Available online at www.elixirpublishers.com (Elixir International Journal)

Geology

ISSN: 2229-712X

Elixir Geology 107 (2017) 47103-47108

Structural Analysis of Geological Features Using Landsat Data: A Case Study of Afikpo and its Environs, SouthEastern Nigeria

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ARTICLE INFO

Article history:
Received: 15 March 2017;
Received in revised form:
2 June 2017;
Accepted: 13 June 2017;

Keywords
Afikpo,
Structural analysis,
Remote sensing,
Lineament,
Drainage,
Tectonic.

ABSTRACT

The study area Afikpo and its environs lie between longitudes $7^{0}45'$E and $8^{o}15'$ E and latitudes $5^{o}45'$N and $60^{o}00'$N. Structural interpretation over the area was carried out using Remote Sensing technique. The objectives of the analysis were to identify the lineament and drainage patterns associated with the study area, identify the structural pattern/trends and correlate the relationship of such structures with groundwater exploration in the area. The image was acquired with an Enhanced Thematic Mapper (ETM) and processed using Integrated Land and Water Information System ILWIS 3.2. Lineament and drainage pattern maps of the same scale as the original landsat imagery were generated and visually analyzed. The orientation of the lineaments in the study area was analysed using a Rose diagram. The result revealed that the area is drained by several rivers observed to be striking NE-SW, NW-SE, N-W and S-E directions, with NE-SW being the dominant trend. The lineament analysis revealed that the drainage observed in the area is structurally controlled and also the trend of the tectonic activity that previously acted in the study area. The regions where the lineaments intercept each are prospective areas for groundwater exploration.

Introduction

Lineaments and drainage patterns are two structural features that can be delineated on landsat imagery. Lineaments could represent faults, folds, fractures or some basement features.

Therefore by definition lineaments are mapable, simple or composite straight/linear features whose part is aligned in a rectilinear or slightly curvilinear relationship and differ distinctly from the patterns of adjacent features and presumably reflect a subsurface phenomenon [16].

Lineaments are classified on the basis of their length into: mega lineament whose length is 300km and above; intermediate lineament with length between 100km and 300km and minor lineament with length less than 100km [4] and [20]. Faults, fractures and dislocations occurring in the brittle basement rocks are caused by tectonism[5] and [6]. These crustal tectonic zones are observed as lineaments on landsat imagery. Such linear zones are weak and are prone to crustal movement.

Lineaments have great controls over the drainage network of any area. Simply put, many lineaments are drainage lines [1], [18] and [17]. This is because streams and rivers travel along zones of weakness and through cracks in the rocks. The relationship between the lineaments and groundwater was proved by [9], [14] and [10] who in their separate studies agreed that high density lineaments indicate in general the presence of groundwater.

In basement rocks, the amount of groundwater available is highly dependent on the storage and rate of infiltration into faults and fractures that are open or close.

It was therefore concluded that tectonic activities which result in brittle deformation generate shear fractures which are orthogonal or inclined to the direction of tectonic stress, that is, it is compressed and light and therefore not transmissive and extension fractures which are parallel to the direction of tectonic stress or orthogonal to the direction of crustal extension are associated with wider aperture [11]. Therefore light/closed fractures (i.e. shear fractures) contain little or no water while open fractures (extension fractures) may produce considerable amount of water. Identifying extension and shear fractures on landsat imagery forms the bases of lineament analysis.

The courses of rivers have been found to lie in the same orientation as structures caused by tectonism and zone of weakness [23] and [18]. Also faults and fractures have been associated with occurrence of waterfalls [24], [19] and [3]. This was seen in the case of the President Figueiredo waterfalls in Brazil where the normal faults and fractures lie in the same direction as the walls of the falls.

Fracture traces and lineaments also reflect secondary permeability and porosity in carbonate rocks. A study carried out by [12] established the important relationship between the occurrence of groundwater and fracture traces for carbonate aquifers. These fracture zones form an interlaced network of high transmissivity and serve as local groundwater conduits for massive rocks in inter fractured area. Fracturing increases the solution of limestone and dolomite, creating avenue for groundwater movement. Therefore, the occurrence of a well defined network proves very useful for groundwater exploration.

