

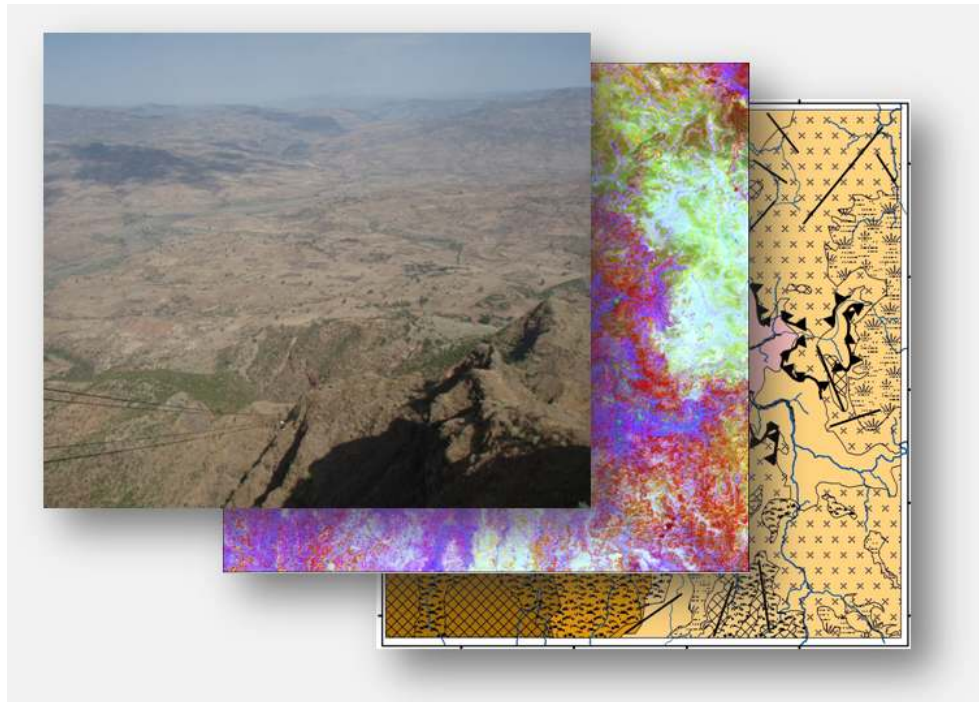
ADDIS ABABA UNIVERSITY
SCIENCE FACULTY, DEPARTMENT OF EARTH SCIENCE
GIS and Remote Sensing Stream



Geomorphological Mapping in the Upstreams of Muger River, Using Geospatial Tools

Yafet Birhanu Gebremariam

June, 2010



A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in GIS and Remote Sensing

Geomorphological Mapping in the Upstreams of Muger River, Using Geospatial Tools

Yafet Birhanu Gebremariam

July, 2010

APPROVED BY EXAMINING BOARD:

SIGNATURE

Dr. Balemwal Atnafu
Chairman, Department of Earth Sciences

Dr.K.V. Surya bhagavan
Adviser

Prof. Tenalem Ayenew
Examiner

Dr. Bekele Abebe
Examiner

ACKNOWLEDGEMENT

First and foremost I offer my sincerest gratitude to my supervisor, Dr.K.V. Surya bhagavan, who has supported me throughout my thesis with his consistent follow-up and advice. I am also thankful for his valuable time and effort spent for on-time resource provisions.

My examiners, Professor Tenalem Ayenew and Dr. Bekele Abebe have gone through the research and have given me very important comments and corrections which greatly helped in improving the quality of this thesis and deserves many thanks.

I like to forward my deepest thanks and respect to my sister Yodit Birhanu, for her patient support throughout this work.

I like to thank Asegid Getahun, Samuel Mola and Tigil Belay who helped me get old aerial photos and important litreatures. I also like to thank Genenew Basazinew and Micheal Nigussie whose ideas were constructive for the work.

I also appreciate and thank my fellow friends for their concern and support towards tackling technical problems faced during the research.

I express my heartily appreciations to Addis Ababa University for the conducive working environment set. Facilitated laboratories with extended working hours have assured on time accomplishment of this work. The financial support provided by the university has also eradicated resource problems that could have been faced.

Abstract

Advancement of GIS and remote sensing, introducing new methodologies and techniques, has made mapping of large areas manageable with few people. Availability of free and commercial datasets, software and tools invites researchers to develop new approach to conduct scientific studies. Advanced Space-born Thermal Emission and Reflection Radiometer (ASTER) satellite imagery, with high spectral resolution, allows a number of band combinations and manipulations making the imagery suitable for geomorphological mapping.

The study area located in the upstream of Muger River, tributary to the Blue Nile River, is known for its distinct geological setup and active river morphology. Sedimentary rock seccusions underlying thick tertiary volcanics is exposed to the surface due to the incision of the Muger River deep in to the highland plateaus. Physiographic zonings of the area made based on existing datasets helped to develop scientific approach for modification of lithological map and surface deposit mapping. Enhancements of ASTER satellite imagery sharpened the boundaries between neighboring lithologies. Surface deposits like Laterite, Colluvials, Residual Soil, Alluvial Soil and Limonite are mapped using a number of enhancements.

Composite relief maps stacked from three relief maps of different illumination azimuth angle allowed mapping of linear features from a single view. Remnants of erosion and their elevation gave information about depth and volume of erosion. Active river morphology is detected from aerial photo of two different times. Generally, geomorphological map of the area is produced and techniques like pan-sharpening using aerial photograph for geomorphological studies are introduced.

Key words: Geomorphological Mapping, Surface Deposits, Muger River, ASTER image, Aerial Photograph, River Morphology

Contents

ACKNOWLEDGEMENT	iii
Abstract	iv
List of figures	vii
List of tables	vii
1. Introduction	1
1.1. Description of the Study Area	2
1.2. Climate	3
1.3. Problem Statement	4
1.4. Justification	4
1.5. Objective	5
1.5.1. Specific objectives	5
1.6. Materials	5
1.7. General Methodology	7
1.7.1. Physiographic Zoning	7
1.7.2. Modifying Lithological Map	7
1.7.3. Mapping Surface Deposits	8
1.7.4. Linear Feature Extraction	8
1.7.5. River Morphology Evaluation	8
1.8. Scope of the study	9
2. Literature Review	11
2.1. General Geology of the Area	11
2.1.1. Basement Rocks	12
2.1.2. Lower Sandstone	12
2.1.3. Lower Limestone	12
2.1.4. Upper Limestone	13
2.1.5. Upper Sandstone	13
2.1.6. Volcanic Rocks	13
2.2. Erosional and Depositional Environment	14
3. Physiographic Zoning	16
3.1. Land Use/Cover Map	16
3.2. Lithological Map	17
3.3. Digital Elevation Model (DEM)	18
3.4. Relief Map	19
3.5. Physiographic Zoning	20
3.5.1. Bare Land Valley	21

3.5.2.	Mountainous Mixed Land Use	22
3.5.3.	Agricultural Flat Land	22
4.	<i>Mapping Geomorphological Units</i>	23
4.1.	Lithological Mapping	23
4.1.1.	Introduction	23
4.1.2.	Image Enhancement Techniques.....	24
4.2.	Surface Deposit Mapping	29
4.2.1.	Introduction	29
4.2.2.	Enhancements for Surface Deposits	31
4.3.	Mapping Linear Features	36
4.3.1.	Introduction	36
4.3.2.	Image Enhancements for Linear Features Mapping	36
5.	<i>Morphological Dynamics and Visualizations</i>	40
5.1.	Erosion Volume Estimation	40
5.2.	River Bed Morphology Change using Aerial Photos	41
5.2.1.	Introduction	41
5.2.2.	Orthorectification	42
5.2.3.	River Morphology	43
5.3.	Pan-Sharpening and 3D Visualization	45
6.	<i>Result and Discussion</i>	47
7.	<i>Conclusion and Recommendation</i>	51
	<i>References</i>	52

