DELINEATION OF GROUNDWATER POTENTIAL ZONES IN ILORIN METROPOLIS, KWARA STATE, NIGERIA.

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Abstract

The integration of data and techniques of remote sensing and geographic information system (GIS) for the exploration of groundwater resources has become a breakthrough in the field of research of the groundwater, which contributes to the assessment, monitoring and conservation of the groundwater resources. In this study, we outlined several areas of groundwater potential to assess the availability of groundwater in the metropolitan area of the Ilorin, Kwara State using remote sensing data and GIS techniques. ASTER GDEM, Rainfall image, Soil shapefile, wells location point shapefile and Landsat 8 (OLI) satellite imagery are used to prepare various thematic layers: topographic elevation, lineament density, slope gradient, land use and land cover, topographic wetness index, drainage density, soil, groundwater level fluctuation and rainfall were prepared in raster format using ArcGIS 10.5. The raster maps of these factors are allocated a fixed score and weight computed from pairwise comparison of Analytical Hierarchical Process (AHP) technique. Moreover, each weighted thematic layer is statistically computed to get the groundwater potential zones. The groundwater potential zones thus obtained were divided into four categories, viz., low, moderate, high, and very high zones. The potential groundwater zones thus obtained were divided into four categories: low, moderate, high, and very high zones. The resulting groundwater potential map showed that about 53.57% of the total surface area ranged from "high" to "very high", indicating that almost half of the study area had good groundwater potential. About 46.25% had moderate potential, while only 0.18% fell below the low potential area. The study's approach can be used as a new way to model geospatial data for the identification and mapping of potential groundwater zones. The results of the study are useful for the information planner of the first line, and local authorities for the assessment, planning, management and administration of groundwater resources in the metropolitan of the Ilorin.

***Keyowrds**: Delineation, Groundwater, Potential, Zones, Ilorin Metropolis.*

Introduction

Water as one of the natural resources required for the survival of man, animals and plants is unevenly distributed on the earth's surface and below the earth's surface. There are a lot of variations in terms of both quantity and quality of natural water whether surface or underground. Yet people and animals need clean potable water to survive. The major sources of clean water are tap, borehole, hand pumps, open wells, streams and rivers. In the absence of available good water, people begin to use unsafe sources and encounter some health problems (Yisa and Jimoh, 2010).

Groundwater is the most existing resources on the Earth basically for life. Groundwater is the 'god blessing' natural source for living things for their life survival. Groundwater is a valuable and the most generally dispersed resources of the Earth and not at all like some other mineral resources, it gets yearly renewal from the brilliant precipitation. Groundwater resources are significant common resources for local or domestic, agricultural and industrial purposes (Kadam et al., 2019). There has been a huge increase in the interest for groundwater because of increase in population, advance irrigation utilization and industrialization. Groundwater is a huge characteristic resources in present day, yet frequent failure in monsoon, undependable surface water, and fast urbanization and industrialization have been made a noteworthy risk to this important resources (Ramamoorthy and Rammohan, 2015).

The ever increasing population in the developing world, especially in the Africa, coupled with increasing agricultural and industrial development warrants greater demand for essential public utilities, most especially water supply for domestic and agricultural purposes. However, the reality of poor economic situation and challenges of expansion of many basic infrastructural facilities to meet the increasing demand on the parts of the government warrants the need for individuals and local communities to look for alternative to the conventional public water supply (Aggarwal et al. 2009; Rodell et al. 2009; Chawla et al. 2010).

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

Remotely sensed data and GIS are playing increasing role in the field of hydrology, groundwater resource development and management. Remote sensing provides multi-spectral, multi temporal and multi sensor data of the earth's surface (Choudhury, 1999 and Lee et al. 2015,). These tools are very effective in delineating groundwater potential zones, and recharge zones. Modern tools of GIS, Remote sensing and Multicriterian analysis using AHP and groundtruthting can provide efficient method for delineating groundwater prospect zones in an area and can establish relationship between geological characteristics and yield data in an area (Kavidha and Elangovan, 2013).

However, the use of GIS and remote sensing technology involves large amounts of spatial data, hence, their wise management of the information in arriving at useful and valid results is desirable. It was reported by Shakeel, Ramaswamy and Abdin (2008) that groundwater occurrence being a sub-surface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features like geological geomorphologic features and their hydrologic characters and wise interpretations.

Satellite remote sensing provides opportunities for better observation and more systematic analysis of various geomorphic units" lineaments features following the integration with the help of GIS to demarcate the groundwater potential zones with the aid of ground truthting. Observation of alluvial structures can also serves as an indicators of groundwater potential.