[1] and [2] in their study of parts of India and Turkey respectively were able to discover a parallel alignment between thermal springs and seismic zones and the trend of the dominantly mega lineament.

This reveals a deep crustal fracturing.Therefore the potentiality of geothermal energy exploration exists in

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such areas. Lineaments and drainage networks have severally been proved to be tectonic in origin. Other geologic activities such as igneous intrusion and sedimentation along faults have been observed as linear features on landsat imagery. [1], [6] and [8] suggested that lineaments could be analyzed with the help of lineament indices. Three main lineament indices for characterizing a fractured zone are distinguished by [7]. These include total length of lineament – X, total number of lineaments – Y, and total number of lineament intersections-Z. The spatial distribution of lineaments is taken into account. These are used in mapping and classifying lineaments.

Geology of the Study Area

The study area is Afikpo in the southeastern Nigeria lies between longitudes 7⁰45'E and 8⁰15'E and latitudes 5⁰45'N and 60⁰00'N (Fig.1). The major part is situated on the southeastern limb of the Ishiagu-Abakaliki anticlinorium. The area is generally referred to as the lower Benue valley. Major parts of the area are accessible by cars except the marshy terrains which hamper accessibility to some areas due to their muddy and water logged nature. However, the marshy terrain is still accessible by foot and cycles.

The study area has terrain characterized by ridges of un-weathered Sandstones and valley of weathering shale. The dominant rock type in the area are sedimentary rocks such as sandstones and siltstones. Structures in the area include sedimentary structures like fossils, ripples, faults etc.

Afikpo sub-basin is one of the oldest basins known to be holding some of the environmental and geologic features of interest in the country and was forming during the uplift of Abakaliki anticlinorium resulting in the depression of both sides called Anambra basin and Afikpo syncline.

Stratigraphically, the study area shows three main litho units [22] and [15]. These include Ezeaku Shale, the Nkporo Shale and Afikpo sandstone back to the upper Cretaceous - pre Santonian period.

The basal bed of the syncline, Ezeaku shale Formation was laid down during the early Turonian transgressive phase [15], but the deposition may have started in the Cenomanian. The type locality of the Ezeaku Shale is the Ezeaku river valley in southeastern Nigeria. The formation comprises of hard grey to black shale and siltstones, with frequent facies change to sandstones or sandy shale. The thickness varies but may attain 100 meters in some places [21]. Locally, at Amasiri, the Ezeaku Formation passes laterally into Amasiri sandstone facies, other lateral changes are into shaly limestone (as in Nkalagu area) calcareous sandstone and sandy limestone. The Ezeaku Formation represents a shallow water deposit. Overlying the Ezeaku Shale in the syncline is the Nkporo Shale, which is known to have been laid down in a marine environment during the late Campanian transgression. The formation is dated Maastrichian by [22], consist of blue dark grey, often friable shale with occasional thin beds of limestone and sandstone.

The depression of Afikpo sandstone over the shale was accomplished during the Maastrichian period. Afikpo sandstone contains feldspaitic sandstone intercalated with pebbles, essentially deposited under shallow marine condition [25].

Afikpo syncline is a moderately hilly area, rising from about 15 meters in the low areas to about 250 meters above sea level in the hilly area. The evolution of the present landscape began in the Tertiary times.

The present geomorphic cycle has attained sub-mature stage, which is almost level in many areas. In the study, there is a repetition of topographic high and low, which gives the area an undulating ridges and erosion of some of the rock materials over a geologic period/Santonian - Eocene in the south western part of the area, where there are few hills ranging from 30 meters. Points occur in the eastern and western parts, with some undulating ridges moving several kilometers in the direction north east. The topographic highs are mainly sandstones, while the low are composed of very fine sands and shale.

Basics of this study, understanding the geology of the area using geological and geophysical techniques becomes imperative in the understanding the features of interest and solving some of the problem in the area including availability of potable water in the area and knowing the effect the soil will have on engineering structures.

