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Integrating Geographic Information System (Gis) and Remote Sensing (Rs) for Groundwater Resources Prospecting

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Abstract: Groundwater can be effectively managed when reliable information is available for planning purposes. The integration of GIS and RS provides a significant approach for assessing groundwater potentiality. This study assessed the role of GIS and RS in groundwater resources management and planning in Afikpo sub-basin of Nigeria, based on the integration of thematic maps such as geology, slope, lineament, land use/land cover and drainage map of the study area. The study revealed that the groundwater potential zones in the study area had excellent, very good, good, moderate and poor prospects with an aerial extent of 136.31 km^2, 1035.44 km^2, 1432.26 km^2, 472.48 km^2 and 13.22 km^2 respectively. The large aerial extent of favorable groundwater recharge potentiality in Afikpo sub-basin was found to have been as a result of the high amount of lineaments and the sedimentary geologic environment. The study further showed that for effective water resources management and planning, the integration of GIS and RS, which could serve as decision support tool needs to be adopted effectively in Nigeria.

Keywords: Groundwater, Remote Sensing, Lineaments, Sedimentary

1. Introduction

The expediency of groundwater development for irrigation, industry and domestic purpose cannot be over emphasized being a main source of potable water [1]. Hence, it is a most valuable natural resource and needs judicious use in order to achieve sustainable management [2].

Groundwater resources are gaining increasing importance and they represent an increasing proportion of the water supplies used for different applications [3].

Integrated remote sensing and GIS has proved to be an efficient innovative tool in groundwater studies [4]. Recently GIS is being used for various purposes such as evaluation of ground and surface water resources, feasibility of recharge sites, identifying contaminated sites, land use pattern, and others [5]. Researchers such as Teeuw [6]; Goyal et al. [7]; Saraf and Choudhary [8] and Senthil and Shankar [2], have successfully applied remote sensing and GIS technique for groundwater prospecting and recharge sites. With the capabilities of the remotely sensed data and GIS techniques, numerous databases can be integrated to produce conceptual model for delineation and evaluation of groundwater potential zones [2].

Groundwater is a vital natural resource for reliable and economic provision of safe water supplies in both the urban and rural environment [9]. Therefore, in the process of exploitation, action is usually taken to protect its quality as well as ensuring the sustainability of the resource [10].

Groundwater occurrence depends primarily on geology, geomorphology/weathering and rainfall (both current and historic). This interplay of these three factors gives rise to complex hydrogeological environments with countless variations in the quantity, quality, ease of access and renewability of groundwater resources [11, 8]. Hydrogeological conditions and the aquifer system's characteristics have a direct bearing on groundwater management [12]. Development of groundwater resource therefore depends on an accurate understanding of the hydrogeology. This is imperative because, without accurate data/information, it is difficult to access the success of groundwater supply.

Hydrological applications such as groundwater for resources assessment, planning, soil erosion and urban drainage system based on remotely sensed data derivative has gained popularity with the advent of raster and vector GIS environment [13, 14, 15]. Groundwater prospecting and development require large amount of diverse data from various sources. Since groundwater occurrence is a subsurface phenomenon, its prospecting is based on indirect analysis of some directly observable terrain features like geological, geomorphological, structural features and their hydrological characteristics [2]

It is based on this that the study integrated innovative technology such as remote sensing and GIS techniques to delineate groundwater prospective zones in the study area.

2. Description of Study Area

Afikpo sub-basin is located in the southeastern part of the sedimentary basin lower Benue Trough. The Afikpo basin is situated in the southeastern Nigeria (figure 1) and it covers about 60, 000 square km [16]. The Afikpo Basin represents an elongate NE-SW depocenter [16]. The climate of the study area is that of tropical rainforest with distinct wet and dry seasons. The wet season is characterized by a period a prolonged period of rainfall which extends from April to October, while the dry season is characterized by a period of dry hot weather. This season extends from November to March including the harmathan period [17]. The mean annual rainfall ranges from 19,900 mm to 2,200 mm [17].