Materials and Methodology

Study aim and objective

The aim of the study is to delineate the groundwater potential of Ilorin metropolis using remote sensing data and GIS techniques. The specific objectives of the study are to:

- ❖ Derive thematic maps of factor influencing groundwater potentials in the study area.
- ❖ Weighting the derived factors using the analytical hierarchical process (AHP).
- ❖ Delineate the groundwater potential zones of the area through integration of various thematic maps.
- ❖ Validate the groundwater potential of the study area.

***Study area*.**

The study area (Ilorin) is the capital of Kwara State. It is located on latitude 80 24` E to 80 36` N and longitude 40 10` to 40 36` with an Area of about 765km square (Kwara State Diary 2014). Being situated in the transitional zone; between the forest and the savanna region of Nigeria i.e. the North and the West coastal region, it therefore serves as a “melting zone/area between the northern and southern culture” and it situated at elevation 320 meters above the sea level (world atlas, 2018). Ilorin falls into the southern savanna zone. This zone is a transition between the high forest in the southern part of the country and the far North with woodland properties and it operates on the WAT time zone (world atlas, 2018).

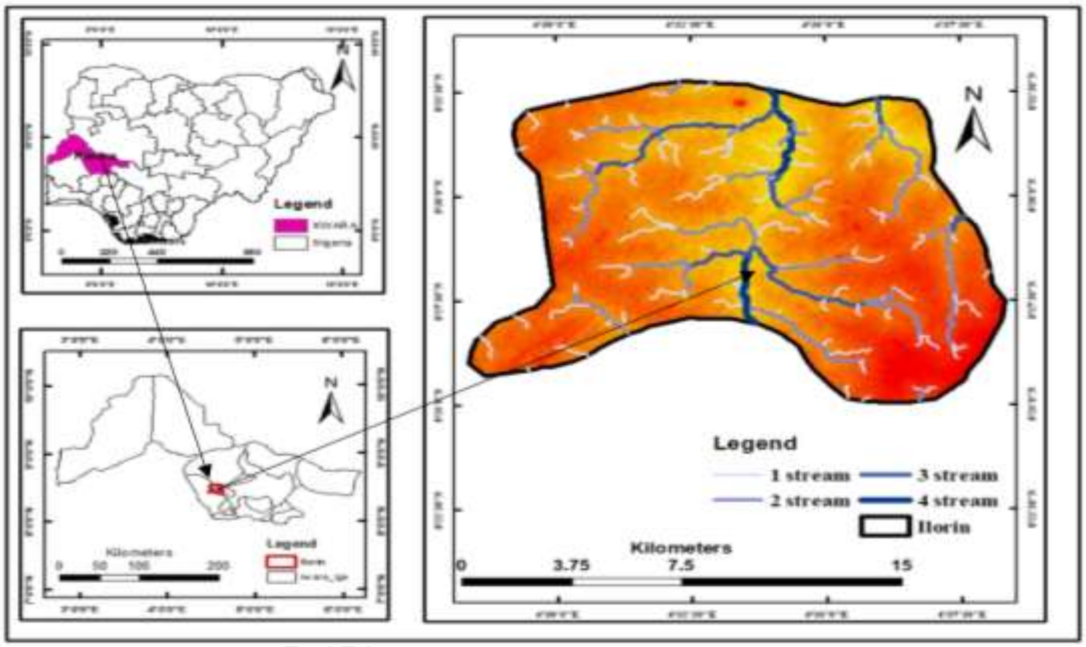


Figure 1: Map showing the study area with its streams order.

Data and software used for the study

Data used include remotely sensed data like Landsat 8 (OLI) image of Ilorin metropolis of year 2019 and ASTER Global Digital Elevation Model (GDEM); conventional maps (soil map of the study area), the rainfall data and literature's.. Software’s used include ArcGIS 10.5, Erdas Imagine 2015, PCI Geomatica 2017, and Microsoft excel. The data and their sources are given in Table.

