, Netherlands. CRC Press/ Balkema*, 13.

Adeyeye, O.A., Ikpokonte, E.A. and Arabi, S.A. (2019) 'The Egyptian Journal of Remote Sensing and Space Sciences GIS-based groundwater potential mapping within Dengi area , North Central Nigeria', *The Egyptian Journal of Remote Sensing and Space Sciences*, 22(2), pp. 175–181. doi:10.1016/j.ejrs.2018.04.003.

Al-Adamat, R.A., Foster, I.D., Baban, S.M. (2003) 'Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, remote sensing and DRASTIC.', *Applied Geography*, 23((4)), pp. 303–324.

Alile O. M., Owens., M and Amadasu, C.V.O. (2008) 'Direct current probing of subsurface Earth for water bearing layer in Oredo local government area, Edo state, Nigeria. Nigeria', *Journal of Applied Science,* 25, pp. 107-116.

Argaz, A. *et al.* (2019) 'Application of Remote Sensing Techniques and GIS-Multicriteria decision Analysis for Groundwater Potential Mapping in Souss Watershed , Morocco', 10(5), pp. 411–421.

Arulbalaji, P., Padmalal, D. and Sreelash, K. (2019) 'GIS and AHP Techniques Based Delineation of Groundwater Potential Zones : a case study from Southern Western Ghats , India', *Scientific Reports*, (June 2018), pp. 1–17. doi:10.1038/s41598-019-38567-x.

Bhange, H.N. *et al.* (2016) 'Use of Remote Sensing and GIS Techniques in Delineation of Groundwater Potential Zones', 4(9), pp. 1–6.

Bolarinwa, A. T and Ibrahim, S. (2015) 'Evaluation of groundwater occurrences in the Precambrian basement complex of Ilorin Metropolis, Southwestern Nigeria', *RMZM& G,* 62, pp. 117-132.
Bsr, U.G.C. (2018) 'Delineation of Groundwater Potential Zones in Jalluttu Watershed using Remote Sensing and GIS', 3085(07), pp. 162–168.
Carter, J. D.; Barber, W. and Tait, E.A. (1963) 'The geology of parts of Adamawa, Bauchi and Bornu Provinces in northeastern Nigeria.', *ulletin of the Geological Survey of Nigeria* [Preprint].
Chowdhury, A., Jha, M.K., Chowdary, V.M. (2010) 'Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur District, West Bengal using RS, GIS, and MCDM techniques.', *Environ. Earth Sci.*, 59(6), pp. 1209, 1222 2009.
Dinesan, V.P., Gopinath, G. and Ashitha, M.K. (2015) 'INTERNATIONAL CONFERENCE ON WATER RESOURCES , COASTAL AND OCEAN Application of Geoinformatics for the Delineation of Groundwater Prospects Zones- a Case Study for Melattur Grama Panchayat in Kerala , India', *Aquatic Procedia*, 4(Icwrcoe), pp. 1389–1396. doi:10.1016/j.aqpro.2015.02.180.
Ekwueme, B.N. (1987) 'Structural orientations and Precambrian deformation episodes of Uwet area, Oban massif.', *Precambrian Research*, 34, pp. 269 – 289.
Farnbauer, B. and Tietz, G. (2000) 'The individuality of laterites developed on the Jos Plateau, central Nigeria (in deutsch)', *Zbl. Geol. Paleont. Tiel I, Heft*, 5(6), pp. 509 – 525.
Federal Republic of Nigeria (2000) 'Water Supply and Sanitation. Interim Strategy Note Abuja, Nigeria'.
Ganapuram, S., Vijaya Kumar, G.T., Murali Krishna, I.V., Kahya, E., Demirel, M.C. (2009) 'Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS', *Adv. Eng. Softw*, 40, pp. 506–518.
Gebrie, T. and Getachew, G. (2019) 'Journal of Hydrology : Regional Studies Groundwater potential assessment using GIS and remote sensing : A case study of Guna tana landscape , upper blue Nile Basin , Ethiopia', *Journal of Hydrology: Regional Studies*, 24(April), p. 100610. doi:10.1016/j.ejrh.2019.100610.
Greenbaum, D. (1985) 'Review of Remote Sensing Applications to Groundwater', *British Geological Survey, Nicker Hill* [Preprint].
Hachem, A.M. *et al.* (2015) 'Using Remote Sensing and GIS-Multicriteria decision Analysis for Groundwater Potential Mapping in the Middle Atlas Plateaus , Morocco', 4(7), pp. 33–41.
Igboekwe, M.U. and Akankpo, A.O. (2011) 'Application of Geographic Information System (GIS) in Mapping Groundwater Quality in Uyo , Nigeria', 2011(November), pp. 394–397. doi:10.4236/ijg.2011.24042.
Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J., Saxena, R. (2003) 'Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development–an approach', *Int. J. Remote Sens.*, 24((5)), pp. 993–1008.
Jasrotia, A. S., Majhi A, S.S. (2009) 'Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India', *International Journal of Water Resources Management*, 23, pp. 3035-3055.
Jha, M.K., Chowdary, V.M., Chowdhury, A. (2010) 'Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system, and multi-criteria decision analysis techniques.', *Hydrogeol. J.*, 18((7)), pp. 1713–1728.
Jha, M.K., Chowdary, V.M. (2007) 'Challenges of using remote sensing and GIS in developing nations.', *Hydrogeol. J.*, 15((1)), pp. 197–200.
Jha, M.K., Peiffer, S. (2006) 'Applications of remote sensing and GIS technologies in groundwater hydrology: past, present, and future', *Bayreuther Forum Okologie*, p. 122 2006.