List of figures

Figure 1: Location Map.	3
Figure 2: Graph of mean annual rainfall.	4
Figure 3: Land use and Land cover map.	17
Figure 4: Geological map. Source: 1: 2 million geological map of Ethiopia	18
Figure 5: Digital Elevation Model (DEM)	19
Figure 6: Relief map	20
Figure 7: Physiographic zone map.	21
Figure 8: Spectral signature of selected areas.	24
Figure 9: a) Relief map b) band ratio of (2/3) x (4/3) of selected area.	25
Figure 10: a) Band ratio of (5/3) + (1/2), enhances Aiba Basalt b) Band ratio of 2/1, enhances Tarmaber Megezez Formation	26
Figure 11: a) ASTER image 13/14, carbonate enhancement, b) Mapping Abay Formation using textural differences	27
Figure 12: Lithological map shows modified boundaries of lithologies	28
Figure 13: Laterite deposit	29
Figure 14: River sand laying on river bed and colluvial material deposited at the river bank	30
Figure 15: Limonite occurrence on basalt	31
Figure 16: a) Band ratio 4/5 used to enhance laterite deposit. b) Slope map. c) Laterite and colluvial deposits	32
Figure 17: a) Band ratio of 2/1 for Fe³⁺ mapping. b) Traced anomalies of limonite	33
Figure 18: False color composite: 4/1, 3/1 and 12/14 in RGB	34
Figure 19: Distribution of surface deposits map	35
Figure 20: a) Slope map. b) Escarpments digitized from slope maps.	37
Figure 21: Composite Image of three relief maps, azimuth angle: 100, 145 and 190. b) PCA of the relief composites. c) Traced linear features and escarpments.	38
Figure 22: a) Relief map showing circular erosion remnants on the basaltic terrain. b) Land form called messa formed by erosion.	39
Figure 23: a) Shows modern DEM. b) Estimated depth of incision	41
Figure 24: Original aerial photograph and orthophoto.	43
Figure 25: Aerial photographs and Google Earth image showing river morphology change on two selected locations.	44
Figure 26: Pan-sharpened image and 3-Dimensional view dumped on DEM.	46
Figure 27: Geomorphological map	49

List of tables

Table 1: 14 bands of ASTER image and their description.	6
Table 2: Selected enhancements for lithological mapping	48
Table 3: Selected enhancements for surface deposits	48

Abbreviations

a.s.l Above Sea Level

ASTER Advanced Space-born Thermal Emission and Reflection Radiometer

Ca. Approximate Time

DEM Digital Elevation Model

DN Digital Number

EMA Ethiopian Mapping Agency

FCC False Color Composite

GIS Geographic Information System

GPS Geographic Positioning System

GSE Geological Survey of Ethiopia

HDF Hierarchical Data Format

Ma Million Years Ago

PCA Principal Component Analysis

RS Remote sensing

1. Introduction

Geomorphology is a science concerned with understanding the form of the Earth's land surface and the processes by which it is shaped, both at the present day as well as in the past. In its strictest sense geomorphology, the science of landform study is concerned with the study of form of the earth (Small, 1983). The science studies about landforms, their classification, origin, development, and history. Landforms are any features of Earth's surface having a distinct shape and origin. Plateaus, Mountains, Valleys, Plains, Hills, Mesas, Buttes and so on are common landforms expected in tropical environments.

The ultimate aim of geomorphology is to explain how individual landforms and, more particularly, landform assemblages have originated (small, 1983). However there are a number of approaches in the study of geomorphology; out of which, relationship which exist between certain types of landforms and particular type of climate, structure or rock. Another approach is assessing from an essential historical point of view, and try to demonstrate the various stages of evolution which the landscape has passed through before attaining its present form. Investigating the relationship between earth's processes and forms is also modern geomorphological approach.

Geomorphologists seek to understand why landscapes look the way they do: to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modeling. Thomas (1974) in his book, Tropical Geomorphology, discusses about weathering processes and products, denudation, deposition, planations and more under study of geomorphology. Generally geomorphologists aim at understanding the history of landscapes and map landforms.

Geomorphological maps have been developed throughout the world, particularly with the increasing availability and use of Geographical Information Systems (GIS). Some are based on generalized mapping, while others emphasize specific areas of geomorphology for particular purposes such as land use planning or hazard mapping. Geomorphological mapping comprises the classification of the natural landscape illustrating mainly form, origin and process (Kamal and Midorikawa, 2004). Geomorphological maps are one of the

most appropriate and synthetic ways of showing the distribution of landforms, surface and near-surface deposits, the processes that act on landforms and the time of their action. Erosional and depositional features, elevation and shape of terrains, escarpments, stream patterns and density are some of the entities which can be represented in a geomorphological map. Beyond this lithology, structure, landuse/landcover, and artificial features can be incorporated in a geomorphological map according to their importance.

Modern geo-technologies (remote sensing, geographical information systems/GIS and global positioning systems/GPS) have brought a huge methodological impetus to geomorphological mapping (Minár and Evans 2007). Remote sensing provides regional, synoptic view and permit recognition of large structural patterns and landforms over contiguous geomorphic domains. The high spectral resolution of satellite images assures considerable advantage for land form separation, river channel analysis and identification of depositional areas. One of the potential, but as yet underdeveloped, uses of digital remote sensing data is for geomorphological study and landscape interpretation (Giles, 1997). Synoptic overviews provided by data such as remotely sensed images can be very powerful in studying the consequences of earth sculpting process (Beaulieu and Gaonach, 2002). Digital elevation Model (DEM) is a derived product of remote sensing imagery. DEMs are set to become a valuable source of topographic data for the landform researcher (Smith and Clark, 2005).

1.1. Description of the Study Area

The study area falls within Blue Nile River Basin from 38⁰, 23' to 38⁰, 48' easting and 9⁰, 18' to 9⁰, 43' northing as shown in figure 1. Its area covers about 2000 km². It has got low lands of 1323 meters elevation to highland plateaus of 3278 meters elevation above sea level. The rugged topography is easily visible from digital elevation model. The area is covered by scares vegetation. Big river called Muger River crosses the study area joining the main Abay River after 45 kilometers of travel. Muger River is one of the biggest tributaries of the Blue Nile. Muger River drains the southern and south-eastern part of the north-western Ethiopian plateau. The study area falls in the up-streams of Muger River.

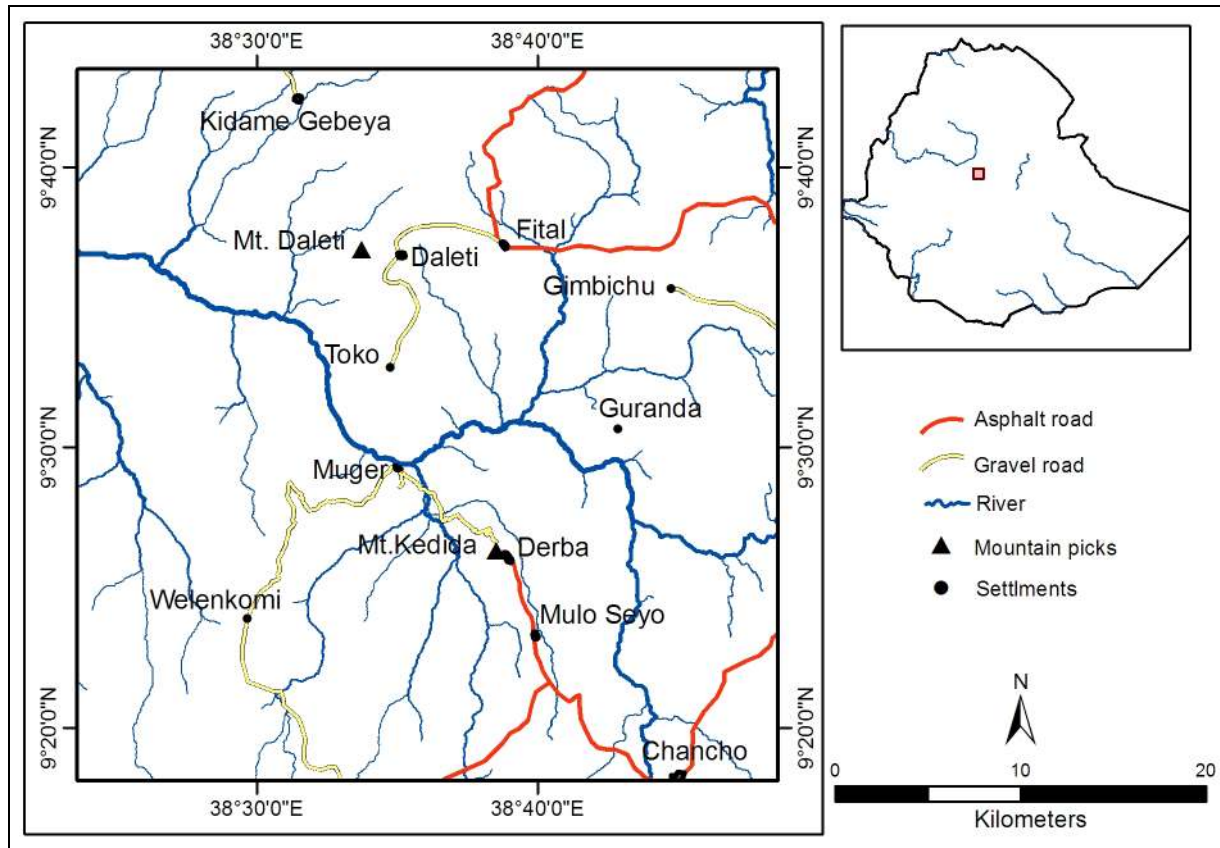


Figure 1: Location Map.