Table 1: Data Types and Sources for the Study

S/NO	TYPES OF DATA	SOURCE	SCALE/RESOLUTION
1	ASTER GDEM	USGS Earth Explorer portal	30 meter resolution
2	Rainfall image	Climate Research Unit (CRU), University of Eastern Anglia (UEA) USA.	15 meter resolution

3	Landsat 8 (OLI)	USGS Earth Explorer portal	Spatial Resolution of 30 m
4	Soil Data	FAO Soil Map and SWAT Database	Scale 1:50000
5	Well observation data	Kwara state water corporation, ilorin	-

Data processing

Procedure for Deriving Thematic Maps

The thematic layers of drainage density, slope, lineament density, land use and land cover, soil types, topographic wetness index, rainfall, topography elevation and groundwater fluctuation map were prepared and integrated for the delineation of groundwater potential zones. Prior to weighting of the thematic layers and delineation of groundwater potential, the groundwater influencing thematic layers was analyzed with series of GIS techniques such as raster calculator, multidimension analysis, inverse distance weight interpolation, line density, Maximum likelihood supervised classification, cell statistics, hydrology, and surface function of spatial analyst tool of ArcGIS 10.5 and Erdas Imagine 2015 software accordingly.

Procedure for weighting the derived maps using the analytical hierarchical process (AHP)

Weighting of individual thematic layer class weight and scores was carried out using the Analytical Hierarchical Process based on Satty's and Vargas (1991) Analytic Hierarchy Process (AHP); in this method the relative importance of each individual class within the same thematic map will be compared to each other by pair-wise comparison matrix and nine important matrices will be prepared for assigning weight to each class. The AHP was used to differentiate the zones into very good, good, moderate, low and very low and these zones was characterized based on the individual thematic layers properties. The delineation of groundwater potential zones for the study area was made by groups the interpreted layers through weighed muti-influencing factor and finally assigned different potential zones as categorized bellows. The processes involve in assignment of weight using AHP shows in table 2.

Procedure for Delineation of the Groundwater Potential Zones

The muti-criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well known GIS based method for delineating groundwater potential zones. This method helps integrating all thematic layers. A total of 9 different thematic layers was considered for this study. These 9 thematic layers are supposed to control factor of flow and storage of water in the study area. The association of these influencing factors was weighted according to their reaction for groundwater occurrence. A parameter with a high weight illustrates a layer with high impact and a parameter with a low weight illustrates a small impact on groundwater potential. To generate groundwater potential zone map of study area, all nine thematic layers were integrated with weighted overlay analysis function of spatial tool in ArcGIS platform using the following equation.

GWPI = [(LDw * LDwi) + (SLw * SLwi) + (DSw * DSwi) + (RFw * RFwi) + (LUw * LUwi) + (STw * STwi) + (TEw * TEwi) + (TWIw * TWIwi) + (GFw * GFwi)

where, GWPI refers to groundwater potential index, LD stands for lineament density, SL for slope, DS for drainage density, RF for rainfall, LU for land use land cover, ST for soil type, TE for topographic elevation, TWI for topographic wetness index and GF for groundwater fluctuation, the subscripts w and wi refers to the normalized weight of a theme and normalized weight of individual features of a theme, respectively. The final groundwater potential zone map will be classified into low, moderate, high and very high zones.

Table 2: Measurement scale of AHP (Saaty 1980)

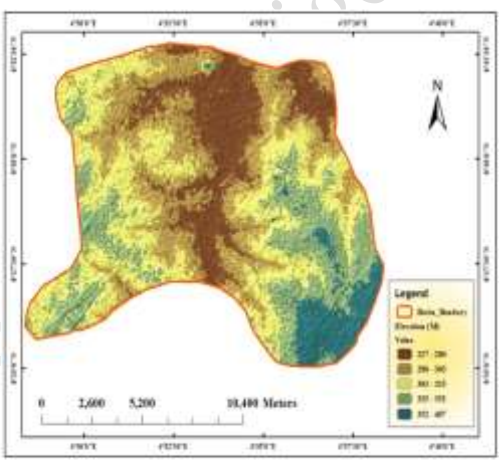
Scale	**Degree of preference**	**Explanation**
1	Equal importance	Two elements contributes equally to the objective
3	Moderate importance	Experience and judge slightly favor one element over another
5	Strong or essential importance	Experience and judgment strongly favor one element another
7	Very strong importance	One element is favored very strongly over. It dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Values for inverse comparison	Can be used to express intermediate values

Procedure for Validation of Groundwater Potential Map.

The validation of the groundwater potential map/model result was accomplished by compare the groundwater potential map result with the wells density map of the study area (Ilorin metropolis). The wells distribution density map was derived using water well distribution dataset acquired from field work (Field work 2019). The density map was derived using point density of density function in spatial analyst tool of ArcGIS 10.5. The wells density map was later reclassified to the same scale as that of groundwater potential map/model output. The two maps were compared using the minus tool in the spatial analyst tool of ArcGIS 10.5 resulting in a suitability difference map. From the suitability difference map, the difference between the observed and the modeled outputs was retrieved from the attribute table and both the area (in ha) and the level of agreement (%) will be computed.

