Hydrology for Disaster Management

Special Publication of the Nigerian Association of Hydrological Sciences, 2012

http://www.unaab.edu.ng

Tectono-Hydrological Study of Akure Metropolis, Southwestern Nigeria

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Abstract

An integrated approach was applied in studying the tectonics and their hydrological implications in Akure metropolis, using remote sensing, structures and secondary geophysical information. Structural geological information was extracted from Landsat ETM^+ imagery covering Akure area. Since the study area is densely built-up, a systematic approach was employed in delineating the fractures which are characteristic of the underlying Basement Complex geology. Based on the fact that drainage system on such terrain is structurally controlled, the lineament trends on the few rock outcrops observable on satellite imagery were correlated with the trends of rivers draining the area. Results highlight specific fracture pattern that is most probable for hydrogeological exploration. The influence of tectonism in defining the basement aquifers underlying the study area as well as their implications for hydrological hazards were also underscored.

The methodology adopted in this study may be used for hydrogeological exploration in urban areas underlain by Basement rocks in view of the challenge encountered in lineament detection in built-up areas.

Key words: Basement Complex, Fractures, Hydrology, Hydrogeology, Tectonism.

Introduction

The Nigerian landmass (Figure 1) is underlain in nearly 75% proportion by basement rocks and the remaining parts by cretaceous sediments. The Nigerian Basement is polycyclic and has suffered various tectonic phases from the Archean to Late Proterozoic times. These have resulted in several generations of folding and faulting, a lot of which are clearly shown on a regional scale (Oluyide, 1988).

The Akure area (Figure 2), which is located in a gently undulating terrain surrounded by inselbergs, is underlain by granites, charnockites, quartzites, granite gneisses and migmatite gneisses (Olarewaju, 1981). The granites occupy about 65% of the area. The migmatite gneisses, being the oldest rocks in the Nigerian basement, are both litho- and tectonostratigraphically basal to all suprajacent lithologies and orogenic events (Rahman, 1976). The area is flanked to north by Ikere Batholith and to the south by Idanre batholith.

The drainage pattern in the area is dendritic and the major rivers are River Ala, River Owena and River Ogburugburu.

Various methods have been used to characterize aquifers in basement regions among which is remote sensing which has resulted in great degrees of success (Gelnett & Gardner, 1979, Meijerink, 2007, Galanos & Rakos, 2006, Sander, 2006). With the aid of remote sensing, this study highlights the influence of tectonism in characterizing the aquifers within the Akure area, with the aim of deciphering whether any lineament orientation set exert controls on the preferred orientations of groundwater occurrence within the area.

Method of Study

A Landsat ETM+ (Enhanced Thematic Mapper Plus) imagery of the study area was acquired and processed. The results were produced as 5, 4, 3 (RGB) colour composite with 6% linear stretching (Figure 3) for the purpose of interpretation, lineament extraction and analysis. Edge enhancement filter was applied to the Landsat ETM+ (band 5) imagery of the study area (Figure 4), so as to increase the contrast between linear features such as fractures. In addition, a Normalized Difference Vegetation Index (NDVI) image of the study area was produced to enhance the densely vegetated areas within the built-up areas of Akure metropolis since such areas highlight depressions with relatively higher hydrological significance than other areas.

A lineament map (Figure 6), as well as rose diagram of the length and orientation of lineaments (Figure 8) in the study area, was produced and tied to the trend of rivers (Figure 9) draining the Akure city area (observable on satellite imagery). The production of lineament density and lineament intersection density maps was disregarded because most parts of the study area are densely covered with human structures which will therefore erroneously isolate areas with dense lineament as well as lineament intersection, to the outskirts of the city which are more pristine in nature.

Both image processing and digitization were done using ILWIS Version 3.3 software. As a complementary method, a geological map of the area was also included to serve as a check for the interpreted imagery.

Results and Discussion

A total number of 274 lineaments (fractures) were extracted by manual interpretation of both 543-RGB false colour composite and edge-enhanced images of the study area; while a total number of 84 unique lineaments (major river channels and tributaries) were extracted from the drainage map (Figure 7) of the study area.

The frequency and length of lineaments (fractures) in the rose diagram for the study area (Figure 8) shows a bi-modal distribution. The highest peak (a double one) trends along ENE-WSW (50° to 70°) to E-W (80°–90° and 90°-100°) directions, which have corresponding peaks on the length-orientation axis of the rose diagram with a total length of a little over 19 km (19,174.8 m and 19,072.3 m). The other peak trends along NW-SE (150°-160°) direction and on the length axis, has a total length of approximately 10 km.

The trend of river channels in the study area (Figure 9) shows significant peaks along the relatively E-W (100°-110° and 70°-90°) direction and relatively N-S (330°-350° and 0°-30°) direction. These sets also have corresponding peaks on the length-orientation axis of the rose diagram.

The resultant lineament map (Figure 6) clearly shows that the study area exhibits relatively low density fracturing with the isolated granitic intrusions possessing the greatest density of fractures and the charnockitic domains exhibiting the least density of fracturing. It also confirms the influence of dense urbanization in hiding the basement discontinuities, which might have been observable on the satellite imageries. It was also observed that the fracture densities increased drastically in the northern segment of the study area which corresponds to the southern drop-off of the Ikere Batholith.

The drainage patterns extracted from the NDVI and 543-RGB false colour composite imageries of the study area suggest that the area is well drained with some major river channels as well as numerous tributaries running obliquely to the trend of the major river channels. In contrast to the low visibility of fractures in the urbanized segment of the study area, the number of extracted river channels suggests the relatively higher visibility of river channels within this segment of the study area.

Generally observable within the study area is the obvious assumption of structural trends by the river channels draining the area, especially in the northern segment where there are significant granitic intrusions (Ikere Batholith).