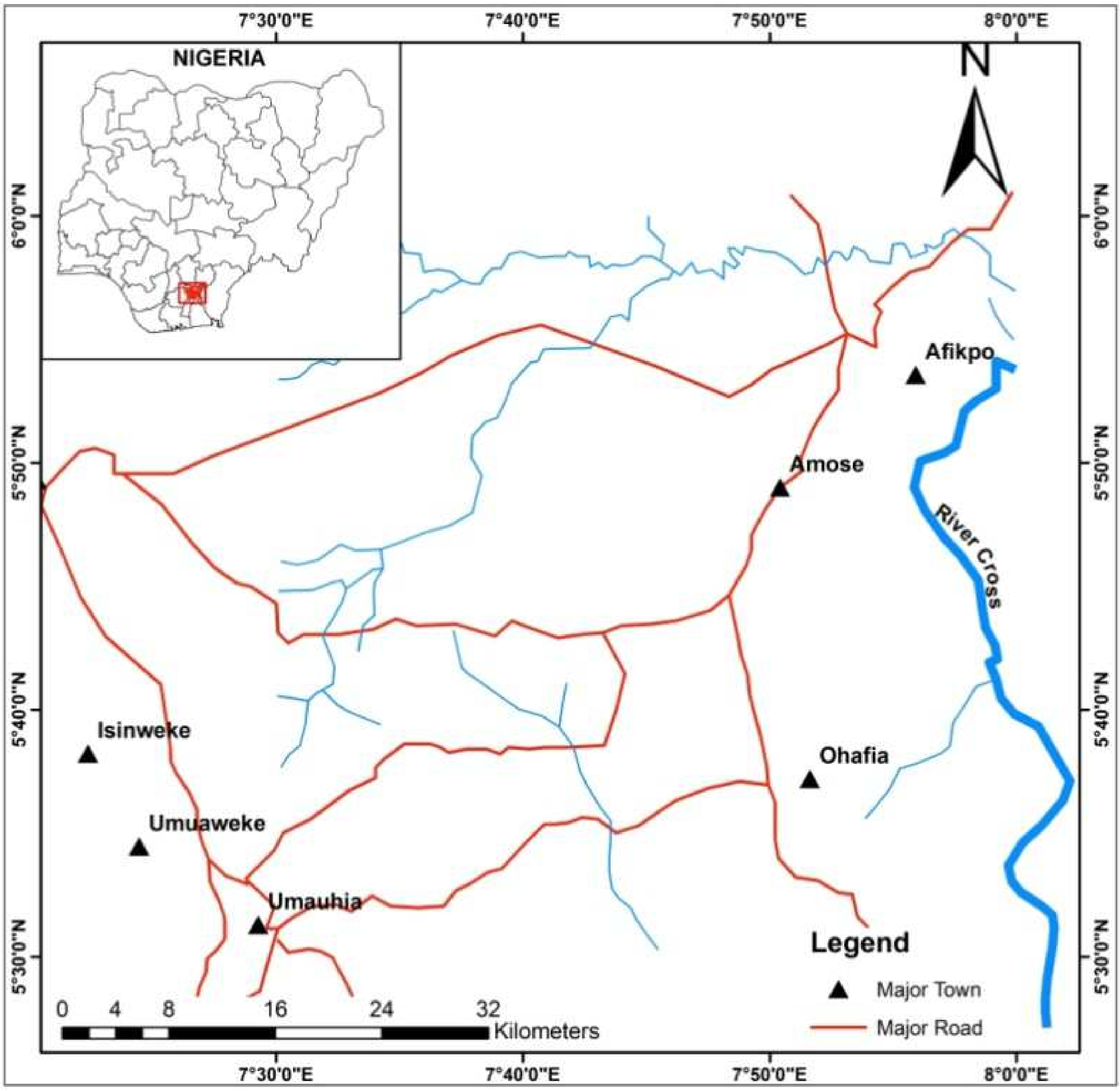

Figure 1. *Map of the Study Area (Adapted from Aiyelokun et al. [1]).*

3. Methodology

3.1. Data Collection

The lands at data used was the Operational land Imager (OLI) acquired on 5th of February 2016. The satellite data have 30m spatial resolutions and spectral range of 0.45-2.35 micro meter with bands 1, 2, 3, 4, 5, 6, 7, 8 and 12. Remotely sensed data, such as aerial photos, was used in the present study to identify factors determining groundwater prospect which include geological features, topography, drainage as well as the land use of the study area (Table 1). Geographic Information System (Arc/GIS 10.0) was used for digitization, editing and topology creation; Assignments of weightages of different themes and classes integration of multi-thematic information and delineation of groundwater prospect map was generated through the weight overlay tool of Arcmap 10.0.