Results

In assessing potential groundwater zones within the study area, factors affecting groundwater potential were mapped and classified. The groundwater potential influencing factor weight was assessed by Analytical Hierarchical Process (AHP) pair wise comparison. Thematic maps derived for the influencing factor of groundwater potential have been classified as very good, good, moderate and low potential. The results of the groundwater potential influencing factor weight table, thematic map derived for the groundwater potential influencing factor and Groundwater potential map are presented in table 1 to 5 and figures 3 to 16.



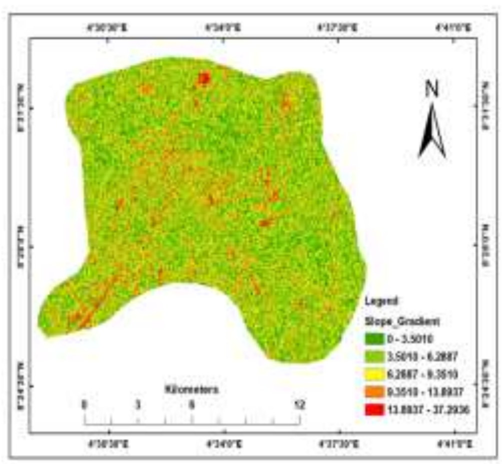


Fig. 2: Topographic Elevation map of Study Area. Fig. 3: Slope Gradient map of Study Area.

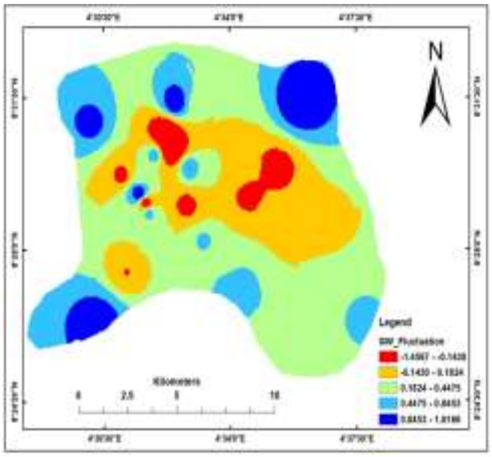


Fig. 4: Groundwater Fluctuation map of Study Area

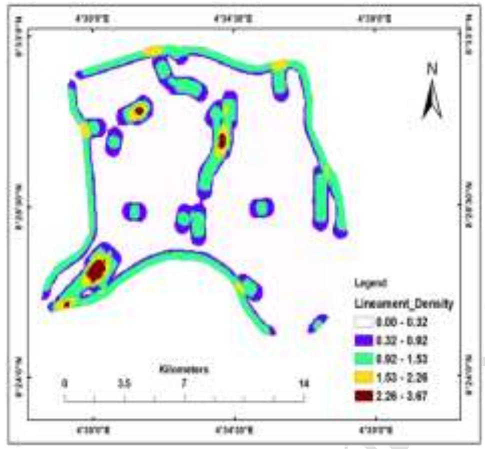


Fig. 5: Lineament Density map of Study Area.

