Nigerian Journal of Hydrological Sciences **ISSN: 2315-6686**
Volume 5, 2017 pp. 76-91

Delineation of Groundwater Potential Zones in Awun Basin and Its Environs Using Remote Sensing and GIS Techniques

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Abstract
An integrated approach using remote sensing and Geographic Information Systems (GIS) was adopted to assess the groundwater potential in the Awun basin and its environs in Kwara State, Nigeria. Digitally enhanced colour composites and panchromatic images of Landsat TM were interpreted to produce thematic maps of the study area. Topographic parameters were derived from digital elevation models and used to map landforms. Fracture patterns and spacing were measured in the field in different rock types and compared with lineaments. All thematic layers were integrated and analysed and a groundwater potential map was generated. The spatial distribution of groundwater potential zones showed regional patterns related to lithologies, lineaments, drainage systems and landforms. Results showed that spatial distribution of the most promising sites for groundwater exploration was dependent on the interrelated factors of lithology, topography and geologic structure. The most promising sites were distributed in 56% of the study area. The results demonstrate that the integration of remote sensing, GIS, traditional fieldwork and models provide a useful tool in the assessment and management of water resources and development of groundwater exploration plans.
Key words: Remote sensing, Geographic Information Systems, groundwater, geomorphology, Digital elevation model, lithology, lineament

Introduction
Groundwater is easily the most important component and constitutes about two thirds of the fresh water resources of the world (Chilton, 1996). Groundwater is a source of sustained water supplies, especially during droughts, its assessment, development and rational utilisation should be given more attention. Hence, the groundwater prospect map is important to identify the possibility of groundwater occurrence and it gives a rational picture of subsurface water resources. The map can show the range in groundwater yield at different depths, besides indicating probable sites for recharging aquifers (Jasmine and Mallikarjuna, 2011). The groundwater prospects in a basin depends on lithology, geological structures, geomorphology, hydrology, meteorological conditions and quality of water, which is useful in predictive groundwater resource management (Lee*et a*l. 2009). The conventional methods used for groundwater studies are still not efficient to identify the favourable areas for groundwater storage (Al Saud 2010). Due to ever-increasing population, application of scientific techniques like remote sensing and geographical information system (GIS) is necessary for proper utilisation and management of groundwater resources.

Remote sensing and GIS provide important data and tools for groundwater exploration. Maps of lithology, slope and drainage patterns can also be extracted from remote sensing data of aerial photography and medium to high resolution satellite imagery, depending on the scale of the study. The groundwater prospects maps form a very good database and help in identifying favourable zones (prospective zones) around the problem areas, thereby narrowing down the target areas. The groundwater prospects maps will serve the twin benefit of helping the field geologists to: quickly identify the prospective groundwater zones for conducting site specific investigations and; Select the sites for planning recharge structures to improve sustainability of drinking water sources, wherever required.

Integration of remote sensing data and GIS for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, which assists in assessing, monitoring, and conserving groundwater resources (Magesh et al, 2012).The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et al., 1996). Conversion of maps into digital layers will enable the analysis of these maps by GIS tools. In models derived through integration of various thematic maps using a GIS approach, several parameters are commonly involved to assess groundwater potential in the study area. This include topography, drainage density, lineament, geology and land use.

Topography relates to the local and regional relief and gives an idea about the general direction of groundwater flow and its influence on groundwater recharge. The drainage density characterizes the relative rainwater that could infiltrate the subsurface. Lineaments are simply linear features on the earth surface, possibly fault lines, cracks etc. Lineaments like joints, fractures and faults are hydrogeologically very important and may provide the pathways for groundwater movement (Sankar, 2002).Fractures in rocks increase their secondary permeability and porosity and thus accelerate vertical water percolation to recharge the aquifers. For this reason, identifying fractures in rocks is considered as a major factor in identifying groundwater productive areas (Machiwal et al., 2011). Lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. The lineament map is generated from the satellite imagery by identifying the fault lines in the imagery using the ArcGIS while the density of the lineament is generated using the lineament map.Geology is the key parameter in identifying groundwater zones. The types of rock formations inherent in the study area are the most valuable clues of all.

Land use is clearly constrained by environmental factors such as soil characteristics, climate, topography, and vegetation. The Land use/ Land cover map of an area provides important indications of the extent of groundwater requirement and utilization (Narendra et al. 2013).
Awun Basin (Figure 3), the study area is a small watershed located within Kwara state, Nigeria and it is located between Latitudes 8°10’00” North and 9°00’00”North and Longitudes 4°10’00”East and 4°50’00”East. The basin has 3 tributaries namely; Oyun sub basin, Moro Sub basin and Asa Sub

ISSN: 2315-6686

basin. The basin is similar to Asa river sub basin which consists mainly of basement complex rocks of the older granite type and also the undifferentiated types. These rocks in many places have been greatly weathered in-situ and hence there are several pockets of weathered sand and sandy clay lenses within the basin, some of these pockets of weathered materials appear on the surface in several areas (Abdulhaleem, *et al*, 2013).The most appropriate scale of management of the river basin in of water resources according to Sule and Alabi (2013) is the stream order concept and he therefore classified Awun River as the highest order stream of watershed or basin in the area.The study seeks to apply the instrument of remote sensing and GIS in the delineation of groundwater potential of basin using Awun catchment as a case study.