An analysis of the dominant sets within the frequency and length rose diagram of the trend of rivers within the study area, highlights the relatively E-W (100°-110° and 70°-90°) trending lineament sets as the dominant sets with the 100°-110° set being the highest and longest lineaments. This suggests that the longest river channels in the study area have been controlled along this direction, which directly correlates with the orientation of the southern boundary of the granitic Ikere Batholith. It is also interesting to note that the major rivers within the study area (Ala, Owena and Ogburugburu Rivers) have been controlled along this direction.

The 330°-350° and 0°-30° drainage sets suggest that rivers which are tributaries to the major ones trend obliquely to the direction of flow of the major rivers in the study area. The length and frequency of the lineament set show that the rivers are relatively shorter but are quite abundant. Since the general trend of tectonic grains within the Nigerian basement are relatively N-S (Oluyide, 1988), these tributaries therefore appear to have been controlled along pre-existing weak zones in the country rock during magmatic intrusion (for granitic regions of the study area) while in the migmatized country rocks, they merely assume the general tectonic trend of the country rocks. It is also important to note the general N-S trends assumed by the Ikere Batholith (Kolawole and Anifowose, 2012) as well as the numerous isolated granitic intrusions within the study area.

The rose diagram of extracted lineaments (fractures) on both the intrusive rocks as well as their host country rocks highlights the ENE-WSW (50° to 70°) to E-W (80°–90° and 90°-100°) trend sets as the dominant sets. These relatively E-W trending sets relate to the influence of the southern boundary of the Ikere Batholith, but they relate more to the shrinkage fractures observable on the intrusions and which generally trend obliquely to the orientation of the granitic intrusions. It had been reported that shrinkage fractures on granitic intrusions develop due to compression and shrinkage effects within the cooling batholith as the magma rose at the time of emplacement (Read and Watson, 1962; Anifowose and Kolawole, 2012).

Since Akure area is underlain by basement rocks, the variability of aquifer responses in the area demands the use of statistical analysis to characterize particular sub-areas, and if possible, to identify correlations with features such as lineaments, which can be observed. Theoretically, the relationship between the trends of fractures on isolated rock outcrops in different parts of the built up metropolis and the trends of river channels within the city can suggest the 'fractural' picture of the underlying basement in the study area. This picture establishes the presence of relatively E-W and N-S lineament sets as the dominant sets within the area, the origin of which have also been tied to tectonic events that have affected the area in ancient times. Since the flow of groundwater in basement areas often take place along preferred paths of secondary porosity in fractures as well as weathered overburden (Wright and Burgess, 1992), it is expected that the two lineament orientation sets (N-S and

E-W trending lineaments) define the preferred orientations of groundwater occurrence within Akure area.

It can therefore be said that among the two lineament orientation sets, the peaking E-W orientation set exerts a greater influence in defining the aquifers within the study area. This is much plausible since the shrinkage fractures are expected to be larger and deeper than the N-S trending fractures as the dominance of the relatively E-W trending lineaments has been observed on both the Ikere and Idanre Batholiths (Odeyemi *et al.* 1999; Anifowose and Kolawole, 2012). An observation of the occurrence of the N-S trending lineaments in the area suggests that they serve as active conduits connecting most springs in the area to the major river channels.

It is also interesting to note that the enclosing spatial character of the Ikere and Idanre batholiths, with respect to Akure area, have made the E-W domains the dominant transportation (road) and access routes into Akure City. This may also possibly be as a result of the greater density of preferred 'pathways' (E-W trending depressions) in the area.

Figure 10 shows the groundwater head map of Akure area, which suggests that groundwater flows into two main collecting (converging) centers (zones A and B). Groundwater flows away from the deep water table zones in the north-western and south-central parts and collects in the high water table zones of the central, southeastern and southwestern parts. The relatively E-W trend of both zones A and B indicates that the E-W orientation set exerts a greater influence in defining the aquifers within the study area and, that the lineaments are favorable to groundwater exploration within Akure metropolis. The location and trend of the groundwater collection zones show a correlation with the flow paths of Rivers Ala and Owena.

It appears that the southern boundary of the Ikere Batholith exacts its greatest influence on the trend of the Ala River channel (Figures 11 and 12) as the river itself flows along the contacts of the batholitic intrusion. It also appears that this might have increased the saturation potentials of the aquifer in the areas enclosing the river channel since drainage channels flowing south from the Ikere massif (in the northern flank of Ala River channel) naturally empty into Ala River. This naturally increases the susceptibility of the areas enclosing Ala River to flooding. Visible from the NDVI and 543-false color composite imageries of the Akure area are the areas along Ala River that are most susceptible to flooding (Figures 12 and 13; Zones A & B). Zone A indicates the area with the greatest susceptibility to flooding. It is located at the southwestern boundary of the charnockitic domain of the southern Ikere-Batholith. The charnockites exhibit the least amount of fracturing compared to the migmatite-gneisses and granites. It is therefore expected that there will be less structural control on drainage in that lithologic domain and all surface water channels will naturally flow downhill and empty into the Ala River channel bounding the lithology to the south. Figure 13 shows a close-up satellite image of Ala River with its flooded channels, as well as photographs of the Araromi area of Akure (Zone B) during a flood event that occurred in July 2010.

Conclusion

The relatively E-W lineament orientation set has been observed to exert significant controls on the preferred orientations of groundwater occurrence within the area.

The influence of tectonism in characterizing the aquifers as well as the hydrological hazards within the Akure area has therefore been underlined, as it relates to the emplacement of the intrusive rocks in the area as well as the E-W trending structures associated with them.