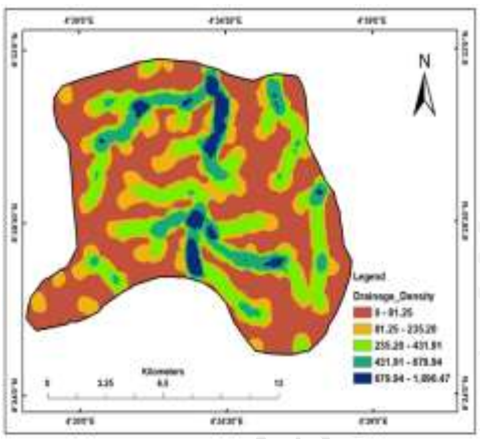


Fig. 6: Drainage density map of Study Area

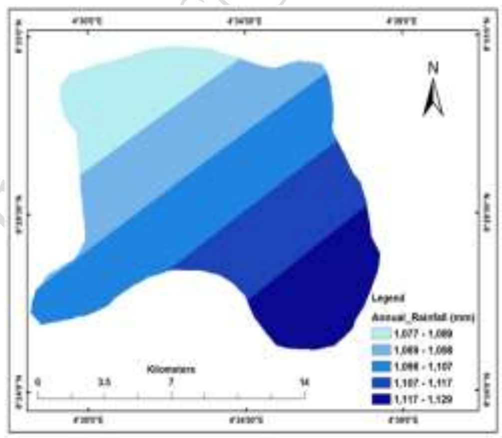
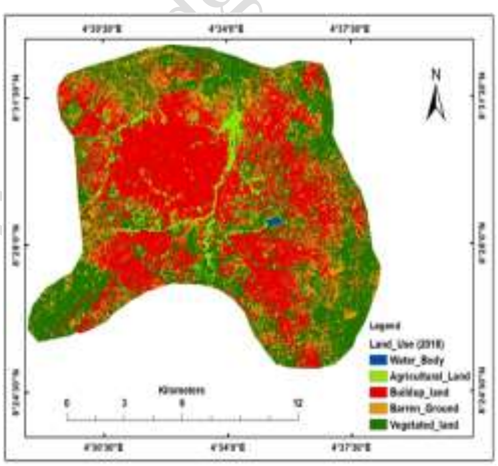


Fig. 7: Rainfall map of Study Area



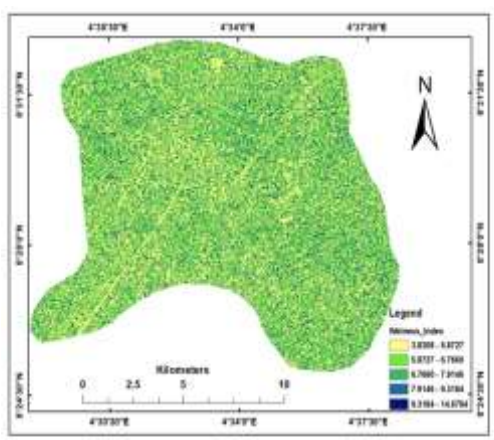
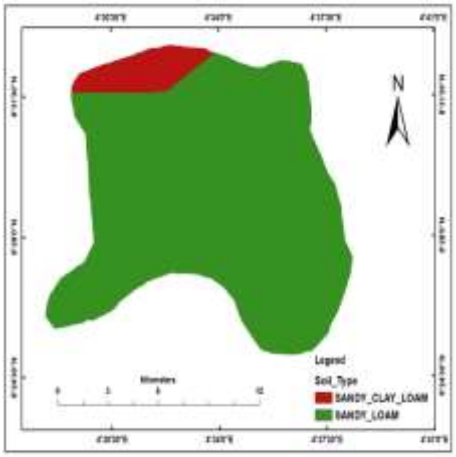


Fig. 8: Land use and land cover map of Study Area Fig. 9: Topographic Wetness Index map of Study Area.



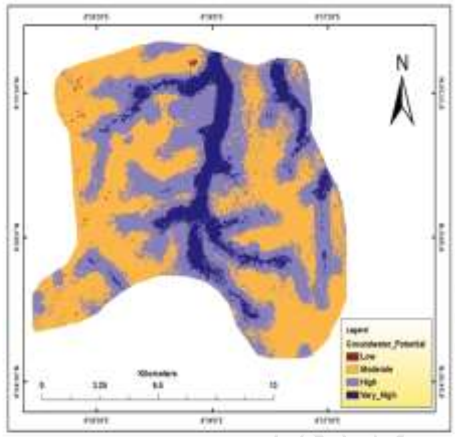
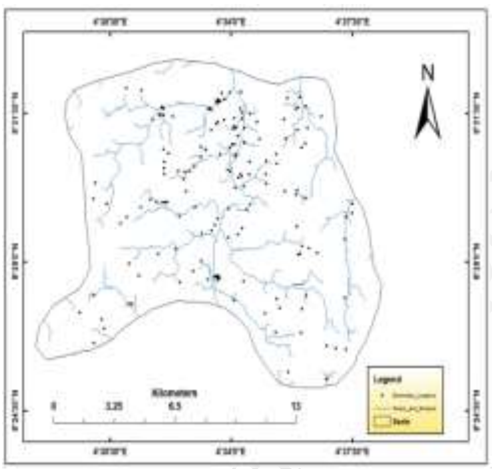