Jones, H. A. and Hockey, R.D. (1964) 'The geology of southwestern Nigeria.', *Bulletin of the Geological Survey of Nigeria,* 31, p. 101.

kinrinade, O. J. and Olabode, O.P. (2015) 'A Integrated geophysical Approach to aquifer delineation in crystalline basement environment.', *International journal of Scientific and Engineering Research,* 6(10), pp. 107–127.

Kogbe, C.A. (1989) 'Geology of Nigeria. Rockview Mige Ltd.', *Jos, 2nd edition*, p. 538.

Kudamnya, E.A. and Andongma, W.T. (2017) 'Predictive Mapping for Groundwater within Sokoto Basin , North Western Nigeria', 10(2), pp. 1–14. doi:10.9734/JGEESI/2017/32440.

Longe, E. O., Malomo, S. & Olorunniwo, M.A. (1987) 'The hydrogeology of Lagos metropolis.', *Journal of African Earth Sciences,* 6, pp. 163 – 174.

MacDonald, A. M., Davies, J. and Carlow, R.C. (2008) 'African hydrogeology and rural water supply. In: S. M. A. Adelana & A. M. Mac Donald (Eds.)', *Applied Groundwater Studies in Africa, London, CRC Press. Mac,* pp. 127–148.

Mondal, Md. Surabuddin, Pandey, A. C., Garg, R.D. (2009) 'Groundwater prospects evaluation based on hydrogeomorphological mapping using high resolution satellite images: A case study in Uttarakhand', *Journal of Indian Society of Remote Sensing*, 36, pp. 69–76.

Nag, S.K. (2016) 'of Waste Resources Delineation of Groundwater Potential Zones in Hard Rock Terrain in Kashipur Block , Purulia District , West Bengal , using Geospatial', 6(1), pp. 1–7. doi:10.4172/2252-5211.1000201.

Nejad, S.G. *et al.* (2017) 'Delineation of groundwater potential zones using remote sensing and GIS-based data-driven models', *Geocarto International*, 6049(May), pp. 1–22. doi:10.1080/10106049.2015.1132481.

Nwachukwu, M.A., Aslan, A. and Nwachukwu, M.I. (2013) 'Application of Geographic Information System (GIS) in sustainable groundwater development , Imo River Basin Nigeria', 5(6), pp. 310–320. doi:10.5897/IJWREE2012.0382.

Obimba, O.H., Alaga, A.T. and Alwadood, J.A. (2017) 'Remote Sensing and GIS Techniques for Ground Water Exploration in Ilesha Area , Osun State , Nigeria', 10(4), pp. 1–10. doi:10.9734/JGEESI/2017/22463.