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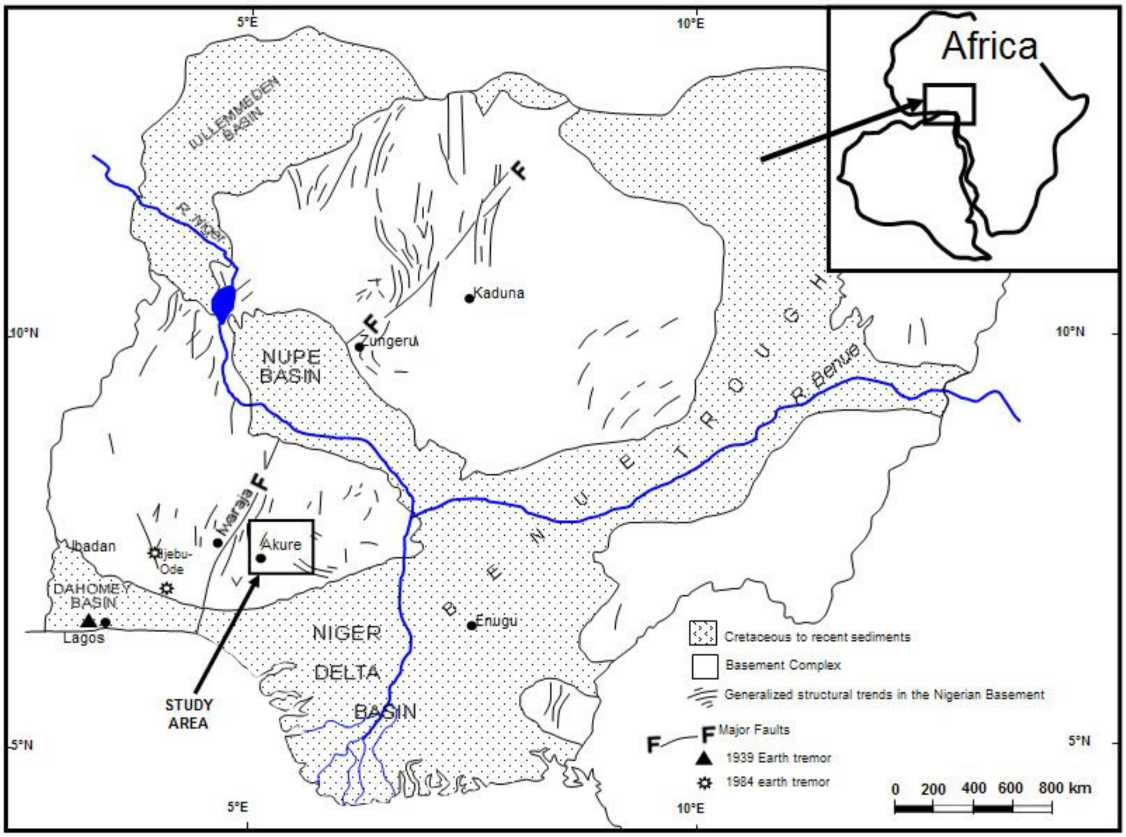

Figure 1: A simplified geological map of Nigeria showing Akure area (After Odeyemi et al., 1999)

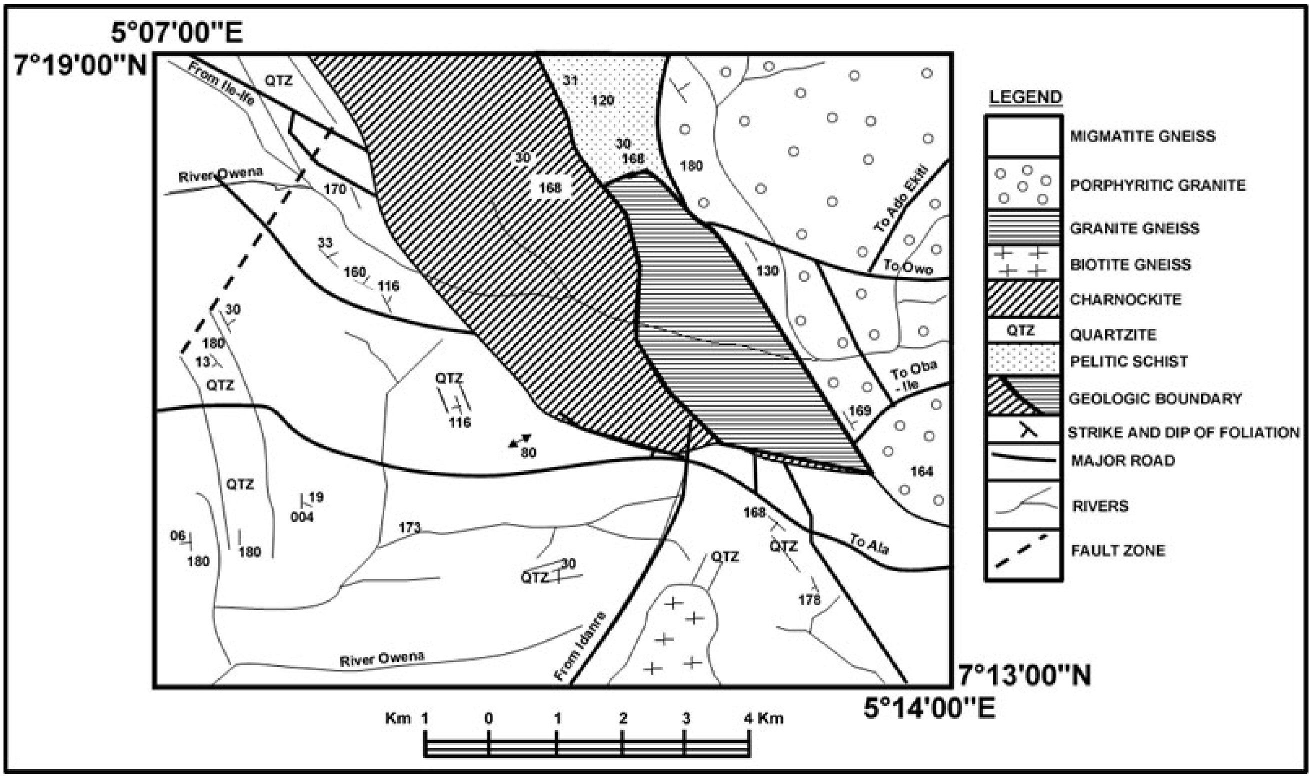

Figure 2: Geologic map of Akure area (after Olorunfemi et al., 1999)