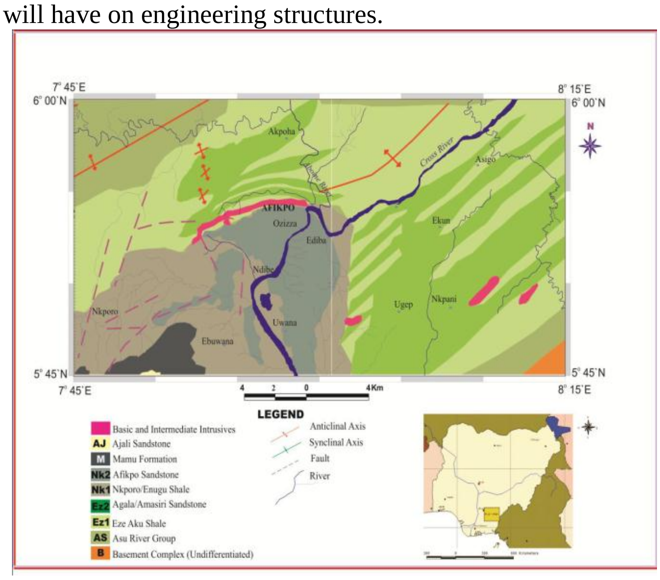

Fig 1. Geological Map of the study Area.

Methodology

Integrated Land and Water Information System (ILWIS) 3.2 was used for creating several themes or layers from the satellite image. This software has the capabilities for various image enhancement techniques such as linear enhancement, statistical analysis, principle component analysis and normalized difference vegetative index. Image enhancement operation carried out include: filtering and edge detector, to enhance the sharpness of the image for better visual interpretation, to reduce noise (distortion) in the image prior to a multi band image classification to detect linear features and edges in the satellite image. To aid the structural interpretation/analysis, the following were used- a high speed large memory electronic PC, printers and plotters, colour monitor for image visual station and table scanners used in scanning all the relevant maps used for this study. ERDAS software was also used in the analysis.

The image was geo-referenced to a Universal Transverse Mercator (UTM) grid using ERDAS software as well as the ILWIS to allow for comparison with other data set. The image was sub-set using the coordinates of the study area.

On screen digitization was carried out on the Landsat 5 TM (Geological and DEM maps). Differential layers or themes were created using ILWIS 3.2.

Discussion/ Interpretation of Results

Simple digital image processing techniques, which involved image classification, linear/edge enhancement, etc. were applied on the image to enhance edges of linear features, followed by computer aided visual interpretation of geological structures and lithological units. The processing led to the production of drainage patterns fractures/lineaments, and geological maps. Further mapping of the area was carried out by producing composites images.

Drainage system of the study area revealed dendritic drainage patterns (Fig.2), while the rivers showed a parallel drainage pattern at their upper course; they however followed a dendritic pattern in their lower course. The dendrite pattern is associated with tree- like branching tributaries joining the main stream at acute angle common to soft sedimentary areas and old dissected coastal plains.

This dendritic drainage patterns without well developed parallel element suggest a uniform stratum without abundant discontinuities and this indicate cracks (breaks and fractures) and/or faults as well as unconformities. The drainage is controlled by the Cross River and its tributaries especially Ebonyi drainage system.

The trend of the drainage is in the northwest southeast, north south and northeast southwest (NW-SE, N-S and NE-SW). This is related to the lineament trend of the area.