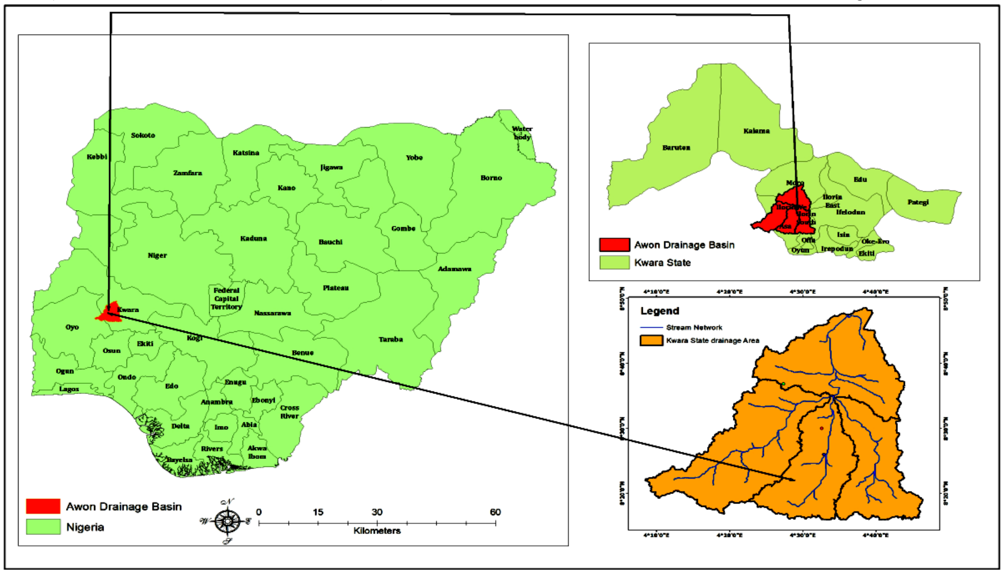

Figure 1: Map of Nigeria showing Kwara State and Awun Drainage basin with network of rivers.

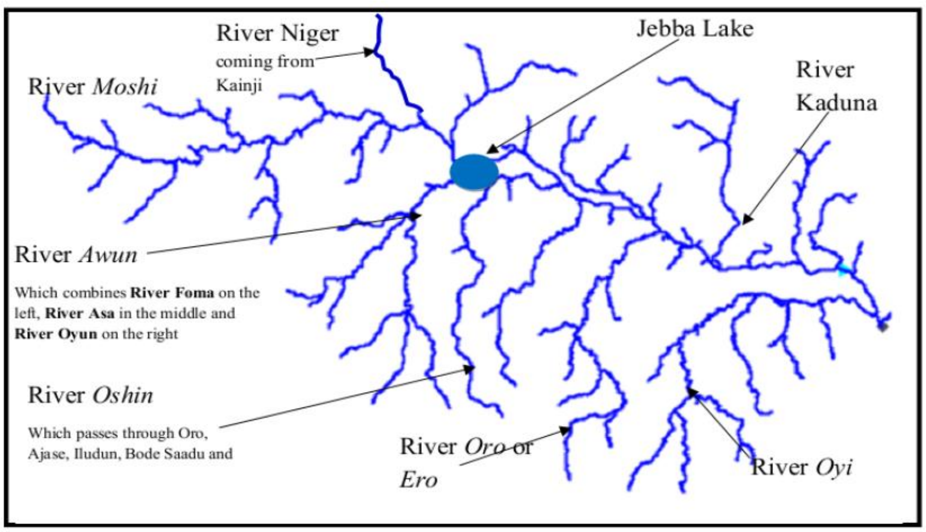

Figure 2: River Awun and other rivers discharging into the River Niger [Source: Sule and Alabi 2013]

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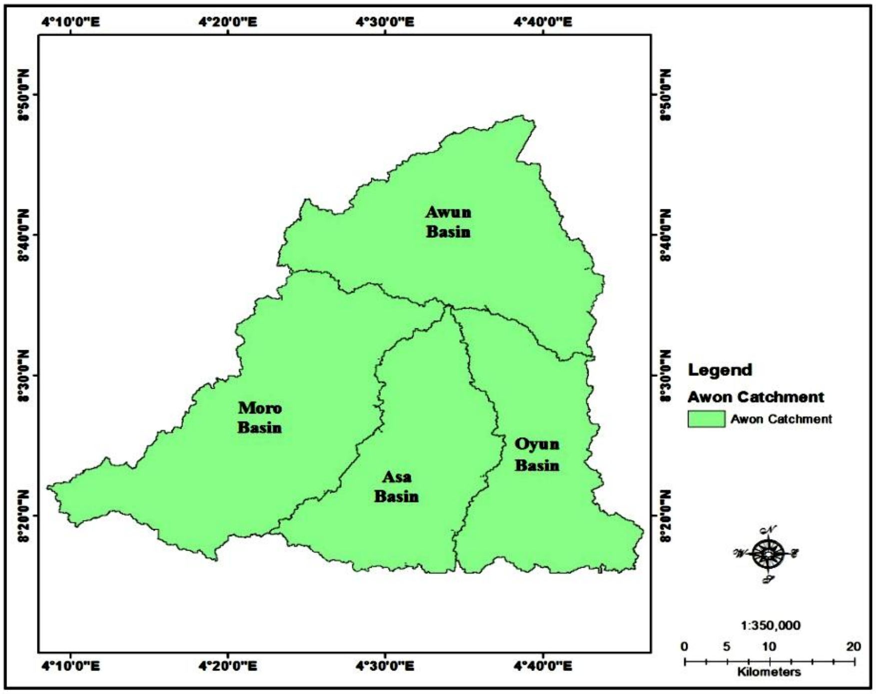