Fig. 10: Soil map of Study Area Fig. 11: Groundwater Potential Zones



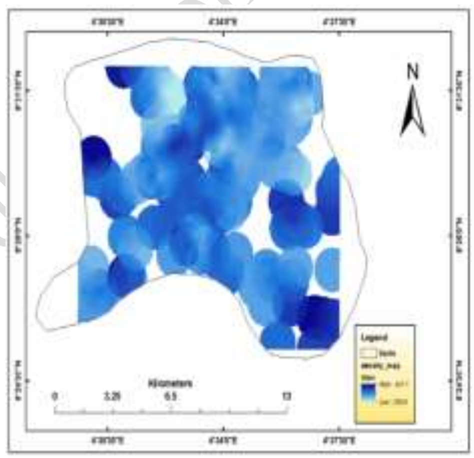
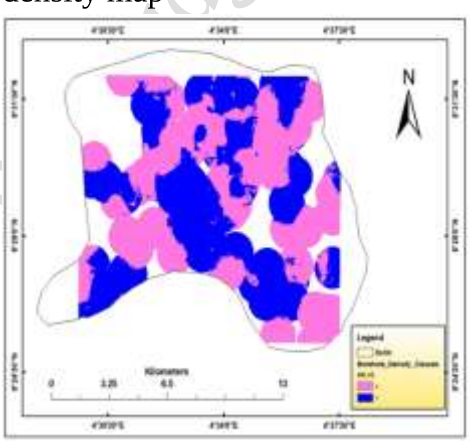


Fig. 12: Boreholes distribution map Fig. 13: Borehole distribution density map



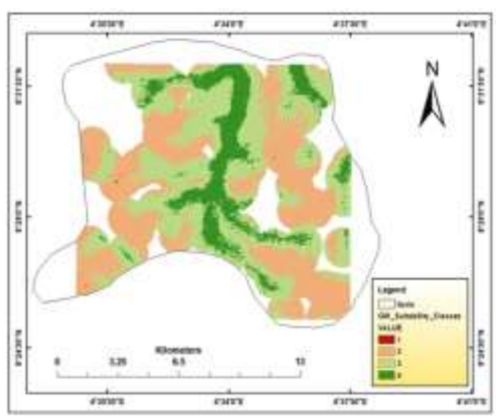


Fig. 14: Reclassified borehole distribution Density Fig. 15: Groundwater Potential model (suitability map)

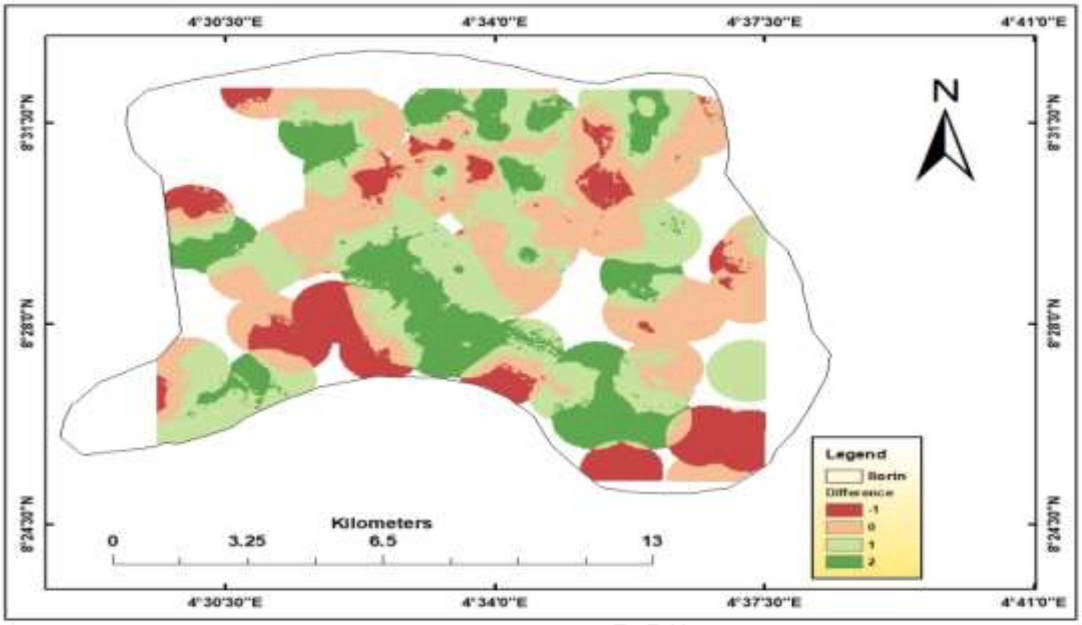


Fig. 16: Groundwater potential validation map

Table 3: Groundwater potential influencing factor Assign weight, Normalized weight and Groundwater Potential.