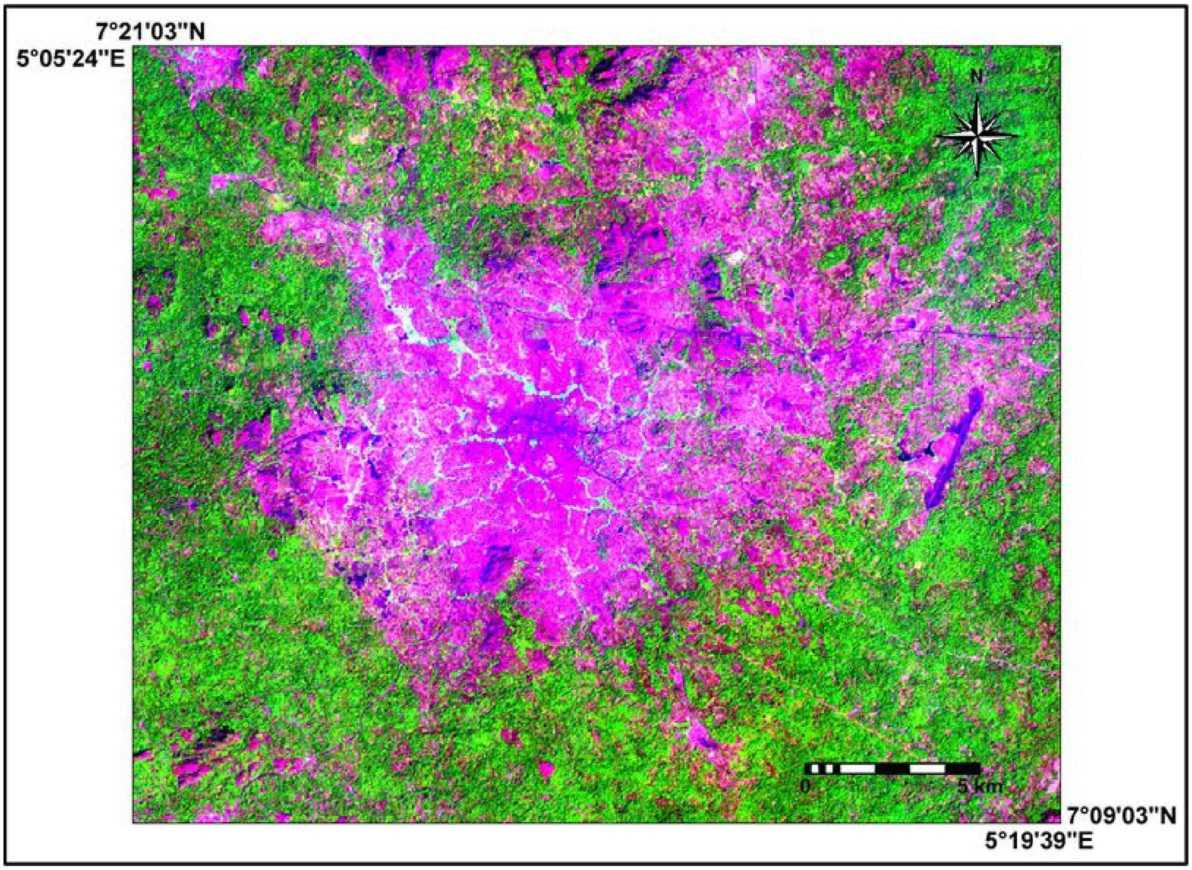

Figure 3: 543-RGB False Colour Composite of Landsat ETM+ imagery of the Akure area.

