Detection and Interpretation of Lineaments using Remote Sensing and GIS Techniques in Amessa Guracha Watershed of the Main Ethiopian Rift Valley, East Africa

Anirudh Bhowmick, Jai Ram Ojha, Subodh Kumar Chaturvedi, Chandra Kant Singh, Tadewos Seyoum

Abstract: The present research paper embodies remote sensing applications of image processing and the use of GIS technique for the manual digitization of linear features in the Amessa Guracha watershed area of Southern Nations Nationalities and Peoples Region (SNNPR) of Ethiopia. The panchromatic image is used to emphasize subtle brightness value differences associated with the linear features. These differences are enhanced with ‘Contrast Enhancement Applications’. The spatial feature manipulation is applied to promote the spatial tonal variations present in the image using digital filters. The enhancement of images with the digital filters is categorically divided into two – ‘directional’ and ‘non-directional’. The rose diagram shows that the orientations of lineament are mostly in NNE and SSE directions. Comparison of the present study with the local geology of the area suggests that these lineaments are the ultimate results of the compressive/tensile stresses developed due to tectonic and lithological influences which in turn, are responsible for the development of lineament in the East African Rift Valley.

Index Terms: Hill Shade, Lineament, Panchromatic Image, Rose Diagram, Sobel Kernel, SRTM, Triangulated Irregular Network.

1 INTRODUCTION

A lineament is a linear feature in a landscape that is an appearance of an underlying geological structure [1]. Typically, a lineament may appear as a fault-aligned valley, a series of fault or fold-aligned hills, a straight coastline or indeed a combination of all these features. Fracture zones, shear zones and igneous intrusions such as dykes can also be expressed as geomorphic lineaments. Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial or satellite photographs [2]. The terrain effects impart geomorphologic and structural linear features present in the area. These features include fractures, faults, joints and other lineaments. The application of ‘Remote Sensing’ with ‘GIS’ is a few decades old techniques. These features after enhancement through image processing techniques are digitized in the GIS environment. The tonal variation can be used in distinguishing the surface features present in satellite images.

This procedure, however, is not specific for linear features because all elements of the scene are enhanced equally, not just the linear elements. Potential faults were assessed as linear structures related to steep slopes, straight valley segments, abrupt changes in vegetation coverage, and sudden bends along river course [3]. Geographers’ map draws man-made linear features such as highways and canals which can also be deciphered as linear features. Some linear features occur as narrow lines against a background of contrasting brightness in an image. Others are the linear contact between adjacent areas of different brightness. In all the cases, linear features are formed by edges. Some edges are marked by pronounced differences in brightness and are readily recognized. However, most of the edges are marked by subtle brightness differences and hence, may be difficult to recognize.

Geological line mapping is considered one of the very significant aspects, particularly, useful for the selection of construction sites (dams, bridges, and highways etc.), in economic mineral exploration and also for the groundwater resource prospecting [4]. For several decades, a wide range of studies has been conducted on regional studies. The extraction of linear characteristics is mainly focused on joints, folds, dykes, crustal fractures and remotely sensed lithological contacts. Some recent researches have assessed lineaments in the Northern Central Jarawa Complex of Nigeria using GIS and remote sensing methods [5]. In order to enhance the interpretations, a digital elevation model has also applied and added to get the desired results [6].

Geomorphology and drainage patterns regulated by the structural geology of the area can be perceived on digital topography or satellite images. It has been observed that near-infrared and thermal infrared are especially might be
helpful in identifying linear patterns of vegetation and soil moisture concentration. However, it is difficult to distinguish the structural origin of a lineament relying only on satellite images. The evaluation of lineaments detected can easily be performed in a GIS environment based on distinguished surface characteristics that could manifest a fault zone (e.g., topography and drainage).

According to [7], the DEM and its derived products have been the most important source for identifying lineaments that are potential faults as these commonly relate to straight valley segments and steep slopes can be defined with contour mapping. The drainage system developed in a region relies exclusively on the path, the nature and attitude of the formation and also on the pattern of local or regional fractures [8]. Most streams are tailored to regional slopes and geological structures and the principal fractures of the underlying rocks.

2 LOCATION & PHYSIOGRAPHY OF THE AREA
The Amessa Guracha watershed is situated on the western boundary of the Abaya Lake near Arba Minch town, Ethiopia (Figure 1).