The area falls in the 1:50,000 topo-sheets of Fital, Minare, Inchini and Derba. Administrative location of the area is Oromiya Regional State, Northern Showa Zone. The study area can be accessed through 32 kilometers of asphalt road from Addis Ababa.

1.2.Climate

Rainfall and temperature data recorded for over 15 years in stations of Debre Tsige ($38^{\circ}48'50''$, $9^{\circ}41'12''$) and Fiche ($38^{\circ}44'00''$, $9^{\circ}47'31''$) shows that the mean annual rainfall is about 1144 mm and 1986 mm respectively. The rainy season extends from June to September majorly being on the months of July and August, shown in figure 2. The highest rainfall is registered in July (Debre Tsige Station: 267mm, Chancho Station:330mm). Similarly temperatures of Fiche station show that the lowest and highest mean monthly temperature is 11.6°c and 33.5°c in the months of April and May respectively.

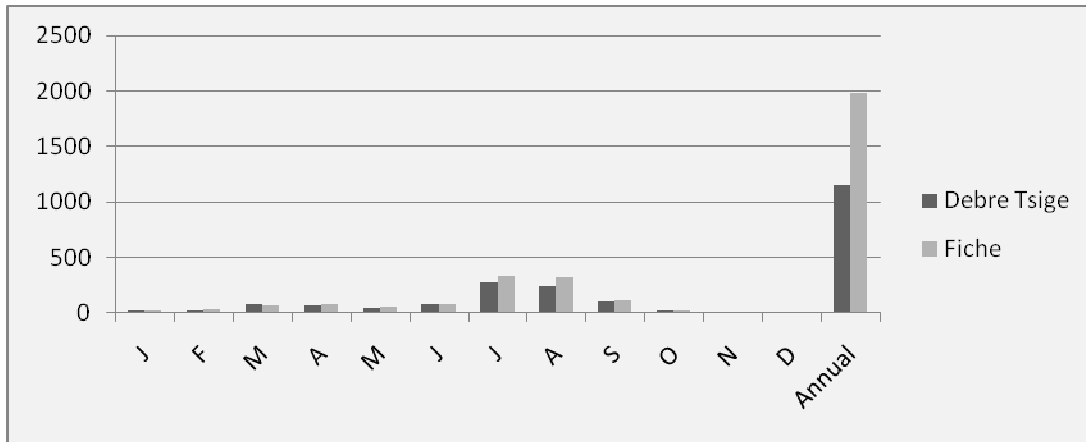


Figure 2: Graph of mean annual rainfall.

1.3.Problem Statement

Despite the intensive development of remote sensing techniques in the past years, the importance of scale/resolution dependence of various remotely sensed fields is underestimated in most area of application (Beaulieu and Gaonach, 2002). A number of previous works using remote sensing imagery as main input data are available. Yet we can say this approach is very young in Ethiopia.

Geomorphology, concentrating on surface processes and deposits, influences the life style and ecosystem of the area directly and quickly than the underlying geology and subsurface processes. However geomorphological maps are not being prepared and provided by responsible bodies in Ethiopia.

Nowadays, satellite images and derived products like DEM are accessible freely and with low cost. Hence, we need case studies made using these datasets to widen applications. Experimenting a number of GIS and Remote Sensing techniques and methodologies for geomorphological mapping using the mentioned datasets is important.

1.4.Justification

The importance of different geomorphological maps in mitigating impact on environment and geo-hazard derived damages has been noted by Kamal and Midorikawa (2004). Surficial deposits targeted by geomorphological studies are the most susceptible environmental systems for pollution and degradation. Availability of geomorphological maps contributes a lot in designing effective land use planning. A geomorphological map

can be used as a base map for production of larger scale engineering geological map, hydrogeological map and land use/cover map. Out of the many applications of geomorphological mapping as stated by America's National Aeronautics and Space Administration (NASA), some important for this paper are: Provide a precise picture of the dynamics of relief and Facilitate the search for connections between landforms.

The high rate of erosion and related active geomorphological activities in the Blue Nile Basin makes geomorphological studies crucial for the area. Muger River, one of the main tributary of Blue Nile River, exemplifies the geological history and active geological processes of the Blue Nile Basin.

1.5.Objective

The main objective of this study is to prepare geomorphological map of the study area.

1.5.1. Specific objectives

To fulfill the main objective of the study, a number of tasks will be conducted meeting specific objectives as follows.

- Preparation of general land use/land cover map
- Physiographic classification of study area
- Modifying existing Lithological boundaries
- Mapping surface deposits
- Identifying effective GIS and Remote Sensing techniques for geomorphological studies

1.6.Materials

A number of spatial and non spatial data will be used for the intended objectives of this study. The main input data is 14 bands of ASTER satellite imagery in level 1A format of acquisition date 2003-04-12. 30 meters resolution ASTER DEM which is derived product of ASTER image is also used. 1:50,000 topographic maps, 1:2,000,000 geological map of Ethiopia and some aerial photographs are the main inputs applied.

ASTER is Advanced Space-born Thermal Emission and Reflection Radiometer, a multi spectral sensor on board one of NASA’s Earth observing system satellites, Terra, which was launched in 1999. ASTER captures high spacial resolution data, in 14 bands from the visible to the thermal infrared wave length, and provide stereo-viewing capability for digital elevation model creation. ASTER measures reflected radiation in three bands between 0.52 and 0.86 um (VNIR) and in six bands from 1.6 to 2.43 um (SWIR), with 15m and 30m resolutions, respectively given in table 1. ASTER also has a back looking VNIR telescope with 15m resolution. In addition emitted radiation is measured at 90m resolution in five bands in the 8.125-11.65 um wavelength region (TIR) (Qari *et al.*, 2008).

The higher spectral resolution of ASTER, especially in the shortwave infrared region of the electromagnetic spectrum makes it possible to identify minerals and mineral groups such as clays, carbonates, silica, iron oxides and other silicates. Cloud cover vegetation and atmospheric effects can severely mask or alter surface signals.

Table 1: 14 bands of ASTER image and their description.

Subsystem	Band No	Spectral Range(um)	Spatial Resolution
VNIR	1	0.52 –0.60	15 meters
	2	0.63 –0.69	
	3B	0.78 –0.86	
	3N	0.78 –0.86	
SWIR	4	1.600 –1.700	30 meters
	5	2.145 –2.185	
	6	2.185 –2.225	
	7	2.235 –2.285	
	8	2.295 –2.365	
	9	2.360 –2.430	
TIR	10	8.124 –8.475	90 meters
	11	8.475 –8.825	
	12	8.925 –9.275	
	13	10.25 –10.95	
	14	10.95 –11.65	

The ASTER image acquired for this analysis was originally level 1A. The ASTER Level 1A raw data are reconstructed, unprocessed instrument digital counts with ground resolution of 15 m, 30 m, and 90 m for 3 VNIR, 6 SWIR, and 5 TIR channels. This product contains depacketized, demultiplexed, and realigned instrument image data with geometric correction

coefficients and radiometric calibration coefficients appended but not applied (ASTER user's guide, 2005). This includes correcting for SWIR parallax as well as registration within and between telescopes. The spacecraft ancillary and instrument engineering data are also included.