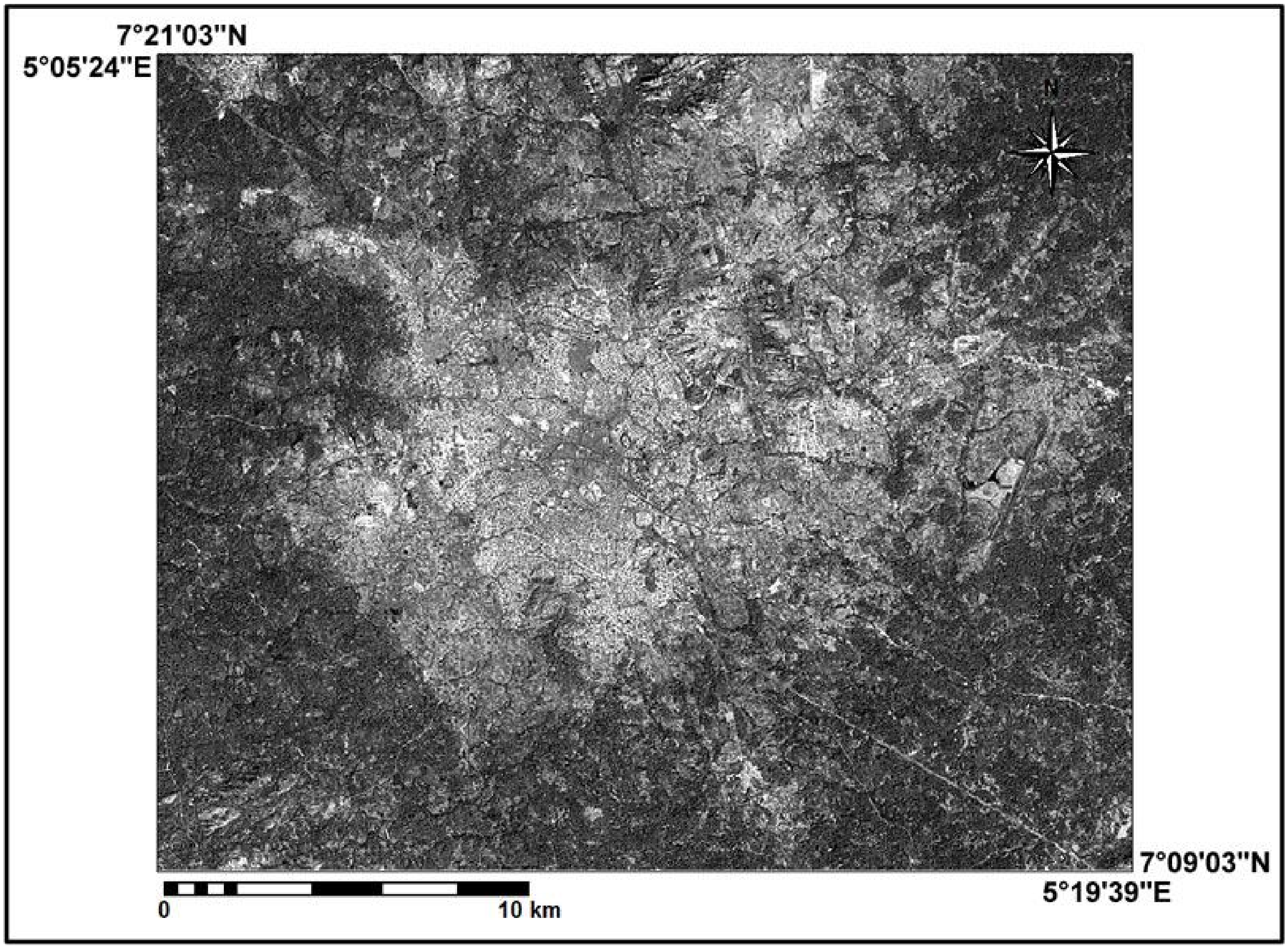

Figure 4: Landsat ETM+ filtered (edge-enhancement on Band 5) imagery of the Akure area.

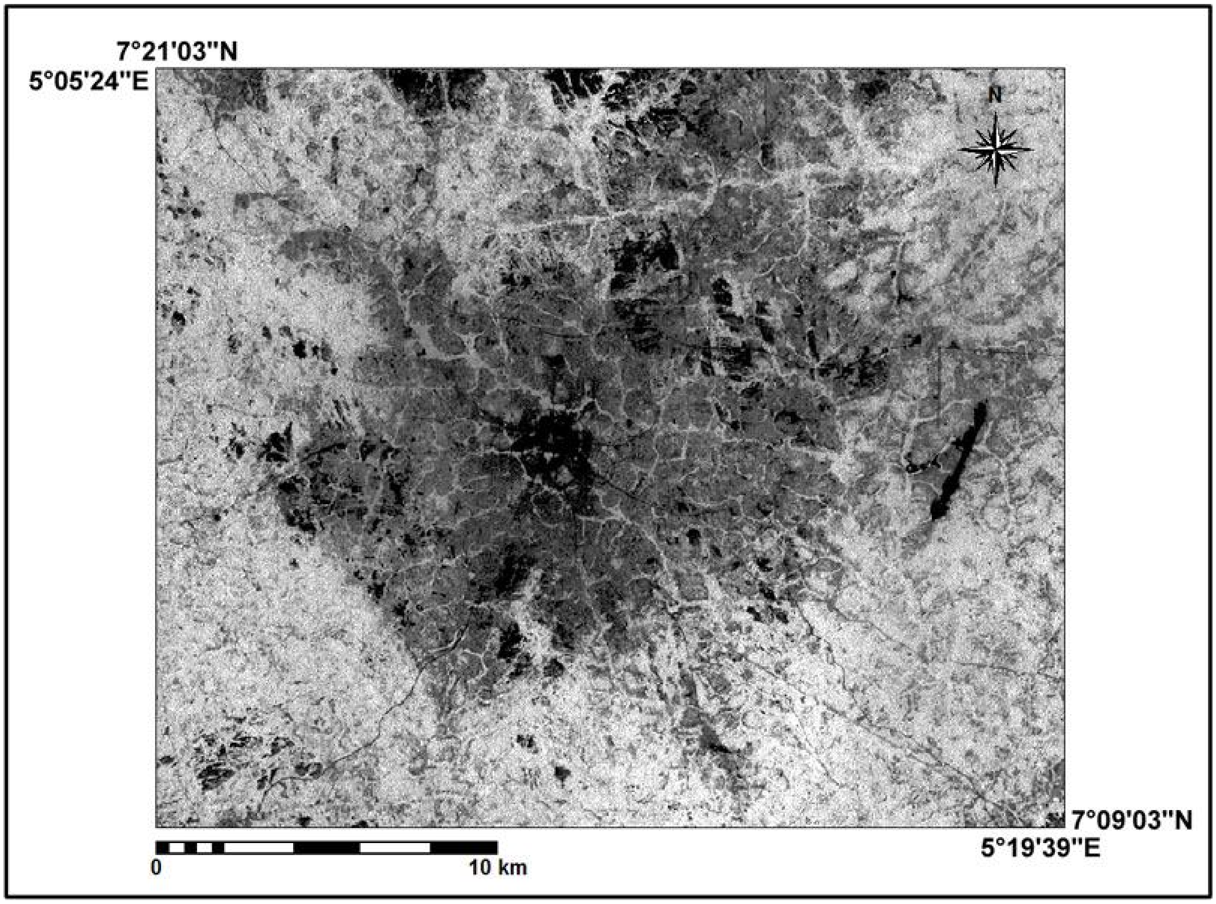

Figure 5: Normalized Difference Vegetation Index (NDVI) imagery of processed from the Landsat ETM+ imagery of the Akure area.