Figure 3: Map of Awun basin with its three major sub-basins: Moro basin, Asa basin and Oyun basin

Materials and Methods

The data required for the study and their sources are as tabulated in Table 1 and the approach used in this study is illustrated step by step in Fig.4. The study area has a total area of 2061 Km^2 and lies within the crystalline hydrogeological province of northern Nigeria belonging to the Younger Granite and BasementComplex suites. The sampling frame for this study covered the entire political boundary of Awun Basin of Kwara State. These involve the data obtained from the satellite image and SRTM.For an accurate delineation of groundwater potential zones, a GIS-based multi-criteria evaluation (MCE) technique involving GIS, Analytical hierarchical process (AHP) by Saaty (1992) and basic descriptive statistical techniques (percentages and charts) was employed. Land use, soil, slope, geologic formation, lineaments and drainage density, as well as borehole logs of the study area, was put into perspective for the analysis while weightages consistent with the percentage influence of each factor on groundwater availability was calculated based on Saaty (1992) AHP model. ArcGIS 10.3 weighted overlay tool was then used to delineate the groundwater potential zones.

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Table 1: Data required for study and their sources

S/No.	Data	Characteristics	Source
1.	Satellite Image of Ilorin west	Landsat Oli/Tirs, 2016, 15m resolution	GLCF
2.	SRTM (Shuttle radar topographic mission)	1.5^0 resolution	MapMart
3.	Thematic Map of Awun Basin	Road networks, streams, railroad, and other features	Open Street Maps (OSM), NASRDA, GISCleric.

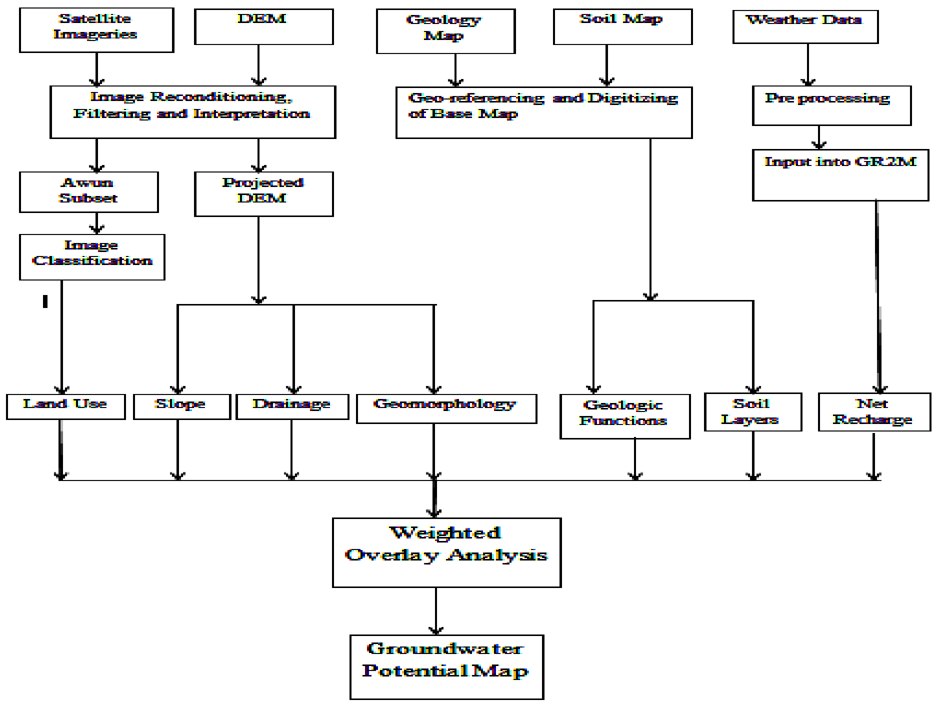

Figure 4: Methodological Framework

The Land-use/Land-cover map was generated from the Landsat OLI/TIRS 2015 satellite imagery while the land use analysis was carried out using ArcGIS 10.3 image classification tool. Five distinct land use classes were generated, i.e. built-up areas, bare surfaces, water bodies, vegetated areas and wastelands. In the context of the multi-criteria analysis (MCA), each land use was ranked on a scale of 1-5 based on its influence on groundwater availability; 1 for lowest contributor and 5 for highest. The slope angle and steepness of the study area was generated using the SRTM of the study area. Drainage density analysis of the study area was carried out in phases. The first phase was the extraction of all stream networks using the SRTM and an Administrative map of the area. The second phase was the generation of the flow direction, accumulation, distribution of the streams, and the density map of the streams. Lineaments was extracted using band combination (7,4,1) of the Landsat 8 images,

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Sobel 5x5 filtering technique was also carried out on the SRTM to generate the lineaments. The lineaments was digitized and densified.