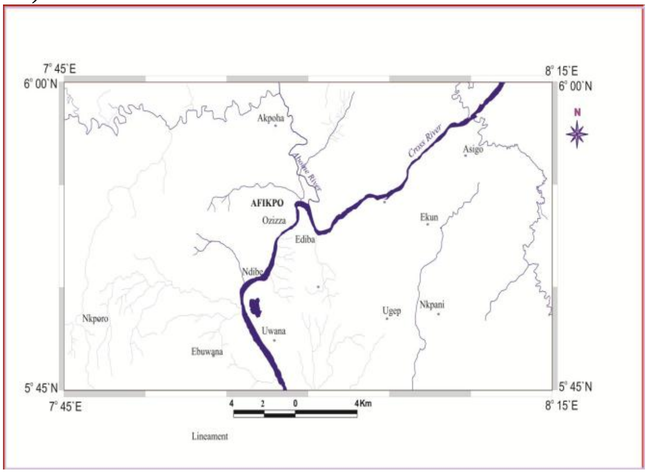

Fig 2. Drainage Map Of the study area.

Fracture analysis is done to delineate zones of fracture concentration, so that information on the structural deformation occurring in the area can be exposed or revealed. Geological interpretation of the landsat imagery revealed a number of lineaments and mega lineaments showing that the study area is partially deformed.

In most cases, recognition of geological features on images is based on the interpretation of surface expression of the underlying geology. One of the most important and reliable surface effects of the geological substratum is landform. These include the tonal variations, structural deformations/lineaments, topography – drainage pattern etc. The lineament map of the study area revealed some structural and tectonic deformations in the study area. Fig. 3 is the lineament map, while Fig. 4 is the lineament density map of the study area. Fig. 5 is the edge enhancement map with superimposed lineaments.

The structure of the different lineament maps indicated that the area has numerous long and short fractures. There is an almost complete absence of lineaments in the sedimentary formations. However, lineament density is very high in basement dominated areas. Lineament density in the area varies between 0 – 4000m per km^2. Trend analysis of the lineaments computed by plotting the strikes and lengths of all the lineaments revealed on the image on a rose diagram, showed structural trends in the E-W, NW –SE, and NE-SW directions with NE-SW and NW-SE structural trends being the most dominant,

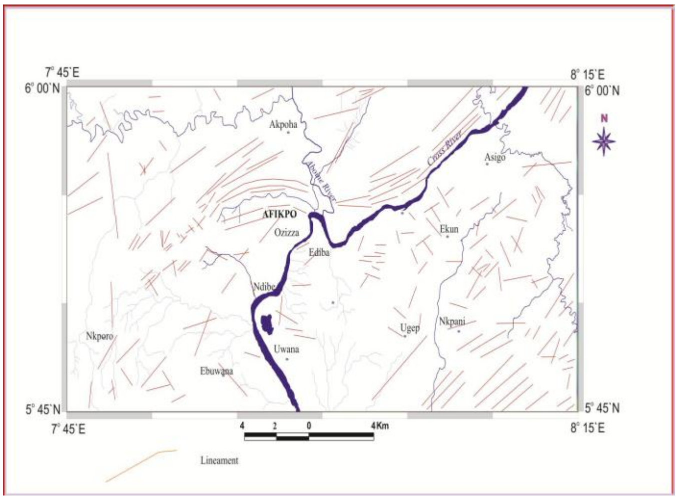

Fig 3. Lineament Map of the study area.

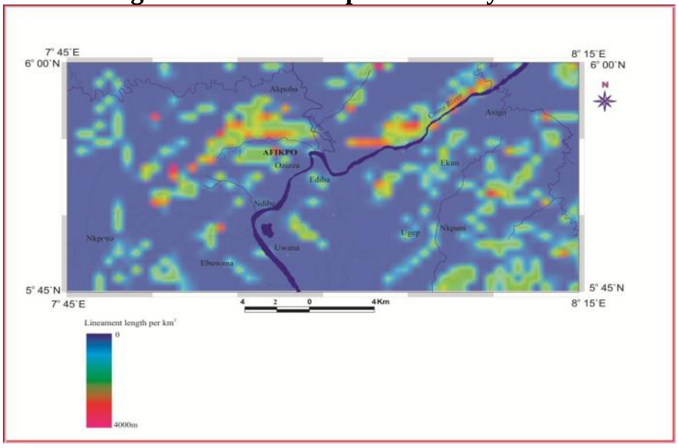

Fig 4. Lineament density map of the study area.