Level 1A ASTER image in file format called HDF is imported to IMAGIN's IMG file format using Erdas IMAGIN import tool. This Level 1B product contains radiometrically calibrated and geometrically co-registered data for all ASTER channels. This product is created by applying the radiometric and geometric coefficients to the Level 1A data. The bands have been co-registered both between and within telescopes, and the data have been resampled to apply the geometric corrections.

The datasets collected are analyzed using GIS and Remote Sensing softwares as: Erdas Imagin 9.1, ENVI 4.3, ArcGIS 9.2, Global Mapper 10.

1.7.General Methodology

Five general methodologies are followed to achieve objectives. Each methodology is described sequentially below. The last methodology, which is river morphology evaluation, is conducted for selected locations of the study area. Flow chart presented below illustrates major work flow carried out.

1.7.1. Physiographic Zoning

Physiographic zoning is conducted by evaluating existing geological map, generalized land use/cover map, digital elevation model and relief map of the area. The zoning is made subjective, aiming to differentiate the area based on degree of exposure or cover. This helps to tune the enhancement methods and extents and also is used to compare geomorphological features with physiography.

1.7.2. Modifying Lithological Map

Enhancements of ASTER imagery is done to modify the existing lithological map which is extracted from 1:2,000,000 geological map. Principal component analysis, band ratios and

false color composite selected for each lithologies are used to delineate the boundaries between them.

1.7.3. Mapping Surface Deposits

The core part of this study is mapping surface deposits. There are different types of geomorphological mapping based on their objective and limitations of methodologies. In this study laterites, limonites, colluvial deposit, alluvial soil, residual soil and river sand are the main geomorphological features targeted to be mapped. False color composites and band ratioing is important approach. Assessing associations of some units with digital elevation models and features like river is important.

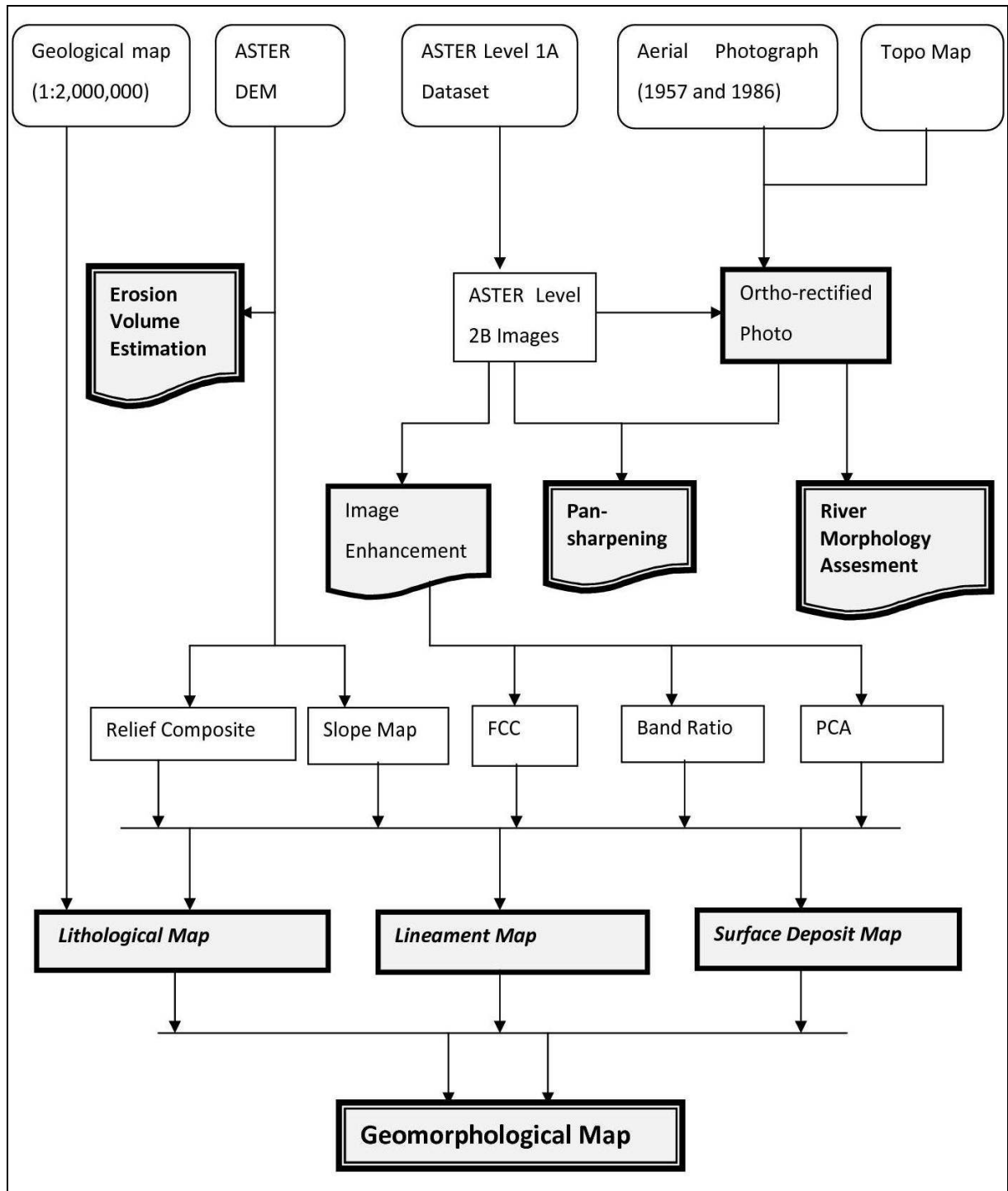
1.7.4. Linear Feature Extraction

Expected lineaments in the study area, emphasizing on lineaments formed with geomorphological phenomena will be mapped. Digital elevation model is the main input for this analysis. Relief maps from different viewing angles will be taken as different bands of image to prepare composite relief maps and their PCA. Directional lineament extraction using convolution matrix is also important approach

1.7.5. River Morphology Evaluation

In this part satellite images and aerial photographs of different times, selected for two areas, are rectified to evaluate how dynamic the river morphology is. Shape of river channel and depositions within it is compared. Here, orthorectification of aerial photographs is the main analysis conducted to produce ortho-photos.

The flow chart below shows the major input dataset, analysis and outputs.



1.8.Scope of the study

This work majorly dependant on ASTER satellite imagery benefits from its high spectral resolution to map geomorphological units in the upstream of Muger River. Modification of existing lithological map frames itself in sharpening boundaries of lithologies. Surface deposits evidence the geomorphological process of the area. Therefore out of many those selected for this area based on the physiography are laterite, colluvials, Alluvium, river sand, residual soil and limonite. Lineaments of tectonic origin are mapped on the highland plateaus only since the highland platues are less affected by erosional denudations. Due to accessibility problems and wideness of the area ground truthing is limited. River morphology analysis conducted using aerial photo is done on selected areas to evaluate the importance of the techniques.

2. Literature Review

2.1. General Geology of the Area

The Blue Nile, a major tributary of the Nile River, extensively dissects the north-western Ethiopian plateau exposing igneous, metamorphic and sedimentary rock units ranging in age from Neoproterozoic to Holocene (Gani *et al.*, 2007). Deeply incised gorge of the Blue Nile is also characteristic in the North-Western Ethiopian plateau. The general geological setup of the study area is quite similar with that of the Blue Nile geology.

The Blue Nile flows south-east from Lake Tana, then south and southwest before it assumes north-west flowing direction as it approaches the lowlands of Sudan. The exposure of Blue Nile basin within the northwestern Ethiopian plateau are bordered by the uplifted escarpments on the western flanks of the afar depression and the main Ethiopian rift in the east and southwest respectively, and in the west by the erosional Tana escarpment. The quaternary aged east-trending Axum-Adigrat and Ambo lineaments bordered this region in the north and south, respectively. (Gani *et al.*, 2008)

The basin contains about 1,400 meters thick section of Mesozoic sedimentary rocks unconformably overlaying Neoproterozoic basement rocks and unconformably overlain by early-late Oligocene and quaternary volcanic rocks (Gani *et al.*, 2008). Mogessie *et al.* (2002) in his research entitled a geological excursion to Mesozoic sediments of the Abay Basin describes the Mesozoic strata as 2,000 meters thick, capped by massive tertiary volcanic.