![Figure 1: Location map of the study area](image1)

Its northern and southern boundaries are bounded by latitude N 6°54’ 32.59” and latitude N 6° 00’ 47.26” respectively. The western boundary of the watershed is bounded by longitude E 37°27’05.72” whereas the eastern boundary is delimited by longitude E 37°58’ 23.19”. The catchment area of the Amessa Guracha river encompasses a considerable part of the Southern Nations Nationalities and Peoples Region of Ethiopia, and consists of woreda namely, Abay, Sodo Zuria, Humbo, Dita, Chencha, Arba Minch, Mirab Abaya and Boreda etc. The total covered area by the watershed is about 1112.5 km². The southern margin of the watershed is separated from the Kulfo Gina watershed while in the northern part, Bilate river watershed is situated.

![Figure 2: Triangulated Irregular Network (TIN) of Amessa Guracha](image2)

![Figure 3: Hill shade of Amessa Guracha watershed](image3)
Physiographically, the Amessa Guracha catchment is a part of the Great Ethiopian Rift. Towards the western and northern extremities of the watershed, much of the valley is bounded by fault scarps or steep slopes, while the eastern side is slowly meeting with the western margin of the Abaya Lake. The altitude of the catchment ranges from 1180 meters at the Lake Abaya to 2960 meters at highlands above the mean sea level situated in the western margin of the catchment. The topography of the area ranges from crescent-shaped lowland alluvial plains to highly rugged and elevated mountainous terrains resulting into a very complex morphology of the study area starting from the edge of the north-east and south-west parts characterized by steep slopes while towards the center and the south, the morphology is changing into quite gentle slopes except for some hilly terrains and steep slopes along the river courses (Figure 2).

Many small streams together with Amessa Guracha River drain towards the east in the Abaya Lake. Most of the tributaries carry a large volume of water from the highlands of the catchment during the rainy season (Figure 3; Figure 7). The relatively downstream might be influenced by the corresponding low rainfall, high evapotranspiration, slower drainage and thermal springs that join the river in the lowland areas.

3 METHODOLOGY

The lineament extraction is a combined approach realized through SRTM 1 arc for DEM, hill shade and TIN preparation of the area. The PAN image of LANDSAT 8 OLI is taken to find linear features present in the image with the help of ERDAS 2015 [9]. The SRTM 1 arc is used for the preparation of the drainage map of the catchment with Arc Hydro tools and Arc Info 10.1. The geomorphic features and lineaments have a combined influence on drainage patterns. Therefore, for the lineament map generation, both the variables are given high priority. Lineaments are structural lines such as faults, which often represent zones of fracturing and increased secondary porosity and permeability, and hence, giving rise to enhancement of groundwater occurrence and its movement. To delineate the lineaments panchromatic band 8 of Landsat 8 OLI (operation land imager) image with a bandwidth of 0.50 – 0.68 µm of 15-meter resolution is chosen as the input image [10].

The software used for image enhancement is ERDAS 2015. ‘Arc Hydro Tool Extension’ with ArcGIS 10.1 has been applied for drainage delineation from 1 arc digital elevation model. Triangulated Irregular Network (TIN) and Hill-Shade have been created from DEM (Figure 2). The image is enhanced radiometrically with histogram equalization before applying filters (Table 1).

**Table 1: Template for Sobel 1&2 and Left-Right Diagonals**

<table>
<thead>
<tr>
<th>Row</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Row</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.000</td>
<td>0.000</td>
<td>1.000</td>
<td>1</td>
<td>-0.000</td>
<td>0.000</td>
<td>2.000</td>
</tr>
<tr>
<td>2</td>
<td>-2.000</td>
<td>0.000</td>
<td>2.000</td>
<td>2</td>
<td>0.000</td>
<td>0.000</td>
<td>2.000</td>
</tr>
<tr>
<td>3</td>
<td>-1.000</td>
<td>0.000</td>
<td>1.000</td>
<td>3</td>
<td>1.000</td>
<td>2.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Sobel 1 vertical 3X3 edge
Sobel 2 3X3 horizontal edge
Sobel 3X3 Left Diagonal edge
Sobel 3X3 Left-Right Diagonals
Sobel 3X3 Right Diagonal edge enhancement
Sobel 3X3 Right-Left Diagonals

The Sobel model can be invoked through a dimensional matrix equal to the window width which determines the length of the edge and the gradient [11]. The Sobel kernel convolution improves the panchromatic image and works by way of filtering on the satellite raster image through averaging high-pass or lower-pass and saves this to a fresh image file [12]. The identification of the kernel convolution suitable for the raster image can be automated or it can be selected from the integrated kernel library.