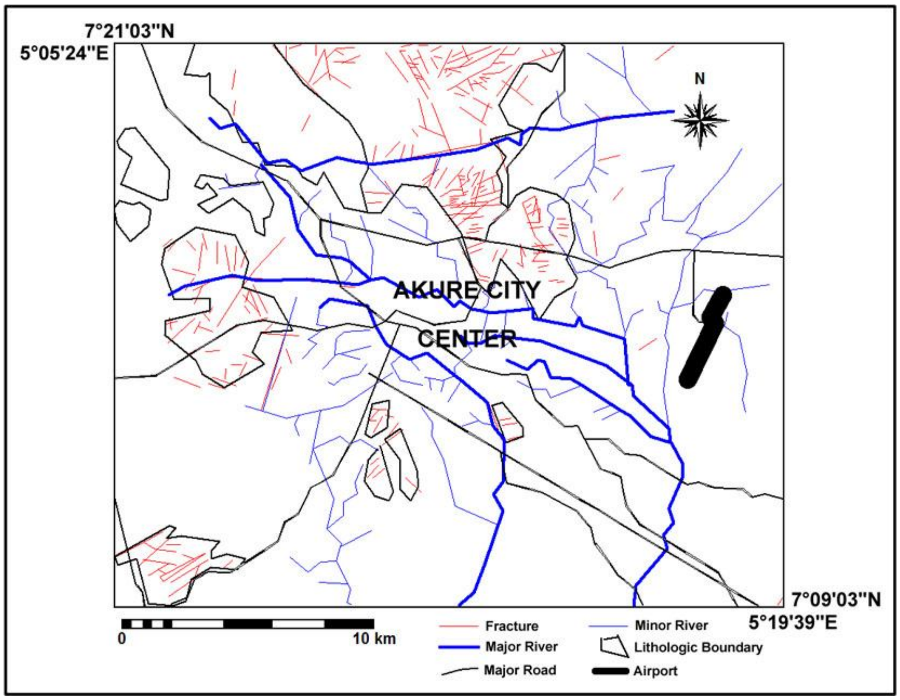

Figure 6: Lineament map of the study area derived from Landsat ETM+.

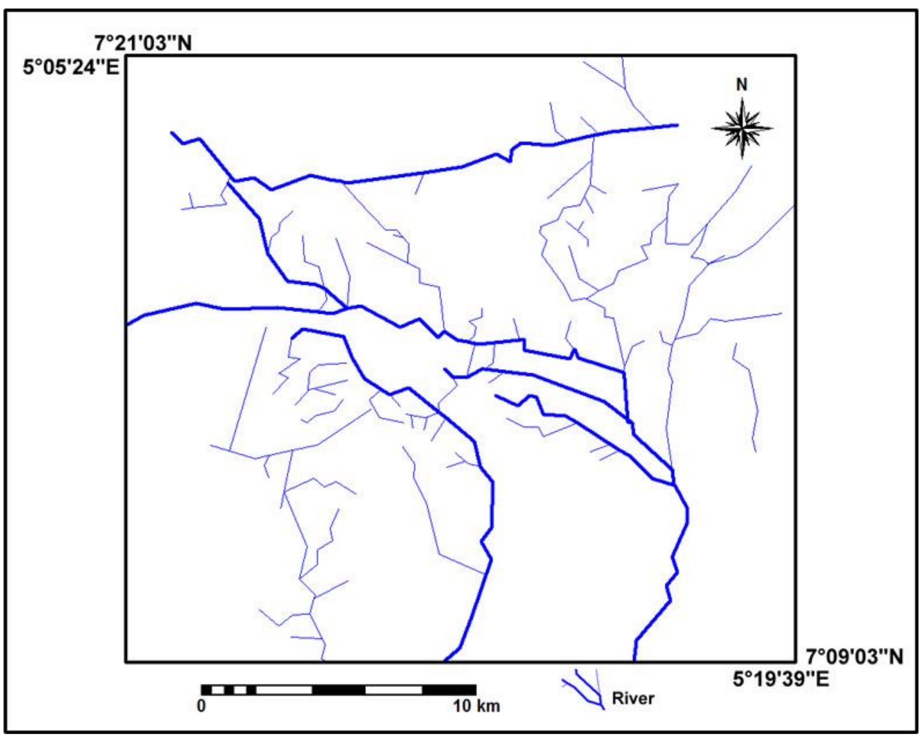

Figure 7: Drainage Map of the study area derived from Landsat ETM+.

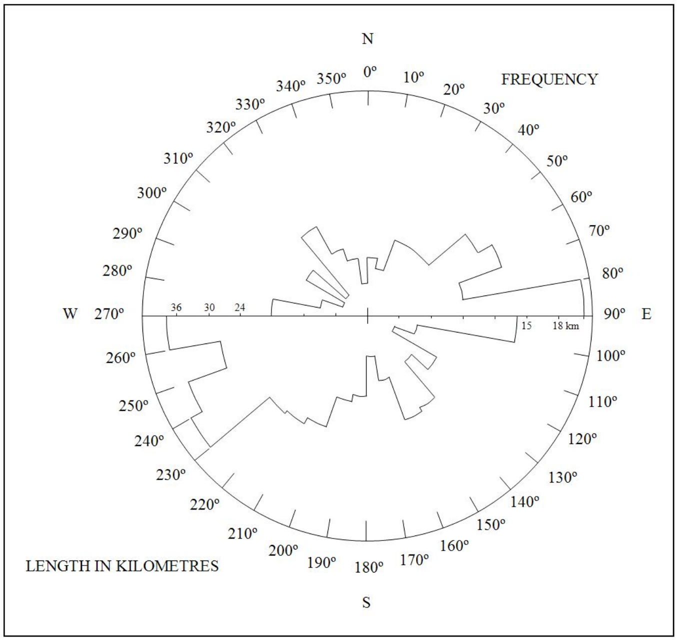

Figure 8: Frequency & Length Rose Diagram of Lineaments (Fracture) in Akure area.