Okosun, E.A. (1998) 'Review of the early Tertiary stratigraphy of southwestern Nigeria.', *Journal of Mining Geology*, 34, pp. 27–35.

Oluwatobi, A. *et al.* (2017) 'Integrating Geographic Information System (Gis) and Remote Sensing (Rs) for Groundwater Resources Prospecting', 1(2), pp. 40–47. doi:10.11648/j.ajese.20170102.12.

Oluyide P. O., Nwajide, C.S. and Oni, A.O. (1998) 'The Geology of the Ilorin Area.', *Bulletin No. 42 of Geological Survey of Nigeria, Published by Federal Government of Nigeria.* [Preprint].

Onokerhoraye, A.G. (2002) 'Population and Demography of Nigeria.', *Africa Atlases, 1st editions,* p. 158.

Oyawoye, M.O. (1972) 'The Basement Complex of Nigeria In: T. F. J. Dessavagie & A. J. Whiteman (Eds.)', *African Geology, Ibadan, University of Ibadan Press,* pp. 66–102.

Oyedele, A.A. (2019) 'Use of remote sensing and GIS techniques for groundwater exploration in the basement complex terrain of Ado - Ekiti , SW Nigeria', *Applied Water Science*, 9(3), pp. 1–13. doi:10.1007/s13201-019-0917-9.

R.S. Savita, H.K.Mittal, U.Satishkumar, P.K.Singh, K.K.Y. (2018) 'Delineation of Groundwater Potential Zones using Remote Sensing and GIS Techniques in Kanakanala Reservoir Subwatershed , Karnataka , India', *Int.J.Curr.Microbiol.App.Sci.*, 7(1), pp. 273-288.

Rahaman, M.A. (1989) 'Review of the Basement Geology of Southwestern Nigeria', *Geology of Nigeria (2nd Ed.) Ibadan, Rock View (Nig) Ltd.* [Preprint].

Reyment, R.A. (1965) 'Aspects of the geology of Nigeria.', *Ibadan, University of Ibadan Press, Nigeria,* p. 145.

S.I. Elmahdy, M.M. Mohamed, U.A. (2014) 'Groundwater potential modelling using remote sensing and GIS : a case study of the Al Dhaid area , United Arab Emirates', *Geocarto International*, 29(4), pp. 37-41. doi:doi:10.1080/10106049.2013.784366.

Saaty, T.L. (1977) 'A scaling method for priorities in hierarchical structures.', *J. Math. Psychol.*, 15, pp. 234–281.

Saha, D., Dhar, Y.R., Vittala, S.S. (2010) 'Delineation of groundwater development potential zones in parts of marginal Ganga Alluvial Plain in South Bihar, Eastern India', *Environ. Monit. Assess*, 165, pp. 179–191.

Saraf, A.K., Choudhury, P.R. (1998) 'Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites.', *Int. J. Remote Sens.*, 19((10)), pp. 1825–1841.

Singh, L.K., Jha, M.K., Chowdary, V.M. (2017) 'Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply.', *J. Clean. Prod.*, 142, pp. 1436–1456.

Solomon, S., Quiel, F. (2006) 'Groundwater study using remote sensing and geographic information systems (GIS) in central highlands of Eritrea.', *Hydrogeol. J.*, 14((5)), pp. 729–741.

Strahler, A.N. (1964) 'Part II. Quantitative geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology.', *McGraw-Hill, New York,* pp. 4–39.

T. Liu, H.Yan, L.Zhai, N.S. (2015) 'Extract relevant features from DEM for groundwater potential mapping.', pp. 21–23. doi:doi:10.5194/isprsarchives-XL-7-W4-113-2015.

Todd. D.K; and May. L.W. (2005) 'Groundwater hydrology. 3rd ed. Hoboken: John Wiley & Sons'.

William R.S. (1983) 'Geological Applications In: Colwell, R.N (eds.)', *Manual of Remote Sensing, Fals Church VA: American Society of Photogrametry,* pp. 1667–1951.

Yeh, H.F., Cheng, Y.S., Lin, H.I., Lee, C.H. (2016) 'Mapping groundwater recharge potential zone using a GIS approach in Hualian River. Taiwan.', *Sust. Environ. Res*, 26(1), pp. 33–43.