Figure 4: Methodology for lineament detection

The software used for image enhancement is ERDAS 2015. ‘Arc Hydro Tool Extension’ with ArcGIS 10.1 has been applied

**Figure 5. Lineament Map of Amessa Guracha watershed**
During visual interpretation of various themes like hill shade, drainage map, TIN and Sobel filtered maps, the appropriate cautions have been taken to avoid misinterpretation of linear features present in remote sensing images after using filters, which can also be mistaken for manmade features such as roads rather than fault lines, traces of dykes, traces of dipping strata etc (Figure 5). Finally, the preparation of the rose diagram from the lineament map shapefile is created with Rockwork 16 (Figure 9). Neo-tectonic faults can be characterized in three ways. Firstly, their morphology, forming asymmetric ridges with one side corresponding to slope or scarp breaks, secondly the displacement of late Neogene lithological borders, structural or erosion surfaces, and thirdly, the occurrence of straight lines of several tens of kilometers in length [13], [14], [15], [16].

3.1 Geology
The geological map is prepared from a base map of the Geological Survey of Ethiopia (first edition, 1973) of that 1:2,000,000 scale then improved using remote sensing indices images.

Figure 6. Geological map of Amessa Guracha watershed

The Main Ethiopian Rift (MER) is a central component of the East African Rift System (EARS) linking up to the Afar depression at the intersection of Aden's Red Sea-Gulf in the north, with the Turkana depression and Kenya Rift to the south. It is a magmatic break that records all the different stages of a break-up, rift initiation and beginning ocean spread [17]. The geology of Ethiopia constitutes stratigraphic sequences from Archean up to Holocene sediments. The Ashangi group is the earliest by age exposed in Amessa Guracha basin, constituting Alkali olivine basalt and tuffs very rare rhyolite of Paleocene-Oligocene Miocene age. Mineral composition of olivine rich basalt use to be weathered easily. Geologically the Magdala group overlain the Ashangi Group, constitute rhyolite, trachytes, rhyolitic and trachytic tuff; ignimbrites agglomerates and basalts. Colluvial sediments are resulted due to mass waste processes under the influence of gravity and they occur at the proximity to escarpments in both Ashangi and Magdala formation. In the most proximal parts of alluvial fans, both colluvial to alluvial sediments are conserved in the watershed. Alluvial sediments from large alluvial fans below the fault scarps on the western bank of the Abaya Lake are due to the deceleration of flow speed in the drainage pattern as gradient reduced abruptly (Figure 6). These deposits of near flatlands, undifferentiated are extensively used for agricultural purposes. Geological formation with overlapping lineament theme shows the control of geology over the lineament present in the area.

3.2 Drainage
The drainage pattern of the area is created from 30m resolution DEM (Figure 7).

Figure 7. Drainage map of Amessa Guracha watershed

For the preparation of the drainage map, GIS flow accumulation method with a threshold of 200 m² is applied [18]. The overall drainage shows dendritic patterns but in some places where drainage order is higher, it shows structural and geological controls. In GIS each order of drainage over lap on the lineament theme to assess the effect of lineaments on the flowing directions.

3.3 ROSE DIAGRAM
The Lineation endpoint data entered into the RockWorks 16 utilities datasheet for the purposes of computing lineation azimuth and creating rose diagrams. A length weighted
frequency rose diagram with angular intervals of $10^\circ$ is created for both the drainage network and the lineament features analysis (Figure 8 & Figure 9).

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{rose_diagram_rivers.png}
\caption{Rose Diagram of Rivers}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{rose_diagram_lineaments.png}
\caption{Rose diagram of Lineaments.}
\end{figure}