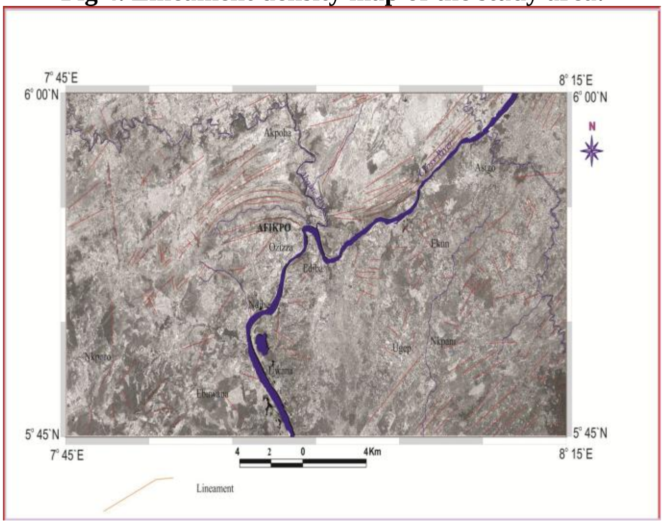

Fig 5. Lineament on Edge Enhanced band 5 Image.

Rose diagrams are used to easily identify the orientation and frequency of lineaments over the study area. The length of all lineaments were measured and computed using the software ILWIS 3.2Academic to obtain the Rose diagram (Fig. 6). The trending surface analysis of the structural features of the study area in relation to the lineaments based on the Rose diagram (Fig. 6) revealed several trends of the lineaments in the NE-SW, NW-SE, N-S and E-W direction. In the rose diagram, number of data plotted was 146. Sector interval angle was 10; scale spacing was 3% (4.4 data), the maximum was 14.2% (21 data), the mean resultant direction was from 056 to 236 and approximately 95% confidence interval of ±15.7 ^{0}.

Axial (non-polar) data; No. of data = 146
Sector angle = 10°; Scale: tick interval = 3% [4.4 data]
Maximum = 14.4% [21 data]; Mean Resultant direction = 056-236 [Approx. 95% Confidence interval = ±15.7°]

Fig 6. Rose Diagram.

Digital Elevation Models (DEMs) are frequently employed as a digital representation of a topographic surface. They are usually in form of a regular lattice of spot height. DEMs may be derived by interpretation of a surface produced from irregularly spaced point, or derived directly using digital photogrammetry. DEMs are usually stored in a raster-like scheme. Fig.7 shows the topographic roughness and geomorphologic structure of the study area. The DEM is employed for structural geological and tectonic interpretations, such as locating drainage patterns, faults, cracks, valleys, ridges plate positions, plate tilts, slope and aspect, folded structures (anticlines and synclines) and angled discordance, lineament and the boundaries of geological formations.

The digital elevation model of the study area (Fig.7) shows the elevation of the major towns around Afikpo. From the legend, it shows that the lowest areas has black colour and highest elevation has a green colour, and are about 277m above sea level.

From the elevation model, some areas like Oziza and Ediba have the highest elevation while areas like Akoha has lowest elevation.

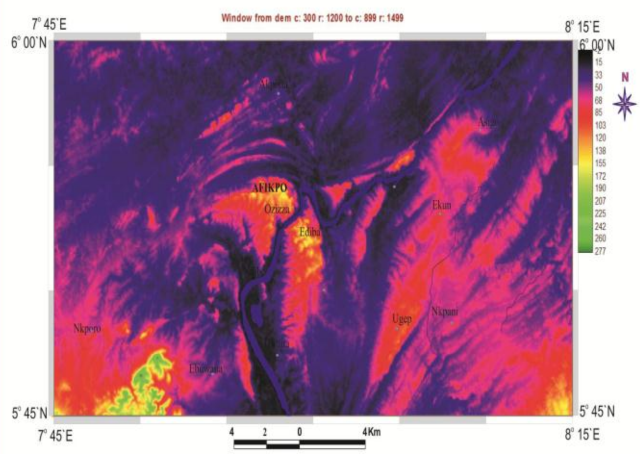

Fig 7. Digital Elevation Model Map (DEM) of the study area.