As a first step in locating favorable conditions for groundwater development, geologic maps and cross sections showing the distribution and positions of the different kinds of rocks, both on the surface and underground was prepared. MCA was used to analyze the level of influence of all variables in order to accurately delineate groundwater potential zones.Weighted index overlay analysis was adopted as a simple mathematical model for a combined analysis of multi-parameters because of its spatial dimensionality and ability to integrate varying complimentary and often unorganized bits of spatial data, (Preeja, *et al*. 2011). During the weighted overlay analysis, the ranking was given for each individual parameter of each thematic map and the weightage were assigned according to the influence of the different parameters and was presented in Table 2. This weightage has been taken considering the works carried out by researchers such as Rao and Jugran (2003), Krishnamurthy et al. (1996) Saraf & Choudhary (1998).

Table 2: Layers and their weighting factors

Thematic layers	Features/Categories	Rank	Weight
Geology	Schist, Undifferentiated	3	25
	Pegmatite	1	
	Quartzite	4	
	Pelitic schist	3	
	Migmatite	1	
Slope	0-5%	5	20
	5-10%	4	
	10-15%	3	
	15-20%	2	
	20-40%	1	
	40-65%	1	
Soil	Ferric Lixisols	4	10
	Ferric Luvisols	3	
Land use/ Land cover	Built up	1	15
	Bare surface	3	
	Vegetation	5	
	Wasteland	3	
	Wetland	5	
Lineament density **(Km/grid)**	0 - 12	5	10
	12 – 23	4	
	23 – 34	3	
	34 – 45	2	
	45 - 56	1	
Drainage density	<0.54	5	5

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Table: 2 Continued

(Km/grid)	0.54-0.71	4	
	0.71-0.93	3	
	0.93-1.23	2	
	> 1.23	1	
Elevation (Meters)	<151	5	15
	152-180	4	
	181-210	3	
	210-250	2	
	250-394	1	

Source: Adapted from Nag et al, (2005)

All the thematic maps were converted into grid (raster format) and superimposed by weighted overlay method (rank and weightage wise thematic maps and integrated with one another. For this analysis, the total weights of the final integrated grids were derived as sum of the weights assigned to the different layers based on suitability. The modelling involved delineation of zones of varying groundwater potential based on integration of six thematic maps in a raster based GIS. The six parameters considered are: Soil, Geology, Land use/ Land Cover, Lineament and Drainage and elevation. Every class in the thematic layers was placed into one of the following categories viz. (i) Moderately High (ii) Moderate (iii) Low, depending on their level of groundwater potential. Considering their behaviour with respect to groundwater control, the different classes were given suitable values, according to their importance relative to other classes in the same thematic layer.

Results and Discussion

Preparation of Thematic Maps

The geology of the study area as shown in Fig. 5, is dominated by the Precambrian basement rock units consisting of Igneous and Metamorphic rock units, i.e. Migmatite Gneiss, Pegmatite, Schist and Quartzite. The Migmatite Gneiss and Schists rocks are widespread over the study area covering about 62.95km^2 (63%) and 30.03km^2 (30%), respectively. Pelitic Schist, Pegmatite and Quartzite are limited to the North eastern and North western parts of the study area covering about 3.68 km^2 (3.7%), 2.622 km^2 (2.6%) and 0.66 km^2 (0.7%), respectively.

An understanding of the local geology was developed based on existing maps as Pegmatite schist and Pelitic schist has little influence on groundwater availability based on its poor infiltration capacity while Quartzite has a moderate influence on groundwater potential. The slope of the study area was classified into six classes: less than 5 percent slope angle (plain area), slope zone 5-10%, 10-15%, 15-20%, 20-40% and above 40%.Weights of 5, 4, 3, 2, and 1 were respectively assigned to them based on their groundwater prospects. In this study, higher weights were given to shallow slopes and lesser weights were assigned to steeper slopes because runoff is directly proportional to slope. The slope degree map of the area was generated from the digital elevation model as shown in Fig.6.

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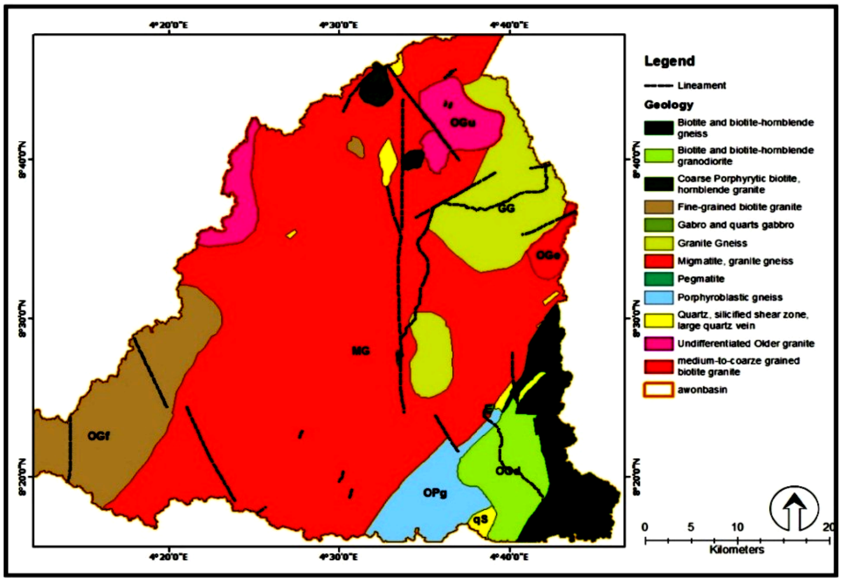