Theme	Sub-theme (Value)	Sub-theme Weight	Normalized weight	Sub-theme Potential	Theme weights (%)
DEM	227 - 280	8	0.3110	Very Good	**4.65**
	280 - 303	6	0.2400	Good	
	303 - 325	5	0.1910	Moderate	
	325 - 352	4	0.1600	Low	
	352 - 407	2	0.0710	Very Low	
Slope Gradient	0 - 3.5010	8	0.3478	Very Good	**6.98**
	3.5010 - 6.2887	6	0.2609	Good	
	6.2887 - 9.3510	4	0.1739	Moderate	
	9.3510 - 13.8937	3	0.1304	Low	
	13.8937 - 37.2936	2	0.0870	Very Low	
Groundwater Fluctuation	-1.4567 - -0.1430	2	0.0710	Very Low	**18.6**
	-0.1430 - 0.1824	4	0.1600	Low	

	0.1824 – 0.4475	5	0.1910	Moderate	
	0.4475 – 0.8453	6	0.2400	Good	
	0.8453 – 1.6166	8	0.3110	Very Good	
Lineament Density	0.0 – 032	2	0.0690	Very Low	**9.3**
	0.32 – 0.92	4	0.1379	Low	
	0.92 – 1.53	6	0.2069	Moderate	
	1.53 – 2.26	8	0.2759	Good	
	2.26 – 3.67	9	0.3103	Very Good	
Drainage Density	0 – 81.25	8	0.3478	Very Good	**20.93**
	81.25 – 235.20	6	0.2609	Good	
	235.20 – 431.91	4	0.1739	Moderate	
	431.91– 679.94	3	0.1304	Low	
	679.94 – 1090.47	2	0.0870	Very Low	
Rainfall	1077 – 1089	2	0.0984	Very Low	**16.28**
	1089 – 1098	3	0.1640	Low	
	1098 – 1107	4	0.1967	Moderate	
	1107 – 1117	5	0.2459	Good	
	1117 – 1129	6	0.2951	Very Good	
Landuse/Landcover	Water body	9	0.3333	Very Good	**2.33**
	Agric land	5	0.1852	Moderate	
	Buildup area	2	0.0741	Very Low	
	Barren ground	3	0.1111	Low	
	Vegetated land	8	0.2963	Good	
Topographic Wetness Index	3.8308–5.8727	2	0.1000	Very Low	**11.63**
	5.8727–6.7660	3	0.1410	Low	
	6.7660–7.9146	4	0.2000	Moderate	
	7.9146–9.3184	5	0.2410	Good	
	9.3184–14.6784	6	0.3000	Very Good	
Soil Types	Sandy_Clay_Loam	6	0.4286	Moderate	**9.3**
	Sandy_Loam	8	0.5714	Very Good	

Class	Groundwater potential class	Area coverage (km^2)	%
1	Low	0.31	0.18%
2	Moderate	80.29	46.25%
3	High	72.20	41.60%

4	Very High	20.79	11.97%

Table 4: The area coverage of the groundwater potential zones in Ilorin

Table 5: The difference between the observed data and the model output.

*Difference	Area (km)	% Agreement
-1	17.95059	14 %
0	43.2186	34 %
1	40.63988	32 %
2	24.97906	20 %
Total	**126.79013**	**100 %**

Discussions of Result

Delineation of Groundwater Potential Zones

The groundwater potential map for the study area was delineated (outlined) according to the groundwater influence factor of topographic elevation, slope gradient, groundwater fluctuation, lineament density, drainage density, rainfall distribution, land use and land cover, topographic wetness index and soil type. Potential underground water areas for the study area were delineated (outlined) by overlaying interpreted layers using a weighted overlay analysis and multiple influence factors. In this study, potential groundwater areas were classified into four categories: low potential (1), moderate potential (2), high potential (3) and very high potential using the pairwise comparison method of Analytical Hierarchy process. Table 3 shows the groundwater weightgate of the influencing surface and subsurface features for ground water-recharge.

It is noted in (Table 3.) that drainage density is considered as the most important factor of groundwater potential (20.93%) followed by groundwater level fluctuations (18.6%), rainfall (16.28%), topographic wetness index (11.63), lineament density (9.3%) and soil type (9.3%). Land use and land cover have the least influence on the potential of groundwater in the study area (2.33%). The map of potential underground water areas of the study area shown in Figure 11.

The delineated map (outlined) shows that the potential groundwater zones in the study area are significantly related to drainage density, groundwater fluctuations, rainfall distribution, topographic wetness index, lineament density, slope gradient, soil types, topographic elevation, land use and land cover. It is clear from the result (Figure 11) that areas with a groundwater potential are very high in the northern areas, while areas with a groundwater potential below are in the southern area.

From thematic maps generated (figure 11) it can be seen that the potential very high groundwater areas in the northern region are characterized by heavy rainfall and are generally flat or low-slope areas. The southern part of the study area with very low groundwater potential are characterized by low rainfall, moderate slopes, low lineament, high drainage density and dominated by Sandy_Clay_Loam with low groundwater potential. This study is correlated with the study of Khalek and Ahmed (2008) who identified the lineament density, drainage density and the slope gradient as the main influential factors that significantly contribute to the recharge of groundwater in the study area.