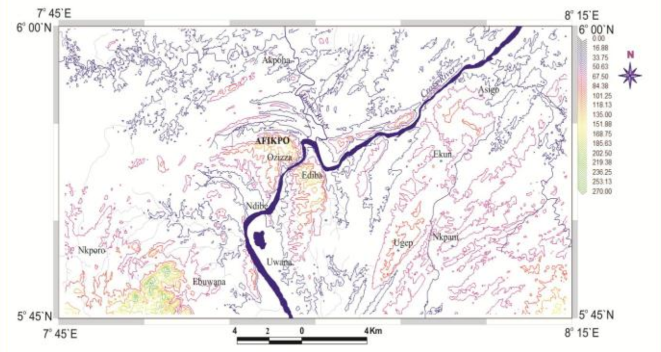

Fig 8. Topographic Map of the study area.

The normalized difference vegetation index (NDVI) is important in groundwater exploration especially if the image was acquired at the peak of dry season, when vegetation survives by sustained groundwater supply. This information on location and abundance of vegetation as highlighted in the image would correspond to potential areas of groundwater occurrence.

The NDVI composite was generated to delineate zones of vegetation and bare rocks. In Fig. 9, dark brown area represents bare rock zones, light brown areas correspond to soil and little vegetation, yellow to sparsely vegetated areas and green to thick vegetation. With this image, transverse for field work can be better planned.

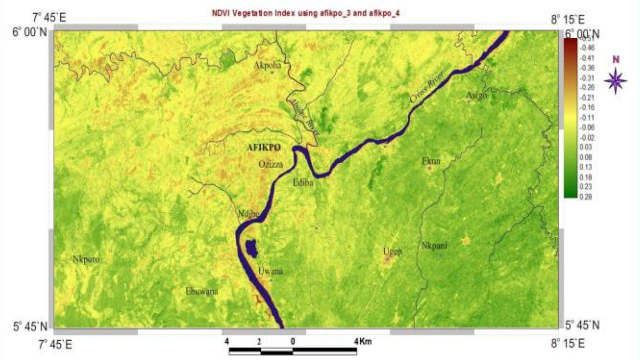

Fig 9. NDVI Map of the study area.

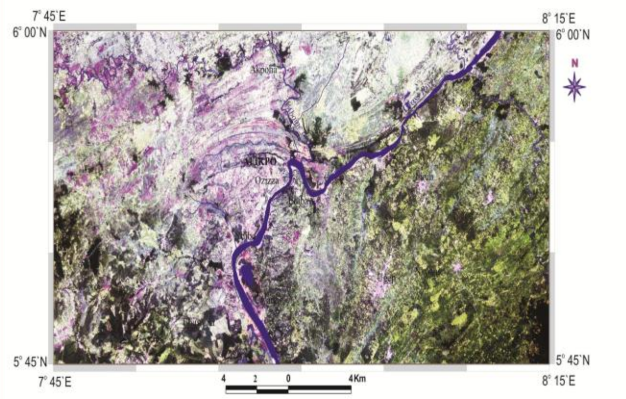

Fig 10. RGB 753 False colour composite map of the study area.

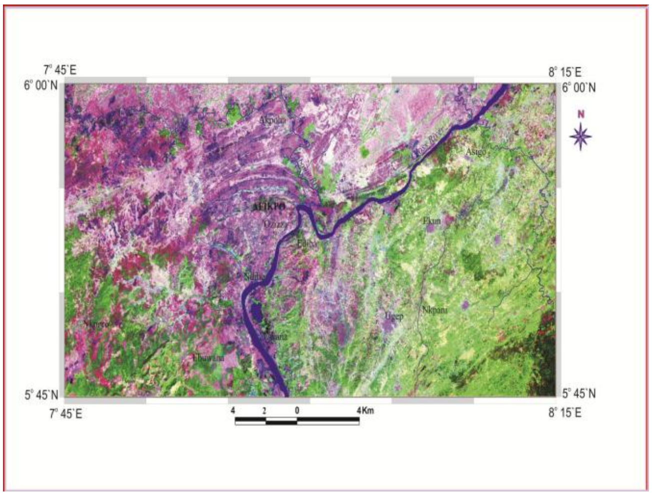

Fig 11. RGB 542 False colour composite Map of the study area.