Table 1. *Factors Affecting Groundwater Prospecting Classified Criteria.*

Factor	Basis of Categorization
Geology	Rock type, weathering character, joint, fractures
Land cover/land use	Type, areal extent, associated vegetation
Lineaments	Lineament density
Drainage	Drainage density
Slope	Slope gradient

3.2. Factor Establishment

Each factor influencing groundwater prospect was examined and was assigned an appropriate weight. According to Hsin-Fu et al. [18], major interrelationship between two factors could be assigned a weight of 1.0, while a minor interrelationship between two factors is assigned a weight of 0.5. The total weight of each factor is the representing weight of the groundwater prospect. For instance, major interrelationships exist for geology on lineaments, drainage and, land use/cover. Therefore, its evaluated weight is 3.0. This high weight value means that the factor significantly influences the groundwater recharge. The process for determining the relative rate of each factor is shown in table 2. The extent of the influence of every factor on groundwater prospect was assessed from the interrelationships among both major and minor factors. The score of each groundwater prospecting factor was calculated as 100 multiplied by the weight of the groundwater prospect divided by the total weight of each prospect potential factor [18] (Table 3).

Table 2. *Relative rates for each factor (Adapted from Hsin-Fu et al. [18]).*

Rates	Calculation Process	Proposed Relative Rate
Geology	3 x 1.0 = 3.0	3
Land cover/land use	1 x 1.0 + 3 x 0.5 = 2.5	2.5
Lineaments	2 x 1.0 = 2.0	2
Drainage	1 x 1.0 + 1 x 0.5 = 1.5	1.5
Slope	1 x 1.0 + 1 x 0.5 = 1.5	1.5

Table 3. *Summary of Map weight (Adapted from Aiyelokun et al. [1]).*

Factor	Calculation Process	Map Weight
Geology	100 x (3/10.5) = 29	29
Land cover/land use	100 x (2.5/10.5) = 24	24
Lineaments	100 x (2/10.5) = 19	19
Drainage	100 x (1.5/10.5) = 14	14
Slope	100 x (1.5/10.5) = 14	14

3.3. Integration of Thematic Maps Through GIS

The integration of various thematic maps through GIS tools involves analysis that considers multiple criteria influencing a process. The various thematic maps used in the study were converted into raster form considering 100 m as cell width to achieve considerable accuracy. These were then reclassified and assigned suitable weightage following the methods used by Srinivasa Rao and Jugran [19], Aravindan et al.[20] and Krishnamurthy et al. [21]. The summary of the process is given in table 4, the occurrence and movement of groundwater in the study area is controlled by five various factors with map weight based on their level of influence.

After assigning the weightages to the themes and features, all the themes were converted to raster format using Spatial analyst, extension of Arc/GIS software. Spatial analyst extension of ArcMap 10.0 was used for converting the features to raster and also for final analysis. In this method, the total weights of the final integrated map were derived as sum or product of the weights assigned to the different layers according to their suitability. Further, different units of each theme were assigned knowledge based hierarchy of ranking from 1 to 5. On the basis of their significance with reference to groundwater prospects, where 1 denotes poor prospects and 5 denotes excellent prospect of groundwater (table 4).