The Mesozoic sedimentary strata is buried beneath the extensive 500 to 2000 meters thick Cenozoic volcanic rocks. However the ~ 1600 meters deep gorge of the Nile (Gani *et al.*, 2008) formed by the blue Nile River on the north-western Ethiopian plateau provides good surface exposure suitable for focused stratigraphic and structural studies. The volcanic rocks covering the Mesozoic succession are associated with the afar mantle plume and subsequent opening of the afar depression and the main Ethiopian rift (Hofman *et al.*, 1997).

The Blue Nile Basin is considered to have formed during Mesozoic break up of Gondwana Land, similar to north-west trending Mesozoic rift that exist throughout northern and central Africa (Gani *et al.* 2008).

2.1.1. Basement Rocks

The basement rocks of the Blue Nile Basin is exposed in the north-west flowing segment of the Blue Nile. The age of the basement rock is considered to be neoproterozoic ranging in age from 850 to 550 Ma (Gani N. D. *et al.*, 2008).

The tract of land along the ethio-sudan border in the west is underlain by gneisses and migmatites known as Baro Group (Mengesha *et al.*, 2002). This rocks are made up of variably metamorphosed quartzo-feldspatic schist and gneisses, migmatites and plutonic rocks. Fractures within the Neoproterozoic basement rocks are dominantly NNE- and ESE-trending.

2.1.2. Lower Sandstone

This unit, found unconformably overlaying Neoproterozoic basement rock, is sometimes called as Adigrat sandstone. The thickness of lower sandstone in the Abay River basin ranges from 100 to 700 meters, (Mogessie *et al.*, 2002) forming nearly vertical cliff. This unit is formed by several layers appear as fine grained sandstone intercalated with reddish shales, mudstone and beds of conglomerates. In some places silicified tree trunks up to 4 meters long mud cracks and vertebrate tracks are found within this unit (Gani *et al.*, 2008). Planar cross bedding structures are characteristic. In some places sandy mudstone at the top of lower sandstone marks the transition to lower limestone. Lower sandstone is affected by dominant north-west trending normal faults.

2.1.3. Lower Limestone

This unit, about 450 meters thick, also known as Gohatsion Formation, is of early to middle Jurassic age. At the lower part it is characterized by green-shiest, gray or brown dolostones of less than 1 meter and shales. Thinly bedded limestone is overlaid by alternating limestone and gypsum beds. Alternation of gypsums and limestones in the upper part of the

unit indicates repetitive drying and flooding of an evaporative basin. Dominant north-west trending normal faults are observed.

2.1.4. Upper Limestone

Upper limestone is about 400 meters thick unit, comprises thinly bedded to massive limestone, also known as the Antalo Limestone, which is of middle-late Jurassic age. The upper limestone is fossiliferous with alternating yellowish limestone and gray calcareous mudstone. The deposition of the upper limestone indicates the second major marine transgression in the Blue Nile Basin. This unit is affected by NW- and NE- trending normal faults. The fractures within this unit are dilational.

Muddy sandstone formation occurs as a transition between upper limestone and upper sandstone. This unit is exposed in the major tributaries of Abay River. The lower part shows alternating gypsum, dolomite and shale. The upper part of this unit is thick vari-colored mudstone. A sandstone facies follows with fine to medium grained sandstone, subdivided in to fining upward sandstones and thick massive sandstones.

2.1.5. Upper Sandstone

The upper sandstone determined to be late Jurassic to early Cretaceous age is also known as Debre Libanos Sandstone. It unconformably overlies the upper limestone unit and unconformably overlain by tertiary basalts. This 200 to 500 meters thick sandstone comprises thickly to thinly bedded sandstones. The color varies from white to pink and is medium to coarse grained. The upper sandstone shows trough cross-beds, convolute beds, flat-beds, scored and channel surfaces and massive beds. This unit is affected by NW- and NE- trending normal fault and dominantly north trending fractures.

2.1.6. Volcanic Rocks

Much of the North-western Ethiopian plateau is covered by flood basalt together with subordinate trachytes and rhyolites aged early-late Oligocene. These volcanic rocks erupted from fissures having thickness from 500 to 2,000 meters. Cenozoic volcanic rocks of Ethiopia are divided into the trap series and Aden series. The term trap series is still widely

used to refer to the whole pile of the tertiary flood basalt sequence with intercalation of felsic lava and pyroclastic rocks (commonly on the upper part) which form the northwestern and southeastern Ethiopian plateaus (Mengesha *et al.*, 1996). This unit in some places is covered by basalts of quaternary shield volcanoes about 300 meters thick. This unit lack columnar joints and is characterized by sheet joints. It has got vesicles filled with green zeolite, calcite and quartz. Red to brown palaeosol horizons of about 30 cm thickness is common.

A number of formations of basalt are categorized under Tertiary Volcanics. Aiba Basalts, Alajae Formation and Tarmaber Megezez Formation occur significantly in the study area. As revised by Mengesha *et al.* (1996), Aiba Basalts are generally aphyric, compact rocks, in place showing stratification and contain rare inter-bedded basic tuffs. The Alajae formation contains basalts transitional to tholeiitic in nature. Basalts of the Tarmaber Formation in contrast to the tholeiitic and mildly alkaline nature of the earlier flood basalts typically have an alkaline affinity.

2.2.Erosional and Depositional Environment

Blue Nile bisects the northwestern Ethiopian plateau to a depth of 0 to 1.6 km, forming very deep canyons. The steep landforms and mountains of the plateau are non-orogenic, rather are remnants of erosion. Thermochronological studies indicate that the erosion at the Blue Nile and Tekeze drainage initiated ca. 29 Ma, shortly after the extensive flooding by thick basalt ca. 30 Ma (Gani *et al.*, 2007). The Blue Nile drainage has at least removed 93,000 km³ of rocks from north western Ethiopian plateau since ca. 29 Ma (Oligocene). 96% of the Nile sediment load is supplied from north-western Ethiopian plateau through the incision of Blue Nile and Tekeze drainage (Gani *et al.*, 2007).

The cause of Blue Nile incision is continuous tectonic uplift of the plateau (Gani *et al.*, 2007). There has been continuous uplift since the start of deposition of upper sandstone ca. 150 Ma, registering net plateau uplift to be 2.2 km. this uplift is majorly related to the rise of Afar Mantle Plume. It is also explained that in the rifting process, the margins of Ethiopian plateau were uplifted (Beaulieu and Haonach, 2002).

The occurrence of early to late Oligocene thick flood basalt has caused subsidence of the plateau due to isostatic adjustment. The unloading of huge volume of rock mass due to erosion (average thickness throughout Blue Nile Basin is about 0.37 km) has also caused long time isostatic uplift. Generally overall plateau uplift has aggravated river erosion. The removed masses were subsequently deposited as sediments in alluvial fans of Sudan and in the Nile Delta and Nile fan of the Mediterranean Sea.

3. Physiographic Zoning

Physiography is the science which treats of the earth's exterior physical features, climate, life, landcover, geology, etc., and of the physical movements or changes on the earth's surface. Physiography concerns itself with the description and the classification of physiographic forms (land forms) on the basis of its origin cause and history. Understanding the physiography of the study area facilitates more precise mapping of lithologic units and landforms.

The different types of remote sensing techniques are not equally efficient in all types of terrains. To adjust the extent of enhancement and to select the type of techniques accordingly based on their importance, dividing the study area in to zones is necessary. Physiographic study can also be taken as a preliminary analysis to hypothesize the geomorphological setup of the area. Hence, based on physiography, zoning of the study area in to manageable numbers is conducted. Land use/cover map, geological map, digital elevation model and relief maps are used to figure out the physiography of the area.