Figure 5: Geological Map of the study area

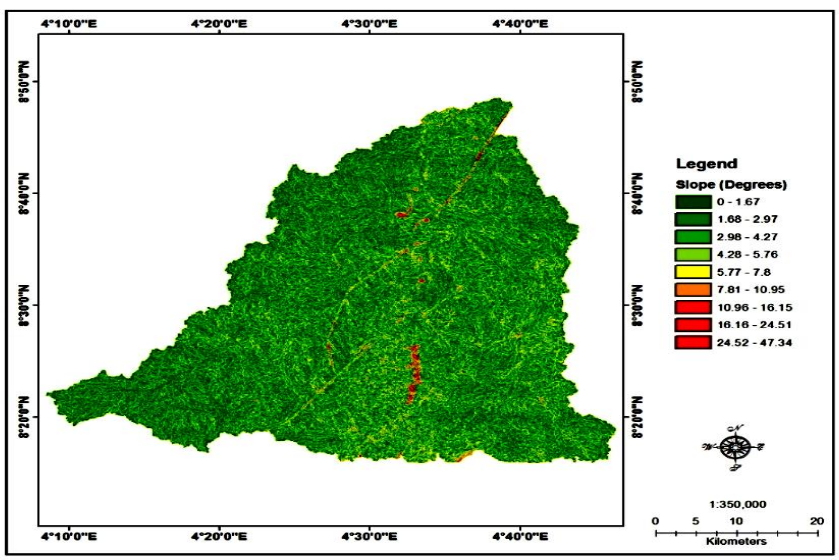

Figure 6: Slope degree map of the study area

Table 3 shows the classification of the entire catchment based on slope percentages. Gentle slope (0-5%) indicates the presence of high groundwater potential zones, high slope (>10%) shows the presence of poor groundwater potential zones as water runs rapidly off the surface.

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Table 3 Slope percentages of study area

Slope Angle %	Area (Km^2)	Percentage
0 - 2.23	855.53	37.16
2.24 - 3.9	840.04	36.48
3.91 - 6.31	490.66	21.31
6.32 - 12.44	108.47	4.71
12.45 - 47.34	7.91	0.34
47	0.00	0.00
Grand Total	2302.61	100

Table 4: Percentage distribution of the land use classes for study area

Land use classes	**Area**	**Percentage**
Artficial surfaces and associated areas	59.11	2.57
Bare areas	4.64	0.20
Closed to open shrubland	1860.75	80.81
Mosaic cropland vegetation	186.38	8.09
Mosaic forest or shrubland/grassland	19.74	0.86
Mosaic vegetation / cropland	0.29	0.01
Open (15-40%) broadleaved decidous forest /woodland	164.23	7.13
Water bodies	7.46	0.32
Grand Total	2302.61	100

The major land use/land cover classes such as built up land, vegetation, bare surfaces, wetlands, and wastelands were identified in the study area as shown in Fig. 7. Table 4 details the land use classes, their percentage distribution as well as assigned weights based on their groundwater prospect zones. Based on land use, wetlands and vegetation are excellent sites for groundwater exploration. About 48.25% of the catchment area, covered by vegetation and wetlands are highly favourable for groundwater potential while 46.42% comprising of wastelands and bare surface are mildly favourable.

Figures 8a and 8b show the drainage density map of the sub-basins and the streams respectively within the study area. The drainage is one of the factors which play the important role in groundwater occurrence. The drainage map of an area gives an idea of the permeability of rocks and is an indication of the yield of the basin (Brater and Wisler, 1959). The area of very high drainage density represents more closeness of drainage channels and vice versa; hence, the higher the drainage density, the greater the runoff and the possibility of recharge or potential of groundwater.