Table 4. *Ranks and Weightages for Various Parameters for Groundwater Prospect (Adapted from Aiyelokun et al. [1]).*

Thematic Layers	Map weight (%)	Individual features	Rank	Groundwater Prospect
Geology	29	Afiko Sycline	2	Moderate
		Ajali Formation	5	Excellent
		Alluvium	4	Very good
		Aisu group	4	Very good
		Ecoene formation	5	Excellent
		Exeaku formation	1	Poor
		Mamu formation	3	Good
		Nkporo group	2	Moderate
		Nsukka formation	4	Very good
		Paleouni Imo Shale	4	Very good
Land use/land cover	24	Agriculture Activities	4	Very good
		Developed Land	2	Moderate

Thematic Layers	Map weight (%)	Individual features	Rank	Groundwater Prospect
		Forest	5	Excellent
		Water Body	4	Very good
Linearment Density	19	High	5	Excellent
		Moderate	3	Good
		Low	1	Poor
Drainage Density	14	High	1	Poor
		Moderate	3	Good
		Low	5	Excellent
Slope	14	High	1	Poor
		Moderate	3	Good
		Low	5	Excellent

4. Results and Discussion of Findings

The integration of GIS and RS for groundwater prospecting in the study area, as well as the maps of various factors influencing groundwater prospect are presented in this section. This involved the implementation of the procedure discussed in the methodology.

4.1. Analysis of Geology

The geology map revealed that ten types of geologic formations could be observed in the study area (figure 2). The detailed description of the geologic formations is explained by Omoboriowo et al. [22] and Chukwu et al. [16]. Based on the characteristics of the rocks, all rocks except Afiko syncline, Mamu formation and Nkporo group could be considered as being in favor of high groundwater prospect in the area having high level of percolation of water.