Level of Groundwater Potential in the Various Potential Zones of Ilorin Metropolis

The area coverage occupied by groundwater potential zones was estimated in ArcGIS attribute table field calculator into kilometer by multiply the delineated groundwater potential map cell count and cell size by 1000000. The levels of groundwater potential was estimated for various potential zones in the study area. Table 4 represents the estimated area coverage of the groundwater potential zones in square kilometer and percentage.

Table 4 shows that the very high groundwater potential zone occupies 20.79 sq. km (11.97%), the high potential zones constitute about 72.20 sq. km (41.60%) of the study area; the moderate potential areas constitute 80.29 sq. km (46.25%). The low potential zone occupies the lowest coverage constituting 0.31 sq. km (0.18%) respectively.

The groundwater potential delineated map (Figure 11) shows that parts of the Ilorin metropolitan area not only cover one area, but pass through two or more areas. For example, some areas of Metropolis (Ilorin) cover moderate and low groundwater potential. The parts covered by low and moderate potential zones include Oko-olowo, Oloje, Sobi Hill area, part of Adewole estate, Ogidi, Hajji Camp, and parts of Fatte area. However, parts of the metropolis are located in moderate groundwater potential zones. This includes areas such as parts of the GRA toward Agba dam area, Fate-Sango area, Okekere, Omoda area, Adangba, Adeta, Alfa Yahya, parts of Adewole towards Olorunsogo, Gaa-Odota, parts of Egbejila and parts of Asa dam road toward Gari-Alimi. The Taiwo Road area is mainly located on zones with moderate, high and very high potential, while Edun, Ojaya, Niger Road area, Karuma area, Akerebiata area, New Yidi Road, Global soap area, parts of Odota area and some parts of Oloje housing estate are lies over the high and moderate Groundwater potential zones.

Obbo road area, Stadium road, Unity road area, Agba dam estate, Oja gboro, Sabo line, mubo, Sabo Oke, Royal valley estate area, and Abata babalaje area is located in very high potential groundwater zones. The groundwater in the Coca cola Road area lies below the very high potential zones, while parts of the government reservation area are lies over the very high, high, moderate, and low groundwater potential zones.

Validation of Groundwater Potential

The validation procedure depended on data from the spatial distribution of the well (figure 12), which used to delineate the density of the well (figure 13) and the potential groundwater map of the study area (figure 11). Reclassification of the well density map depended on the assumption that the higher the density of the well distribution, the greater the potential of groundwater (figure 14). For comparative purposes, we used the well density map to clip the observed groundwater potentials map (figure 11) to obtain a potential groundwater modelling map (suitability map) (Figure 15) and the finally the two maps (observed and model groundwater potential map figure 11 and 15) were compared using the minus tool in the spatial analyst tool of ArcGIS 10.5 which resulted in a suitability difference map (Figure.16 Groundwater potential validation map).
The study found that zoning of groundwater potential using a Geographical Information System and integrated remote sensing methods are clearly identified with accessible well inventory data (figure 12). The number of wells was not very high in the low-potential area, recommending a decent statement of the result. Based on the comparative assessment result in (Table 5) there was an absolute Concordance of 34% with 0 contrast between the observed groundwater potential map and the groundwater potential modeled map. The model underestimates about 14% and overestimates about 34%, but both fall into an acceptable range.

Conclusion and Recommendation

Conclusion

The underground water potential areas were derived for the metropolis Ilorin, Kwara State, Nigeria, and were divided into essentially four classes, namely very high, high, moderate and low potential. The study found that very good areas of groundwater potential are located in the southern part of the study area.
This study showed that there is a wide spatial variety of groundwater potential. Variability closely followed the variability of precipitation, topography, slope, lineament density and density of drainage characteristics, land use and land cover

in the study area. The most promising potential area of the region is related to high precipitation, low slope and high density of features. Most areas with low groundwater potential are far from the lineament. This study generally shows that GIS and remote sensing techniques combined with field data could be used to study potential groundwater areas in a given area.

Recommendation

1. Surface water development is recommended in low yield areas compared to groundwater development.
2. High groundwater potential areas for groundwater recharge can be explored in the study area, therefore it is recommended to combine these areas with detailed geophysical maps for quantitative assessment of groundwater potential in the study area.
3. The mapping of potential underground areas should be carried out for the entire state of Kwara and for the whole country in order to serve as a guide for water agency.

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