4 RESULTS AND DISCUSSION

The study area belongs to East African Orogen (EAO) separated from the Gondwana assembly during its Mesozoic breakup. Southern Ethiopia is a crucial area for understanding the evolution of the East African rift system, as it is the contact zone between the central Ethiopian rift (MER) and the Kenyan rift. It is interesting to note that strike directions of Ashangi Group, Magdala Group, and other ‘Undifferentiated’ Groups are almost parallel to the major lineaments of the region (Figures 5 & 6). The active faults scarped recognized by higher elevation and longer continuation of scarp line and generally separated by lithological contacts. The whole area is covered by the volcanic rocks and volcanogenic sediments of Paleogene to Quaternary age. As per the rose diagrams of lineament (Figures 9), the density of lineaments are concentrated in the NNE-SSW direction. Since lineaments are the weak zones generated by tectonic forces, the present ones too appear to be controlled by the extensional stress regime [19]. On the basis of the analysis of the rose diagrams, it has been inferred that a tensile stress regime from NNW-SSE direction might be responsible for the genesis of the present lineaments and mostly recognized by dip slip faults [20]. The most probable stress direction would have been effective in N 60-70° W to S 60-70° E to produce these lineaments. In the southwestern part of the watershed where highland and structural tectonic landforms are dominated the first-order drainage moderately follows lineaments [21]. In the rest of the watershed mostly drainage doesn’t follow the lineaments. In the alluvial plains area 1st order as well 2nd order doesn’t follow lineaments baring only a few drainages. Mostly third-order and fourth-order the trunk river directions are also in accordance with the lineament trend (Figure 8). Thus, the present study indicates a strong control of tectonics and lithology on the stream patterns. Furthermore, the huge database generated during the present endeavor may prove its worth in the future infrastructural development of the region. Additionally, the authors are of the opinion that the study area and surroundings appear to be seismically prone because the entire upper crustal parts are dominated by the Cenozoic volcanic flows which might have been erupted out to the surface through the major lineaments and hence, weak zones in the crust (NE-SW directions) already exist. Ethiopia lies at the tectonically strategic intersection where the Red Sea, Gulf of Aden, and the African Rift System meet. Recent geological uplifts combined with rapid down-cutting erosion by rivers, notably the Blue Nile (Abay) is a common phenomenon. Ethiopia is the largely mountainous and the most volcanically active country in Africa. Therefore, there are chances of accumulation of stress in the sub-crustal part of this region. If these accumulated stresses would release, it may get a path to reach the surface through the existing weak zones already identified as the major lineaments in the present study. Thus, the present research infers that in future chances of seismic shocks could not be ignored in this region.

5 CONCLUSIONS

The study reveals that manual extraction of lineaments with remote sensing image using filters are effectively useful for its detection. Other linear features like roads, canals, pathways etc. can also be deciphered effectively through manual digitization. The Landsat 8 panchromatic band is suitable as it has 15 meters of resolution and hence, can help in the detection of tonal variations more than this resolution. Combination of Hill-Shadow, TIN and drainage patterns relates the edges and it can be observed visually in a very efficient manner for delineation of linear features manually. The rose diagrams of drainage show structural control which is mostly related to few streams at higher reaches and also with mainstream flowing in NNE and SSW directions. The area is dominated by the intermittent drainage system. The present study has identified various linear structures present in the Amessa Guracha watershed. The application of Remote Sensing and GIS techniques shows encouraging results in study of linear features and may be effectively utilized in the Main Ethiopian Rift system or in similar terrain studies for neotectonic settings. The validation of the lineaments is done with a ‘Coarse Resolution’ Tectonic Map, prepared by the Ethiopian Geological Society.

6 ACKNOWLEDGMENTS

The authors are grateful to the President of the Arba Minch
University for his encouragement and support. The administrative support and encouragement received by the Dean of the Faculty of Meteorology and Hydrology, my students Adem Ebiso, Abdisa Abata, Mahlet Abebe and, the Department of Geology are highly acknowledged.

7 REFERENCES


[3]. Eirini S. Papadaki1, Stelios P. Mertikas1, and Apostolos Sarris (2011), Identification of lineaments with possible structural origin using Aster images and DEM derived products in Western Crete, Greece, EARSeL eProceedings 10.


[7]. Eirini S. Papadaki1, Stelios P. Mertikas1, and Apostolos Sarris (2011), Identification of lineaments with possible structural origin using Aster images and DEM derived products in Western Crete, Greece, EARSeL eProceedings 10.


BIOGRAPHIES

First Author Dr. Anirudh Bhowmick, completed his Ph.D. degree in Geology from Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya of Satna, M.P. in 2010. The author’s area of specialization is in the field of advanced GIS and remote sensing applications in groundwater prospecting and in mineral exploration. The author also worked as a Geologist in Niger for uranium exploration. Presently author is working as an Associate Professor in the Faculty of Meteorology and Hydrology, Arba Minch Water Technology Institute, Arba Minch University of Ethiopia, East Africa. Dr. Anirudh Bhowmick may be reached at bhowmick.anirudh@amu.edu.et