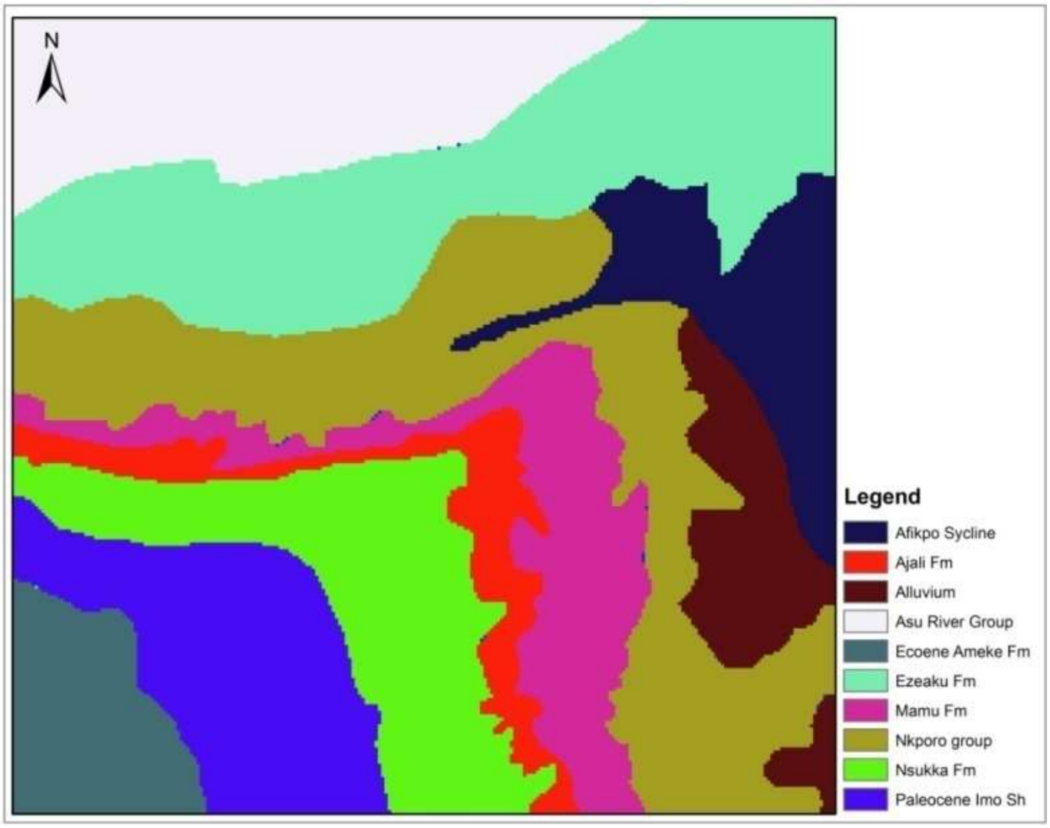

Figure 2. *Geology of the Study Area (Adapted from Aiyelokun et al. [1]).*

4.2. Analysis of Land Use/Land Cover

Land use/cover of the study area is depicted in figure 3. It includes the distribution of areas covered by agricultural activities, and forest, developed area and water body. Shaban et al. [23] concluded that vegetation cover benefits groundwater recharge, which also benefits ground water prospect because biological decomposition of the roots helps loosen the rock and soil, so that water can percolate to the surface of the earth easily. Vegetation prevents direct evaporation of *water* from soil, and the roots of a plant can absorb water, thus preventing water loss. It can be seen from that map that large part of the study area is covered by agricultural activities.

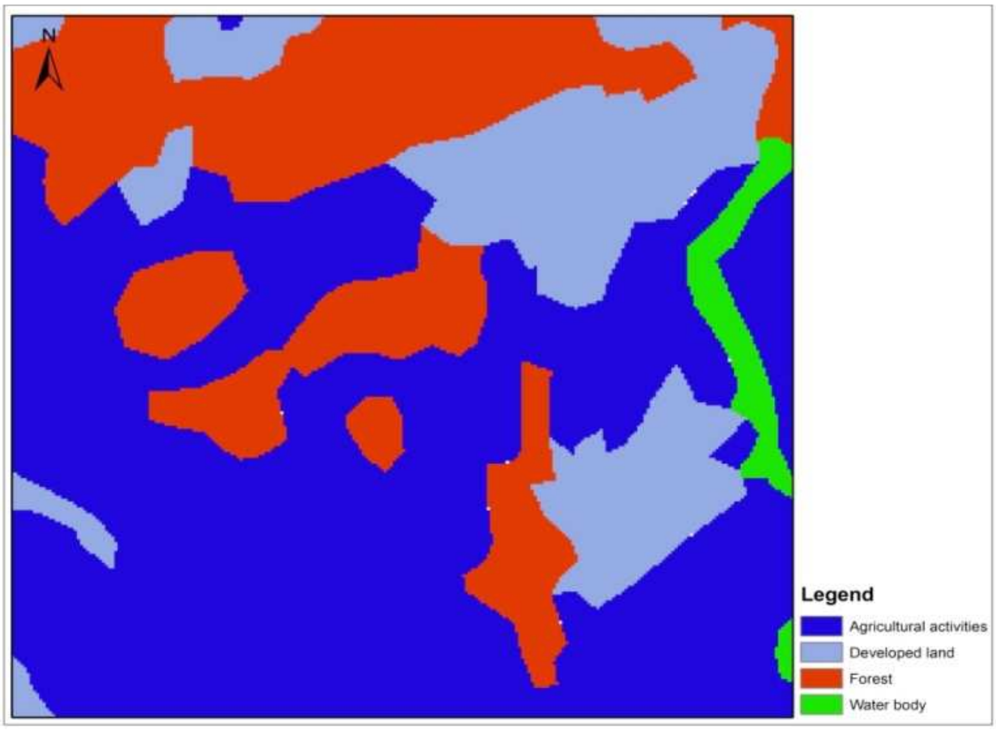

Figure 3. *Land use/land cover of the Study Area (Adapted from Aiyelokun et al. [1]).*

4.3. Analysis of Lineament Density

Lineaments are linear features in a landscape which is an expression underlying geological structures such as faults [16], they are generally referred to in the analysis of remote sensing of fractures or structures [18]. As shown in figure 4, a large part of the study area has low lineament density which implies that only few areas could be regarded has having high prospect for groundwater resources. It could be observed that the north-eastern of the study area has large lineament density which is in agreement with [16].