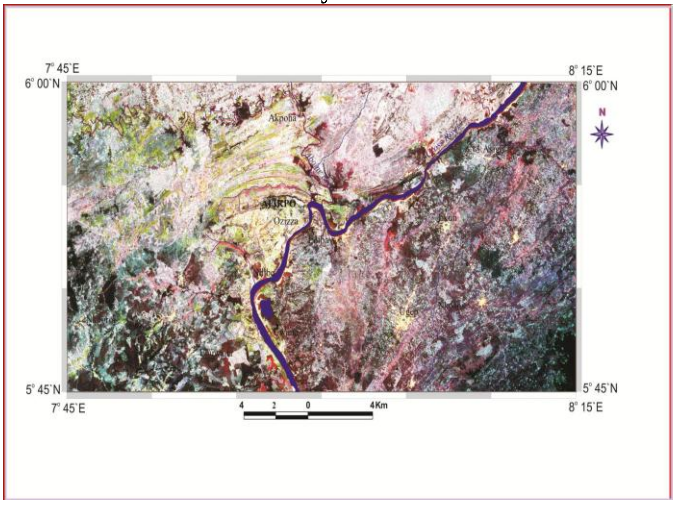

Fig 12. RGB 275 False colour composite Map of the study area.

Colour and colour tone

Colour and colour tone are the brightness levels in digital images. Reflection of colour tones of different materials on the earth helps distinguish different material and their boundaries. For instance, water is distinguished from soil since the water has different tone than the soil [13]. In this study, three false colour composite images with RGB 275, RGB 542, RGB 753 (where R = Red, G = Green, B = Blue bands are Landsat 5 TM multi-spectral image, respectively), RGB 275; Landsat TM bands 2, 5 and 7, colour coded as blue, green and red. TM band 2 is green light. TM bands 5 and 7 are mid-infrared portions of the spectrum, which are particularly sensitive to active vegetation, soil moisture and water bodies. This composite provides a naturalistic, earth tone view of the landscape and two false colour composite images, RGB 542; is used to determine vegetation stress and vigor, while RGB 753 is used to assess water quality. Turbid water gives bright blue and clear water gives dark blue. Turbid water (water with more sediment particles) clear water (water with less sediment particles), green area is vegetation (trees) and red area is ground (bare rocks) was used to interpret geological structures and distinguish them from other land surface materials and also show shapes and sizes of features. Landsat 5 TM images constitute texture of features. Textures describe the structure of the variation in brightness within an object as same mean brightness, but they have different textures. Therefore, they can be differentiated using the texture knowledge of vegetation and water. Looking at the vegetation, dense vegetation can be seen and the edges of vegetation show formation boundaries.

There is a river channel integrated with vegetation showing a geological formation boundary.

Conclusion

Afikpo and its environs tend to pose a problem in terms of its hydrogeology/groundwater exploration. From the analysis, areas where the lineaments cross each other are prospective areas for groundwater exploration.

Fracture/lineament analysis is done to delineate zones of fracture concentration so the information on the structural deformation occurring in the region can be revealed. The analysis is the most effective method of mapping sub-surface deformation (shear and extensional feature) [7]. Spatial and directional attributes of the lineaments which were carefully traced out from the Landsat imagery of the study area were taken into account in the interpretation. The analysis shows a structural trend dominantly in a NE-SW direction. It should also be noted that the drainage pattern in the area is tectonically controlled.

Vegetation is low reflectance in red band and high reflectance in infrared band. By normalizing these two bands, one can measure vegetation stress and vigour in the study area. General formula for NDVI is (infrared - Red)/ (infrared Red). The value is between +1 (vigor) and -1 (stress).

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