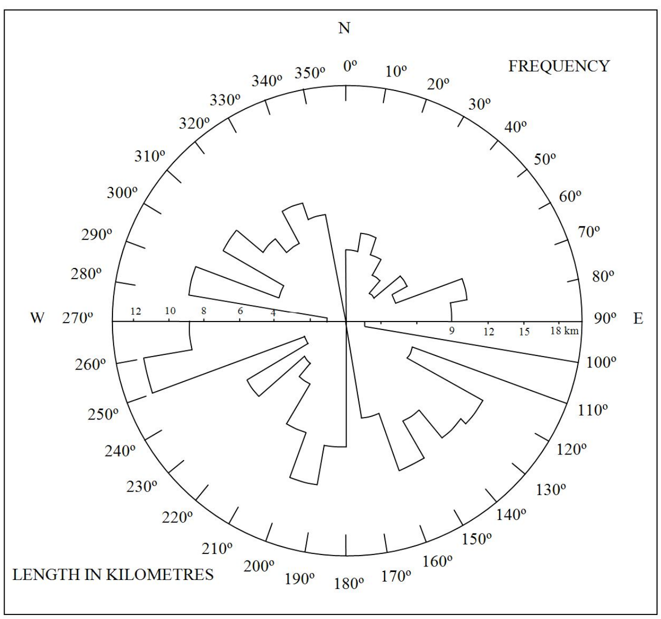

Figure 9: Frequency & Length Rose Diagram of River Trends in Akure area.

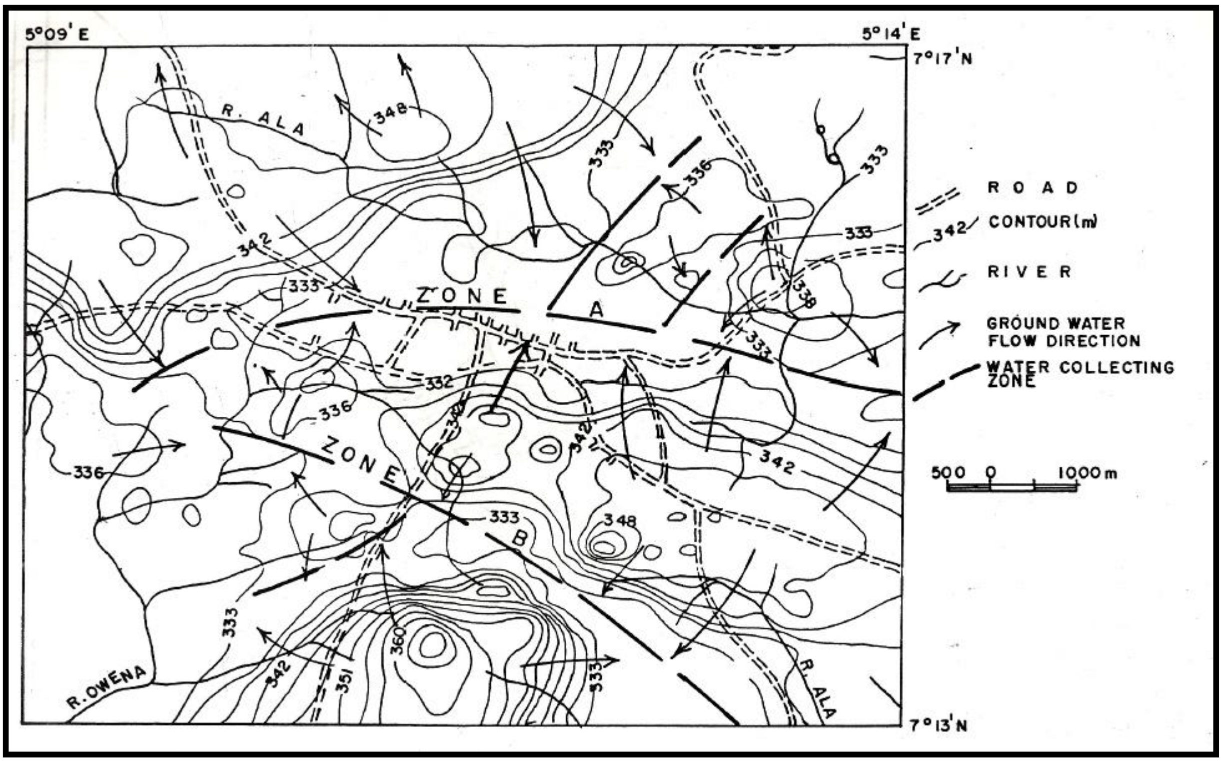

Figure 10: Groundwater Head map of the Akure area (Olorunfemi *et al.*, 1999).