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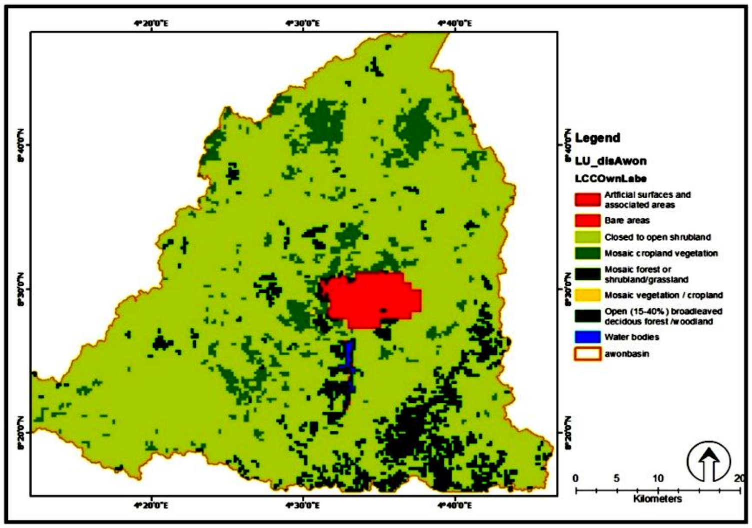

Figure 7: Land Use classes for the study area

Furthermore, it has been suggested that a measure for permeability is drainage (Meijerink, 2007). The tributaries have spread irregularly in all directions and join the main stream at all angles. This suggests a dendritic and sub-dendritic drainage reflecting the homogenous character of the subsurface materials in the study area. The drainage density map was generated from drainage network of the basin using GIS software. High drainage density is an unfavourable site for groundwater existence, moderate drainage density has moderate groundwater potential and less/no drainage density is high groundwater potential zone (Todd and Mays, 2005).

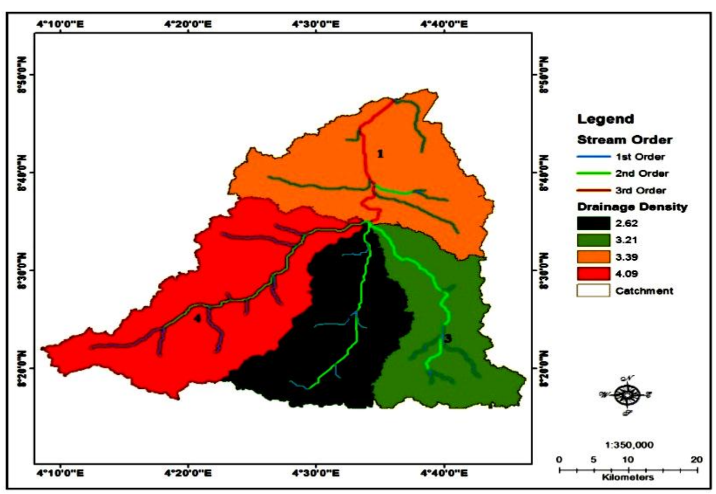

Figure 8a: Drainage density of the sub basins within the study area

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The study area is criss-crossed with lineaments consequent to a number of tectonic activities in the past. The prominent directions identified are S-SE, N-E trends. Areas with high lineament density include: Oloru, Shao, River Oyun, Dongari, Owode, Ore and Ogbondoroko. Areas with higher lineament density are regarded as good for groundwater development. The weights have been given by setting more threat levels to higher lineament density which is groundwater prone (Fig.9).

Fine-grained soils limit infiltration due to apparently low permeability unlike coarse-grained soil materials where water can infiltrate easily because of high permeability. Table 5 shows the percentages of soil classification for the study area. In this study, two main soil units were identified: Ferric Lixisols and Ferric Alisols as shown in Fig. 10. Given the relationship between the sand content/coarse grained materials and permeability, higher weightage was given to soils with relatively higher permeability; thus Lixisols are assigned a weightage rank of 4 compared with that of Alisols with a rank of 2 indicating lower groundwater potentials.The rainfall distribution in the study area ranges from 1,300 to 1,350 mm suggesting a humid tropical terrain with the entire study area receiving more than 1,000 mm of rainfall annually.

Table 5 Soil classification in percentages

Soil	Area	Percentage
Lf26-a	1960.21	85.13
Lf12-a	329.82	14.32
Lf1	12.58	0.55
Grand Total	2302.61	100.00