3.1.Land Use/Cover Map

Supervised classification of ASTER satellite imagery of the study area gave the general look of Land Use/Cover map, shown on figure 3. Five types of land-cover units are easily identified. Forest, cropland/grassland, agricultural land (cultivated land), bare land and river sand are the major land covers displayed on figure 3. Patchy forests are found in the central part extending to the west and north-east. It covers 16 % of the area. The cropland which is confusing with the grassland is distributed in much of the study area except in the north-western part. It covers about 4.7 % of the study area. Much of the study area, agricultural land, is found in the peripheries except in the north western part. This land unit indicates only the cultivated and exposed one. The boundaries of the farm lands give defined rectangular pattern to this unit. Agricultural unit acquires 40.2 % of the area. The bare land is majorly located in the north western part of the study area narrowing to the central part. The bare land having 37.9 % of aerial coverage follows the main river. The river is easily

visible by its association with the river sand which has unique spectral signature. It has the least areal coverage of 1.3 %.

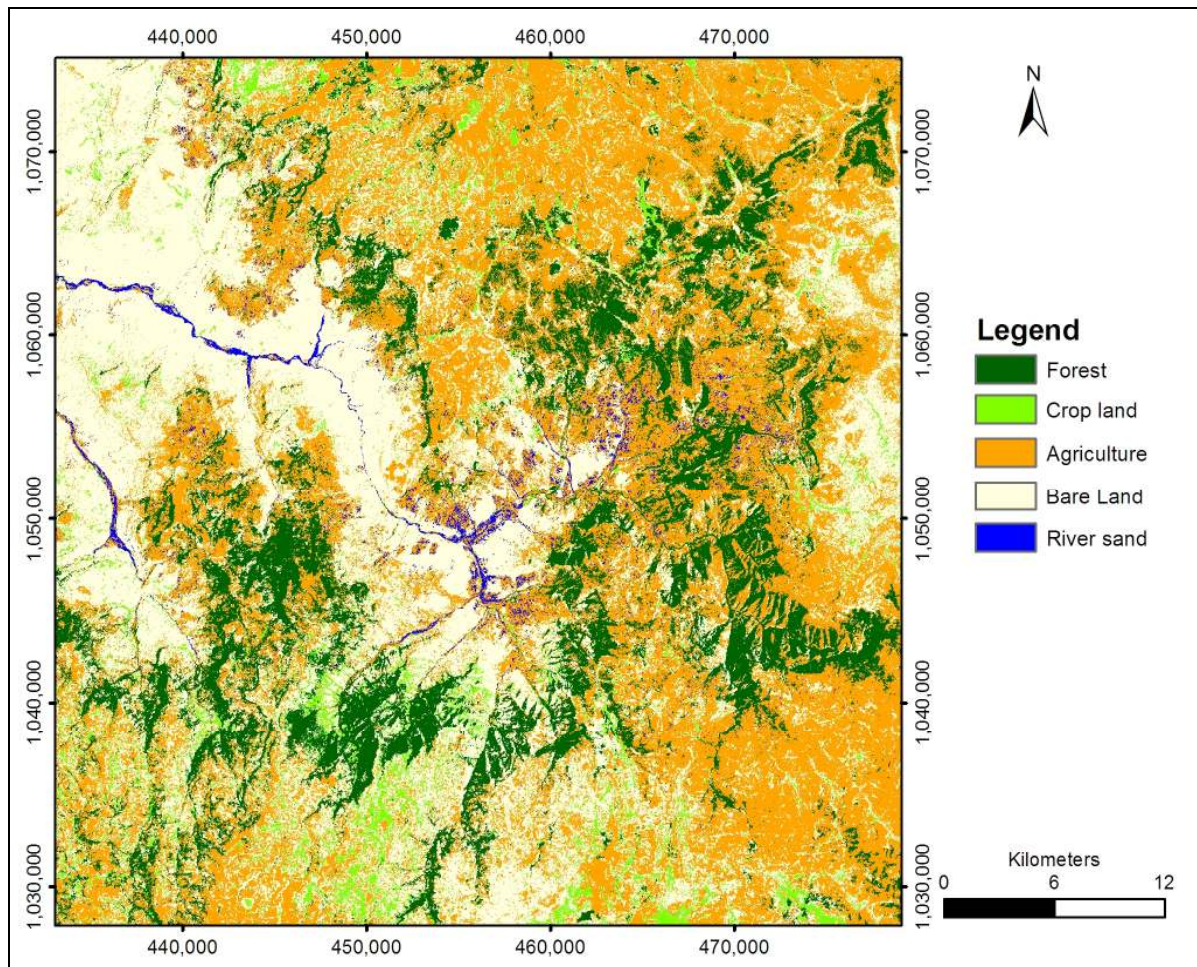


Figure 3: Land use and Land cover map.

3.2.Lithological Map

The lithological map of the study area, shown below in figure 4, is clipped from 1:2 million scale geological map of Ethiopia. Except the Precambrian rocks all the layers summarized in the previous chapter are exposed in the study area. Much of the area is covered by formations of basalt. Following the basalt large area is covered by upper sandstone exposed in both sides of the river. Lithological variation follows the river flow direction which is from the peripheries to the north western part. Upper Sandstone, Antalo Limestone, Abay Formation and Adigrat Formation occur successively towards north-west. Aerial coverage of Adigrat Formation is very small within the study area.

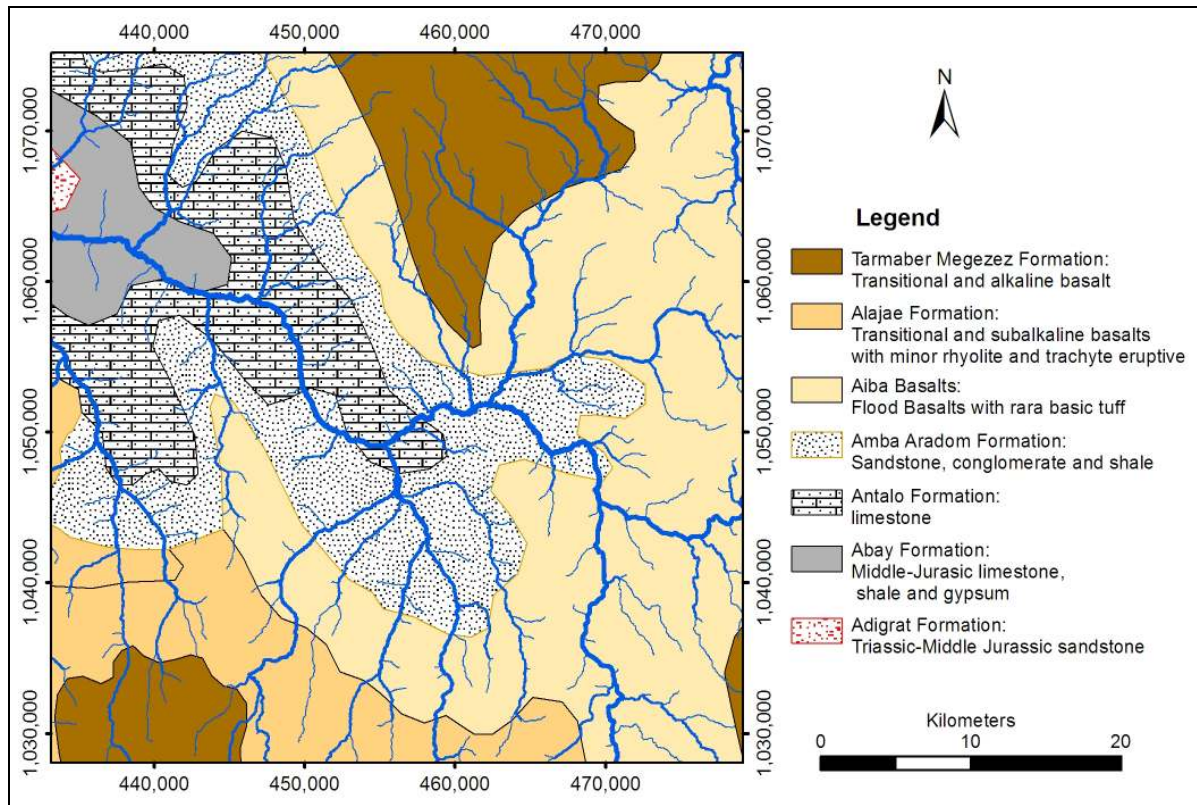


Figure 4: Geological map. Source: 1: 2 million geological map of Ethiopia

3.3. Digital Elevation Model (DEM)

The DEM of the area is clipped from ASTER DEM of 30 meters resolution. The digital elevation model without further enhancement shows the cliffs, mountains, plateau, canyons, gorges and other landforms. The pathes of the major river and its tributaries can be easily traced. Elevated plateau of altitudes greater than 3,000 meters above sea level are visible in the north and north-eastern part. The southern part is also elevated plateau showing erosion marks caused by northward flowing tributaries. The river has made incisions below 1,500 meters a.s.l. within the study area.