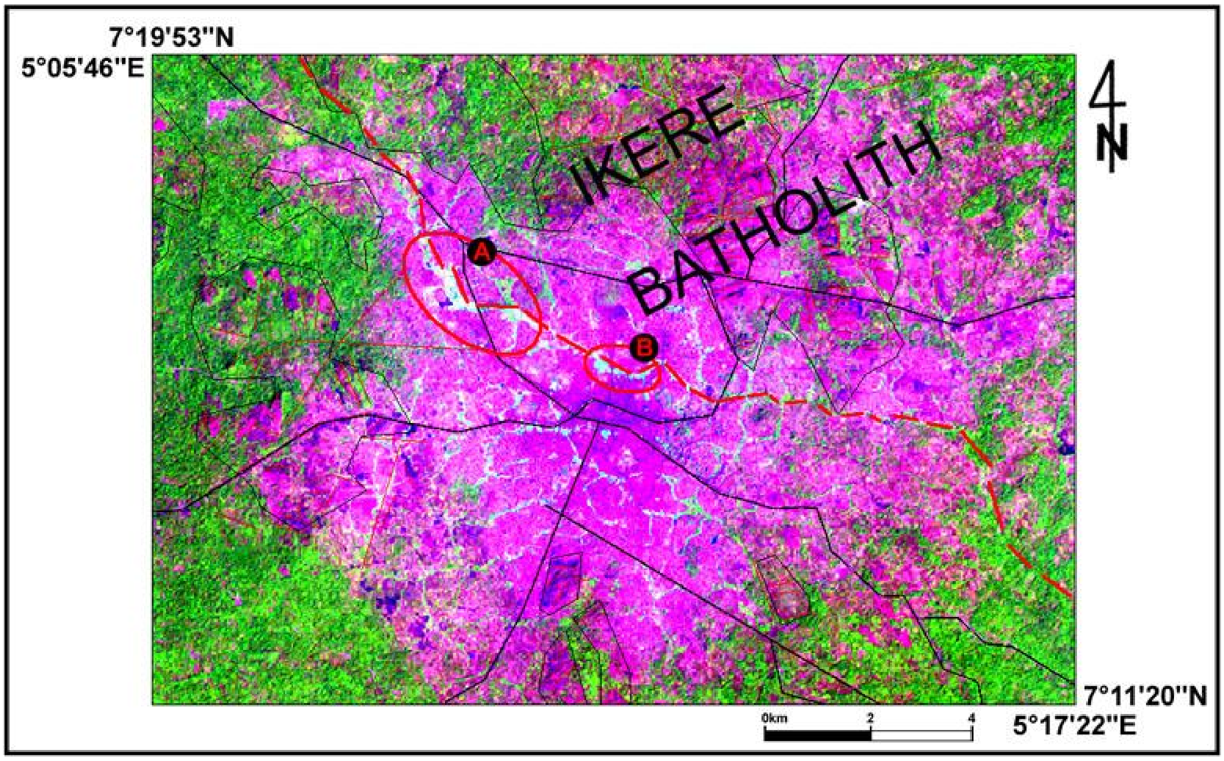

Figure 11: NDVI imagery of Akure City showing the approximate geologic boundary of the Ikere batholith (green dotted line) and the most susceptible areas to flooding within the metropolis (red circles).

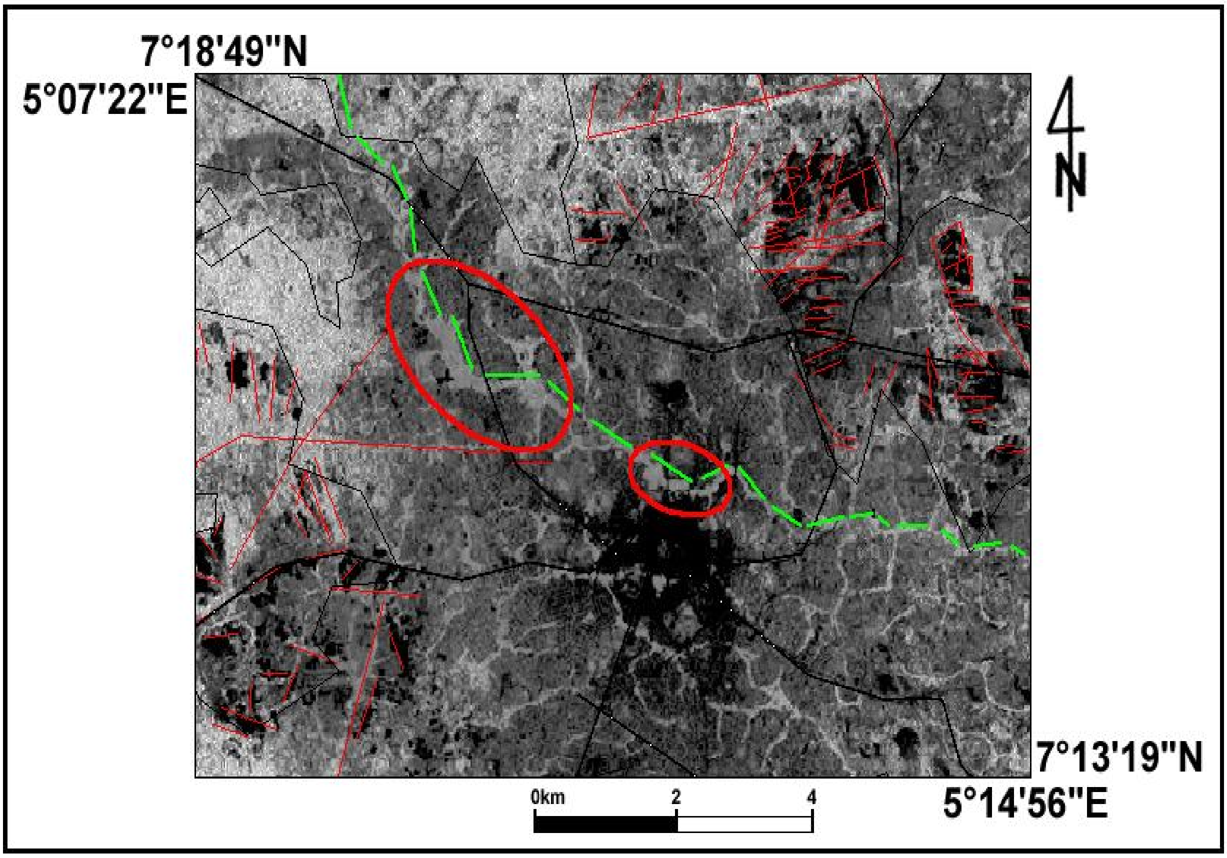

Figure 12: 543-RGB False Colour Composite imagery of Akure City showing the approximate geologic boundary of the Ikere batholith (red dotted line) and the most susceptible areas to flooding within the metropolis (Zones A & B).

Araromi Street in Akure flooded by Ala River. (Rainy season, July 2010).

Mr. Adelaja's residence flooded by Ala River during the rainy season in July 2010.

Figure 13: Satellite image of Akure City (Source: Google Earth) showing the flooded Ala River channel as well as photos of the Araromi area of Akure (Zone B) during a flooding event that occurred in July 2010