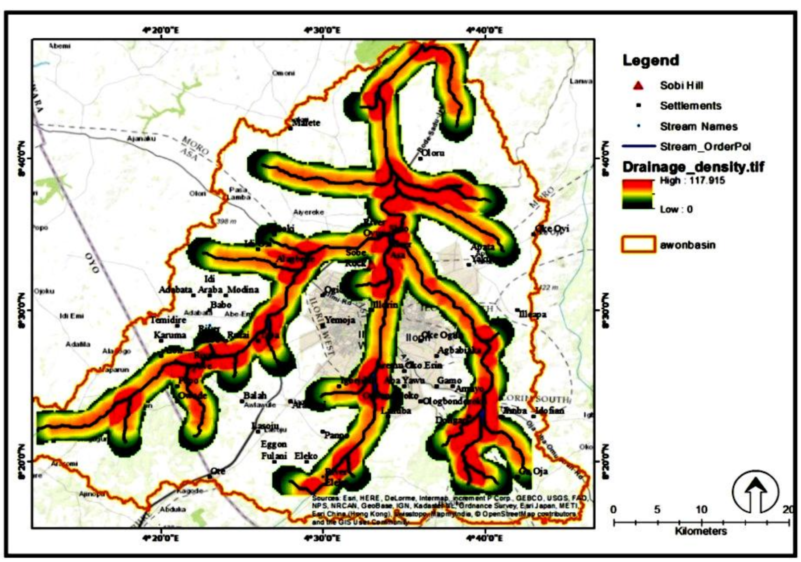

Figure 8b: Drainage density of streams in the study area

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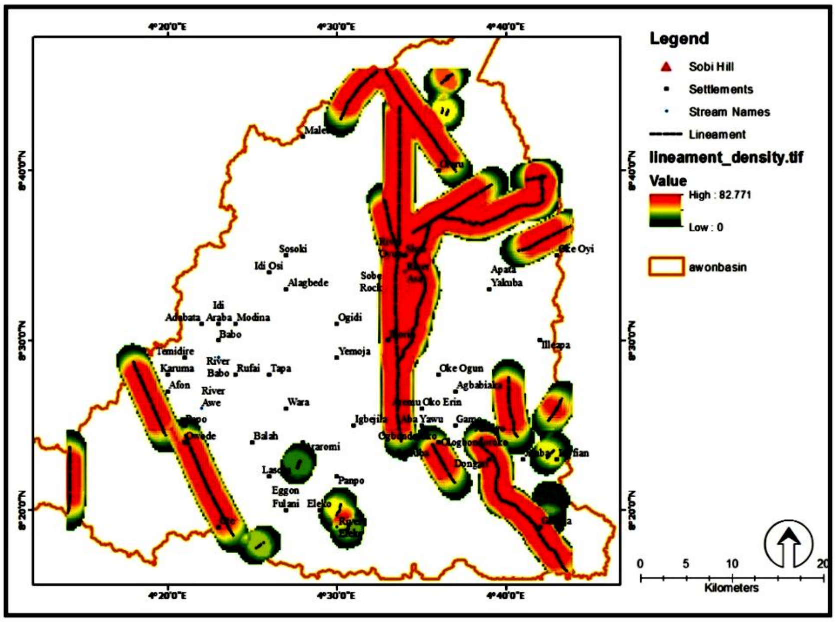

Figure 9: Lineament density of the study area

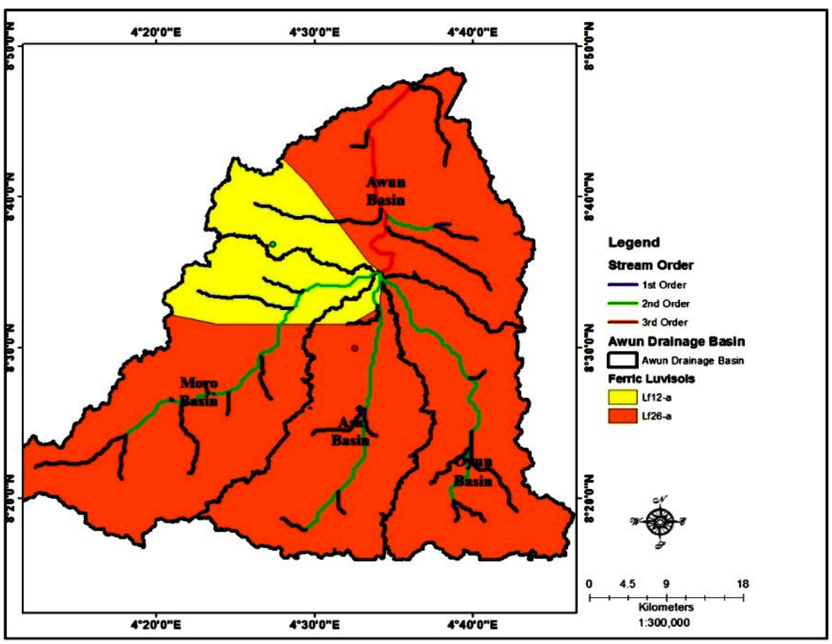

Figure 10: Soil classification of the study area

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Groundwater Potential Zones

From the analysis carried out, results of the weighted overlay shows that there are no areas of acutely high or low groundwater potential in the study area. Moderate potentials of groundwater is obtainable. The spatial distribution of the various zones of groundwater potential obtained from the model generally shows regional patterns related to soils, drainage, geology, lineament and land use patterns. The good zonal categories are along major lineaments and drainage channels with and without structural control, highlighting the importance of lineaments, geological and soil units for groundwater investigations. Areas with moderate groundwater potential are attributed to combinations of lithology and landform. The poor categories of groundwater potential are distributed mainly along hills, ridges and pediments and to some extent along lineaments in the low to poor slope classes as shown on Fig. 11.

Table 6 shows the percentage of groundwater potential zones while Table 7 shows the yield bases on the existing boreholes in the area as presented by Sule, *et al* (2013). The actual borehole data in the area reveals that yields in the area ranges between 0.24 and 2.52 l/s (Table 7). Areas with low potential account for less than 1% of the study area with a yiel less than 0.24 l/s. For the areas with moderate and moderately high account for 43.7% (0,24 - 1.00 l/s yields) and 56% (1.00 -2.52 l/s yields) respectively. The areas with moderately high groundwater potentials include; Malete, Shao, Ogidi, Agbabiaka, Oko Erin, Oyun and Sobi. The Groundwater potential map indicates that the study area with about 99% of the area has moderate groundwater potential.