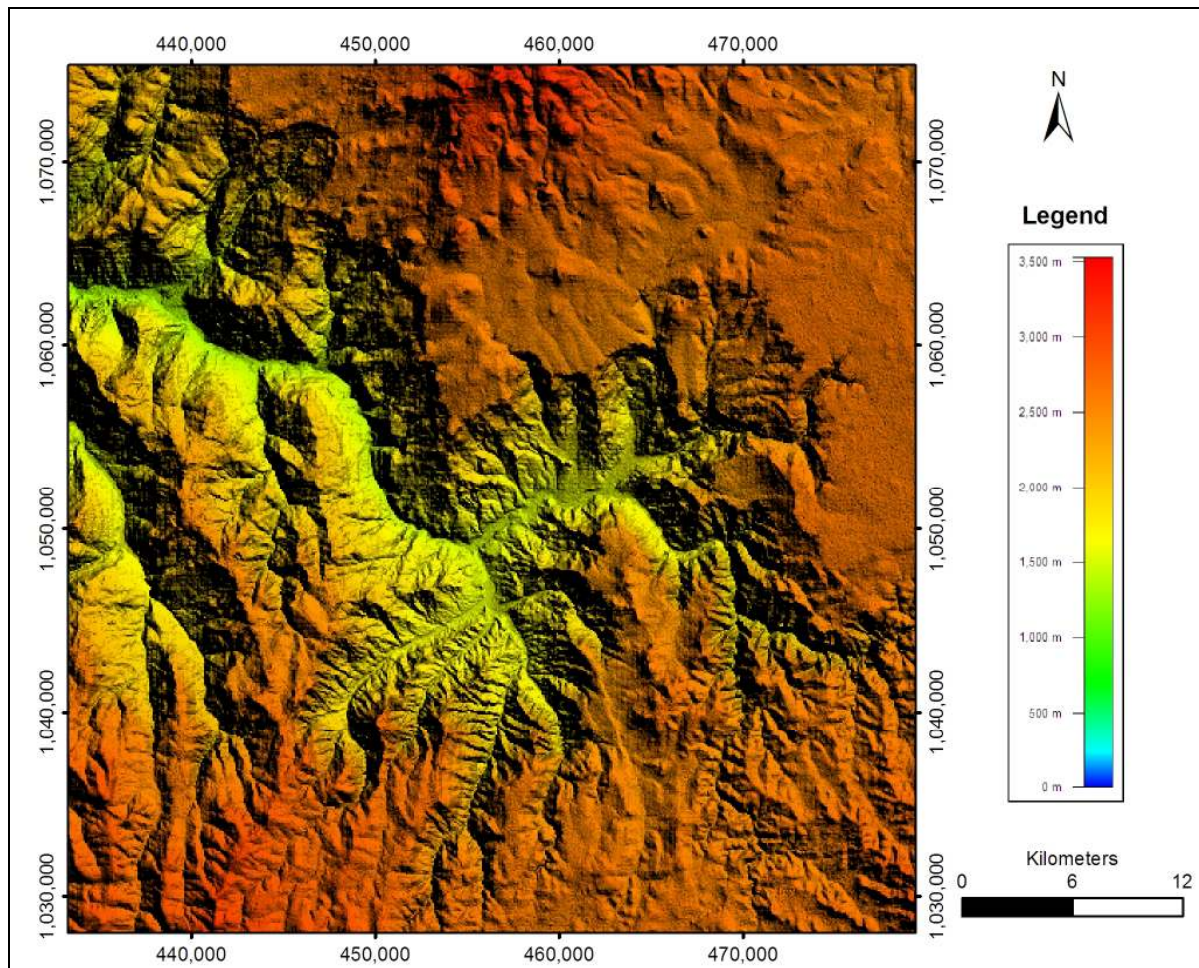


Figure 5: Digital Elevation Model (DEM)

3.4. Relief Map

The relief map prepared from the digital elevation model is used to discriminate the area based on its flatness and ruggedness, see figure 6. The central part shows high river incision within small area relative to the entire western part which is also affected by river erosion and form very rugged topography. The relief map shows small variation between the northern and north-eastern part witnessing its flatness. The flatness of the plateau in the southern part is affected by northward flowing tributaries of the major river.

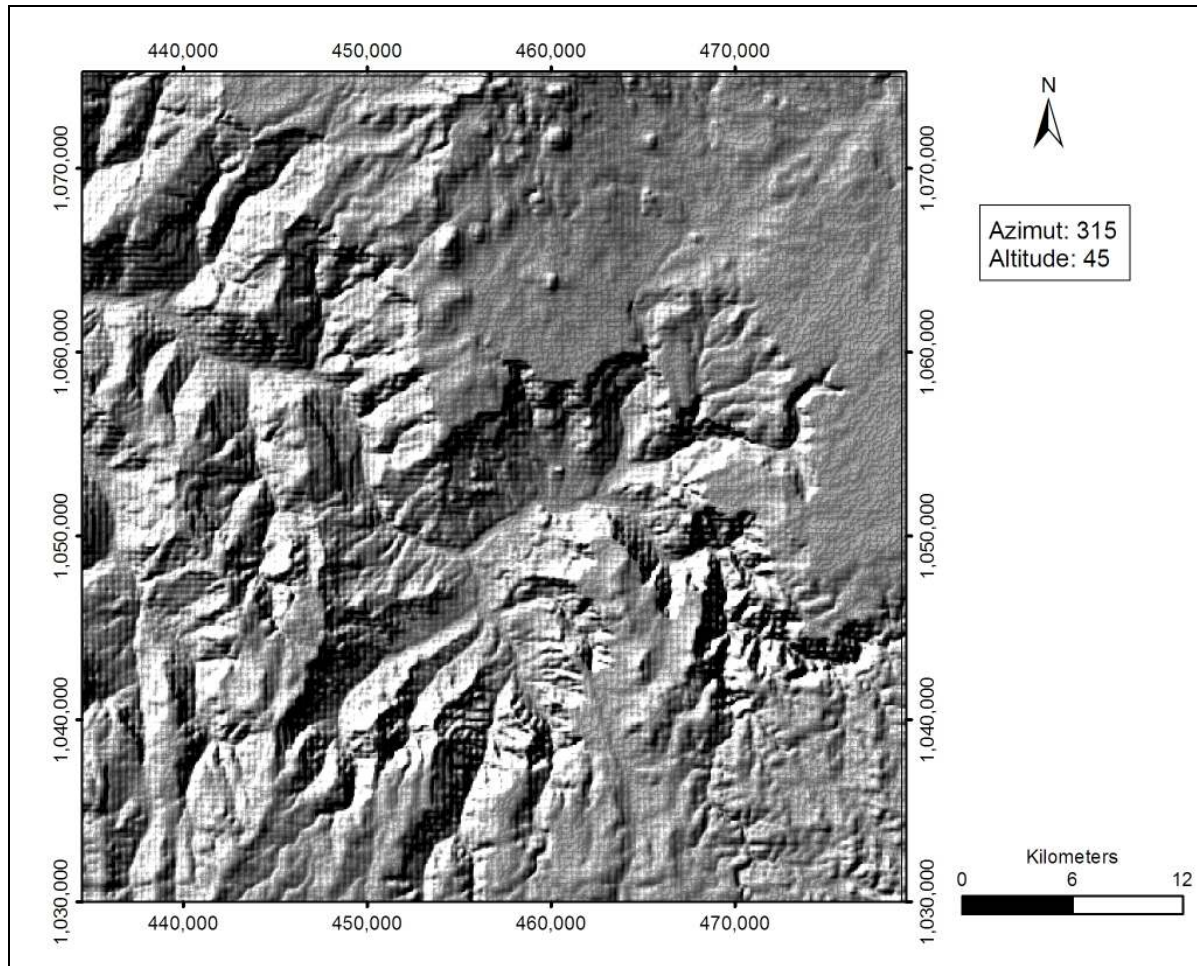


Figure 6: Relief map

3.5. Physiographic Zoning

Physiographic zoning is done by considering the four types of maps discussed above. Each map is considered as a single layer of information to influence the physiography of the area. The four layers (parameters) not only influence the physiography but also are inter-related. The geology of the area affects the topography. Some rocks like basalt and massive limestone are resistant to erosion forming positive topography. Where as shale is easily eroded and forms gentle slopes. The erosion remnants also vary in shape. Adigrat sandstone has a tendency of forming nearly vertical cliff. The limestone is known to show dissolution features at close observation and also creates consecutive benches following the bed lines. Generally the geological setup affects the topography. The relief map is drawn out from the digital elevation model which is also influenced by the geology similarly.