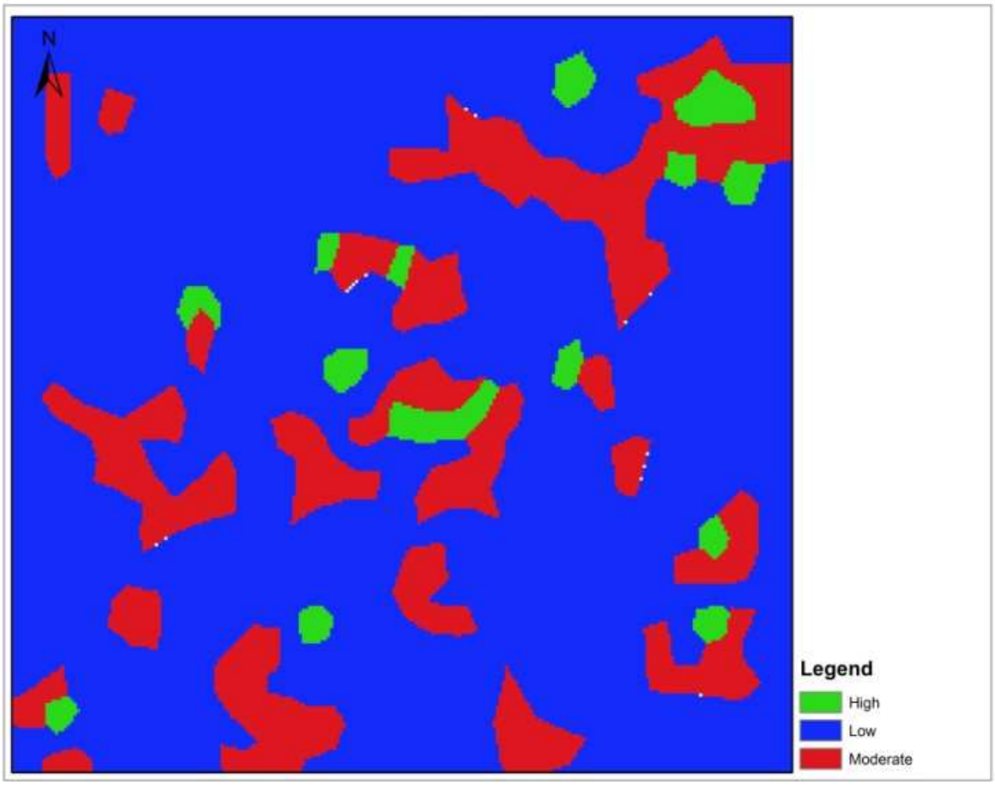

Figure 4. *Lineament Density of the Study Area (Adapted from Aiyelokun et al. [1]).*

4.4. Analysis of Drainage Density

The development of stream segments is affected by slope and local relief and these may produce differences in drainage density from place to place [9]. The drainage density of the area is shown in figure 5, and were classified into very high, high, moderate and low. Drainage density (km/km^2) indicates closeness of spacing of channels as well as the nature of surface material [9]. The more the drainage density, higher would be runoff, and vise visa. Since runoff has negative effect of groundwater percolation, it could be posited that larger part of the study area supported high prospect of groundwater resources based on drainage density.