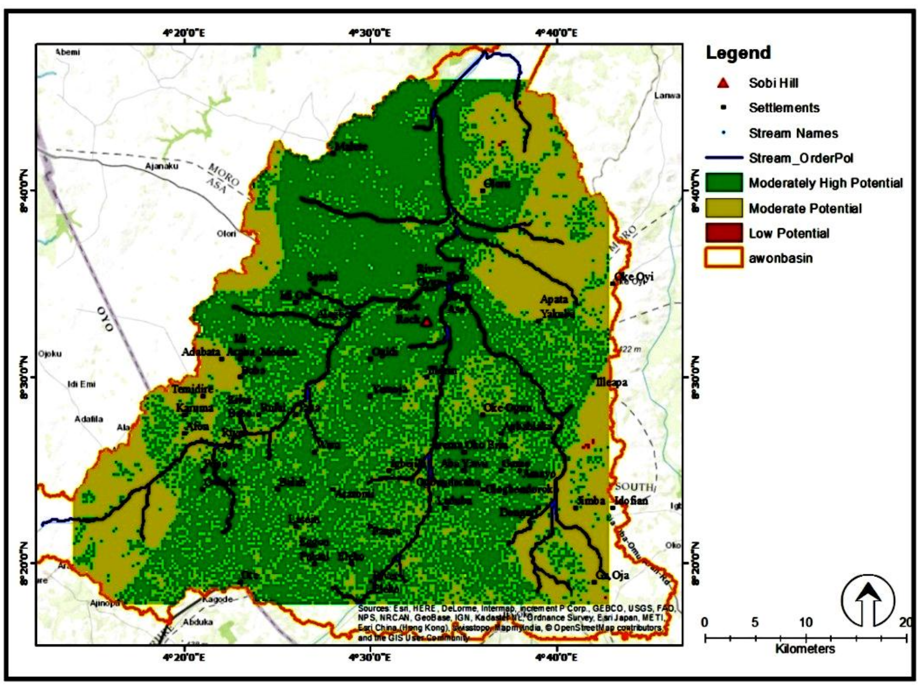

Figure 11: Map of Groundwater Potentials

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Table 6: Percentage of groundwater potential zones

GWP	Area	Yield (l/s)	Percentage
Moderately High Potential	1294.333295	1.00 – 2.52	56.21157272
Moderately Potential	1007.548995	0.24 – 1.00	43.75682354
Low Potential	0.727711015	< 0.24	0.031603746
Total	2302.61		100

Conclusion

This work has applied the use of remote sensing and GIS to effectively delineate groundwater potential areas. It can be inferred that high, moderate and low potential zones of ground water prospect were observed in the study area with about 99% of the area having moderate groundwater potential. Rainwater harvesting or any other artificial recharge methods will be suitable in improving the ground water potential in low and moderate potential zones. Recharging process can be made effective and efficient to meet the demands of water for human consumption and irrigation purpose through planning and using appropriate scientific methods and tools.

Table 7: Results of aquifer characteristics within [Adopted from Sule, *et al*, 2013]

S/N.	Location	Coordinates (Northing, Easting)	Discharge (l/s)	GW Potential Zone Class
1	Sarumi	8° 30’21”N, 4°32’16”E	0.3	MP
2	Adewole	8° 29’5.05”N, 4°30’30.00”E	1.7	MHP
3	Agbo-Oba	8° 29’11.05”N, 4°31’39.15”E	1.3	MHP
4	Alanamu	8°29’4.15”N, 4°32’9.35”E	1.15	MHP
5	Baboko Market	8°29’23.55”N, 4°32’20.40”E	2.52	MHP
6	Eruda	8°28’08.15”N, 4°32’3.45”E	1.5	MHP
7	Gbagba	8°26’08.20”N, 4°30’30.05”E	0.24	MP
8	Irewolede	8°28’14.15”N, 4°33’14.55”E	1.2	MHP
9	Ita-Amodu	8°30’01.15”N, 4°32’20.05”E	0.5	MP
10	Oja-Iya	8°29’11.05”N, 4°32’52.10”E	1.0	MHP
11	Oja-Oba	8°29’17.10”N, 4°32’3.15”E	1.35	MHP
12	Oju-Ekun	8°30’24.15”N, 4°32’17.12”E	0.55	MP
13	Oke-Aluko	8°29’06.05”N, 4°33’10.10”E	1.0	MP
14	Okeleru	8°30’01.10”N, 4°32’02.20”E	0.75	MP
15	Oko-Erin	8°28’28.10”N, 4°32’20.11”E	0.854	MP
16	Oko-Olowo	8°31’57.10”N, 4°29’18.10”E	0.55	MP
17	Oloje Low Cost	8°30’17.05”N, 4°30’11.25”E	1.25	MHP
18	Olunlade	8°28’00.05”N, 4°34’14.55”E	0.684	MHP
19	Pakata	8°29’50.00”N, 4°31’29.05”E	1.13	MHP
20	Sawmill	8°28’14.15”N, 4°31’55.00”E	1.0	MHP
21	Surulere	8°28’53.05”N, 4°32’10.00”E	0.9	MP

Note: MP – Moderately Potential, MHP – Moderately High Potential

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