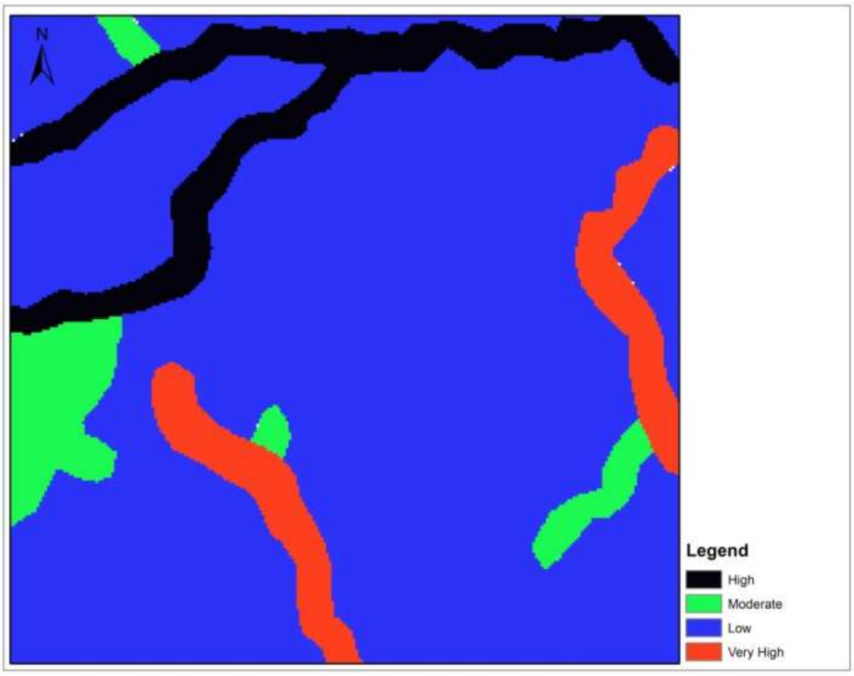

Figure 5. *Drainage Density of the Study Area (Adapted from Aiyelokun et al. [1]).*

4.5. Analysis of Slope

The slope analysis function in GIS was used to assess the variation of slope in the study area. as depicted in figure 6, the slope of the area were classified as high, medium and low slope. A precipitous terrain usually causes rapid runoff and does not store water easily, whereas in gentle slope areas, the time for percolation is increased. Therefore, the high slope the lower the groundwater prospect of the area.

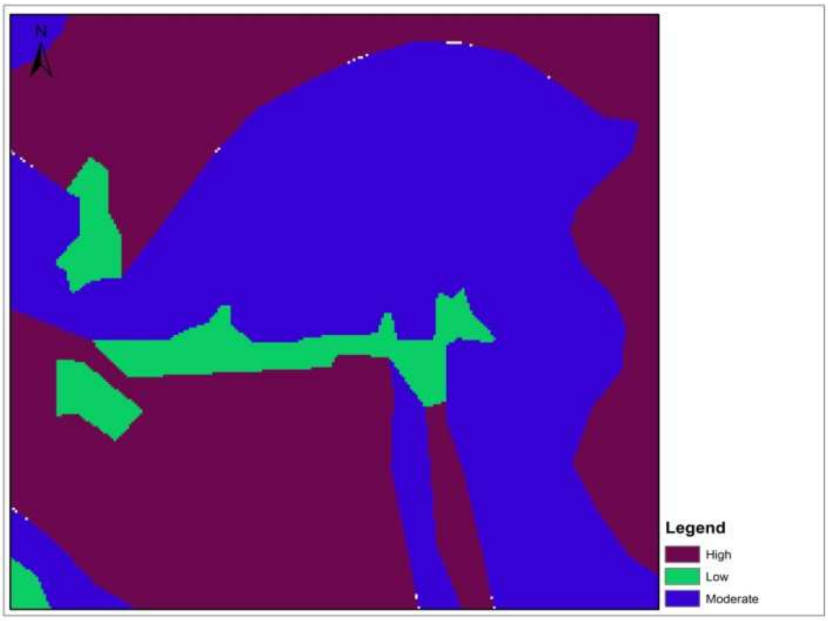

Figure 6. *Slope Map of the Study Area (Adapted from Aiyelokun et al. [1]).*

4.6. Delineation of Groundwater Prospect Zones

In order to delineate the groundwater prospect of the study area, each thematic maps such as geology, lineament density, slope, Landuse/landcover, and drainage density were integrated with appropriate factors using GIS. The summary delineated area is presented in table 6, the table shows larger part of the study area has good prospect for abstracting groundwater resources, while 0.4% of the area has poor groundwater prospect. The high groundwater recharge potentiality in the Afikpo sub-basin of Nigeria is majorly favored by the high amount of lineaments and the sedimentary geologic environment. Furthermore, figure 7 shows the spatial distribution of groundwater resources category with excellent, very good, good, moderate and poor prospects covering an area of 136.31 km^2, 1035.44 km^2, 1432.26 km^2, 472.48 km^2 and 13.22 km^2 respectively.

Table 6. *Summary of Groundwater Potential Zones (Adapted from Aiyelokun et al. [1]).*

Groundwater Potential	Area (Km^2)	Percent
Excellent	136.31	4.4
Very good	1035.44	33.5
Good	1432.26	46.4
Moderate	472.48	15.3
Poor	13.22	0.4
Total	3089.71	100

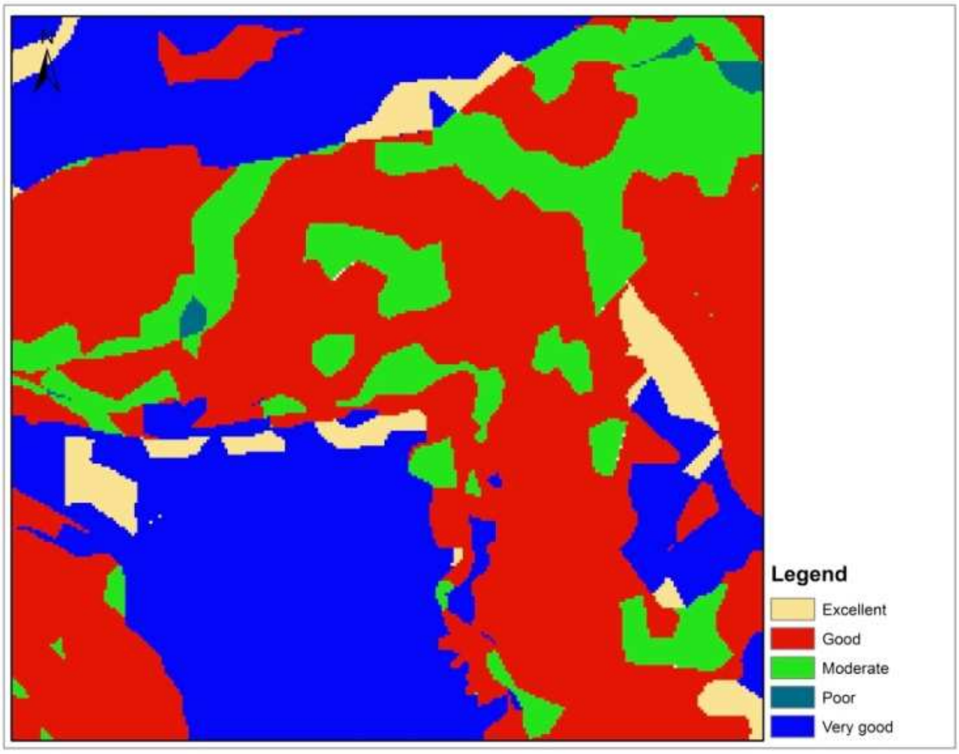

Figure 7. *Groundwater Prospect Potential Map (Adapted from Aiyelokun et al. [1]).*

4.7. Discussion of Findings

The integration of GIS and RS is a promising approach for an effective groundwater resources management and planning, since it can provide a synoptic overview of the hydrogeomorphological characteristics of an area of interest. The findings of the study demonstrate that the groundwater potential zone based on its suitability for abstraction in Afikpo sub-basin can be divided into five categories, namely very good, good, moderate, Excellent, and poor, based on the analysis of the five factors of groundwater potential. Innovative technologies such as Remote Sensing and Geographic Information System (GIS) are very constructive because it involves the integration of various geospatial data especially for groundwater potential zone mapping [2]. Analytical results also demonstrate that the good groundwater prospect potential zone concentrated in the study is due to the distribution of sedimentary geologic formations, forest and agricultural land which have high infiltration ability. According to Aiyelokun et al [1], these findings could be of benefit to water supply planners in strategizing for abstraction of groundwater; it would also be beneficial to environmental engineers in assessing landfill construction prospects, and other stakeholders for the promotion of sustainable development within the study area and Nigeria at large.

5. Conclusion

Groundwater resources in Afikpo sub-basin and other part of Nigeria can be effectively managed if innovative technologies are promoted and welcomed as robust information resource and part of criteria for decision making in prospecting, constructing and managing underground water.

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