The land cover map better than others is highly influenced by the physical setups explained earlier. It also is the manifestation of the physiography. In the plateaus of the study area, where basalt is exposed, produces thick fertile soil and becomes favorable for agriculture. In the same condition if the topography is rugged it shows a tendency of becoming forest area. The shale and limestone exposed in the steep sides of the river are not favorable for the formation of thick fertile soil leaving the area bare land.

All the layers discussed above influence the land cover second to physiography. Therefore high weight is given to the land cover map of the area during subjective physiographic zoning. Three types of zones are developed out of which one is found in three different locations within the study area. The physiographic zones are named and shown in figure 7.

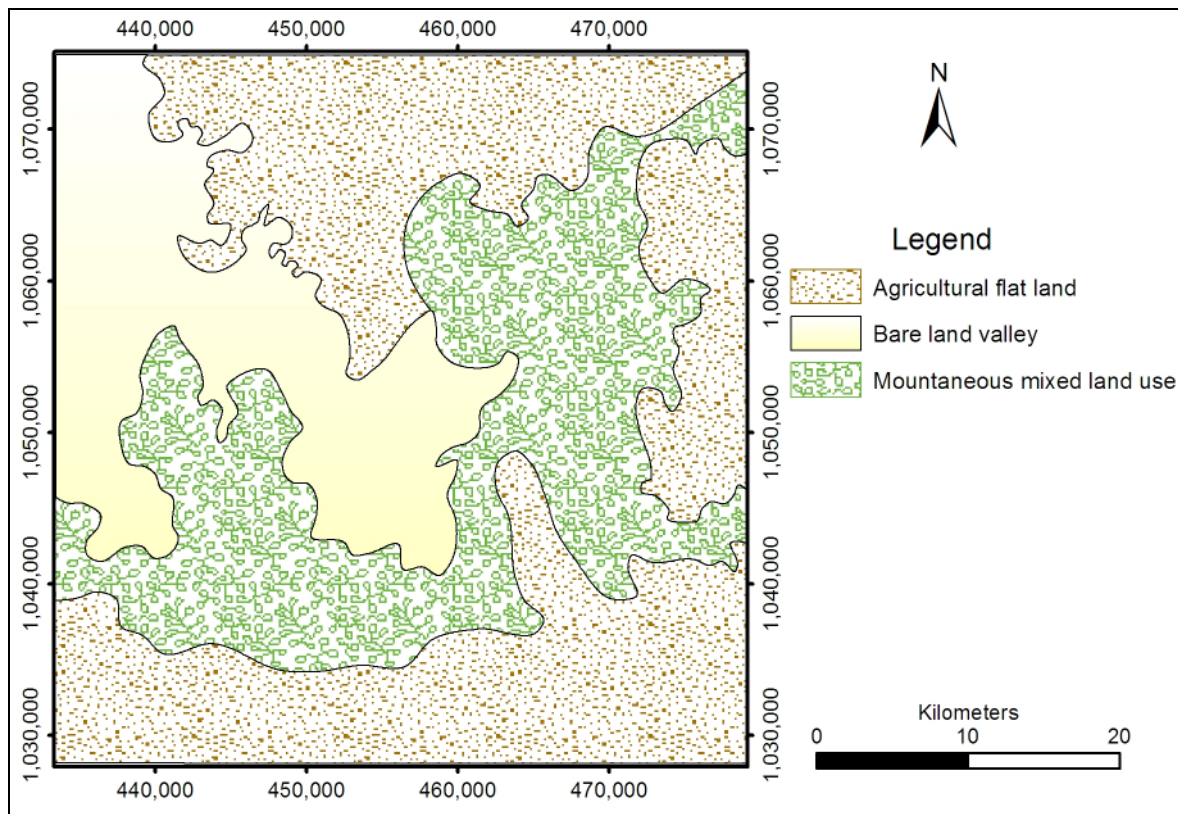


Figure 7: Physiographic zone map.

3.5.1. Bare Land Valley

This physiographic zone occupies about 22 % of the total area. Its land cover is bare land found at both sides of the main river from the central to the north-western part. Steep valley

and river bed cover the area. The main lithologies are limestone and shale. This physiographic zone is highly exposed. Due to the steepness of this zone, no residual soil is expected.

3.5.2. Mountainous Mixed Land Use

This physiographic zone occupying about 32 % is mixed land cover. Most of the forest cover of the area is found in this physiographic zone hence loose surface materials are present. Small aerial coverage of river bed and considerable cover of cropland and agricultural land is visible. Basalt and sandstone are the main lithologic units available in this rugged topographic area. This zone is relatively covered by forest and cropland which makes mapping difficult and needs fine enhancements and techniques.

3.5.3. Agricultural Flat Land

The Largest areal coverage which is about 46% is accommodated in the agricultural flat land physiographic zone. It is found in the elevated plateaus of northern, eastern and southern part. The lithology is dominated by basalt. This unit is found in three places of the study area, showing a tendency of connecting with each other outside the study area. This zone though exposed to erosion is covered by thick soil. Near surface features can be mapped leaving lithologic mapping challenging.

4. Mapping Geomorphological Units

A number of types of Geomorphological maps available today are produced based on intended purposes, methodology used and desired scale of the map. This project majorly depending on remote sensing dataset in GIS environment is intended to produce 1:200,000 scale regional geomorphological map. Surface deposits: laterite, Colluvial deposit, Alluvial soil, residual soil and river sand are prioritized to be mapped after assessing the physiography of the area in the previous chapter. Linear features are mapped after analysis made on DEM. Since geomorphology is highly influenced by geology, existing lithological map is modified. The general geomorphological map produced comprises modified Lithological map, surface deposits and linear features.

4.1.Lithological Mapping

4.1.1. Introduction

Geomorphology is not only the study of landforms, but also analysis their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features. Due to this geomorphology is highly related with lithology. Rock types (lithologies) vary in number of ways, out of which susceptibility to physical and chemical weathering and chemical composition can be mentioned.

The most dominant rock types in the area, discussed in chapter one, are different types of basalt, sandstone, limestone and shale. Compositionally basalt and red sandstone are rich in iron. Limestone is reach in carbonate; shale is expected to bear clay minerals. This compositional variation between rocks bring occurrence of different types of surface materials. Besides, the type of weathering expected in each unit is different. A type of chemical weathering like oxidation is expected in iron rich rocks. Dissolution features are common on limestones. Physical breakdown of materials is expected in shales. Topographic remnants of lithologies after chemical and physical weathering are distinct.

Lithological map of the area is extracted from existing 1:2,000,000 Ethiopian geological maps provided by GSE. Five types of rock formations are mapped and described within the study area. This small scale geological map is compiled in 1996. It is prepared by

collecting data along widely spaced traverses. Such type of mapping is subject to error at the boundaries of rock units.

4.1.2. Image Enhancement Techniques

In this unit a number of enhancements of satellite images are conducted to modify the boundaries of existing lithology. Most of band ratios and combinations used in this analysis are adopted from ASTER Mineral Index Processing Manual (Kalinowski and Oliver, 2004). Band ratio options for enhancements of features like Ferrous rocks, Carbonates, Silicates and Silica are stated. Few suitable band ratios and combinations are used to modify lithological boundaries. Spectral reflectance curves of known areas are analyzed to draw out band ratios. Digital elevation and relief map is also used for similar purpose. The following graph on figure 8. shows spectral signature of selected areas.

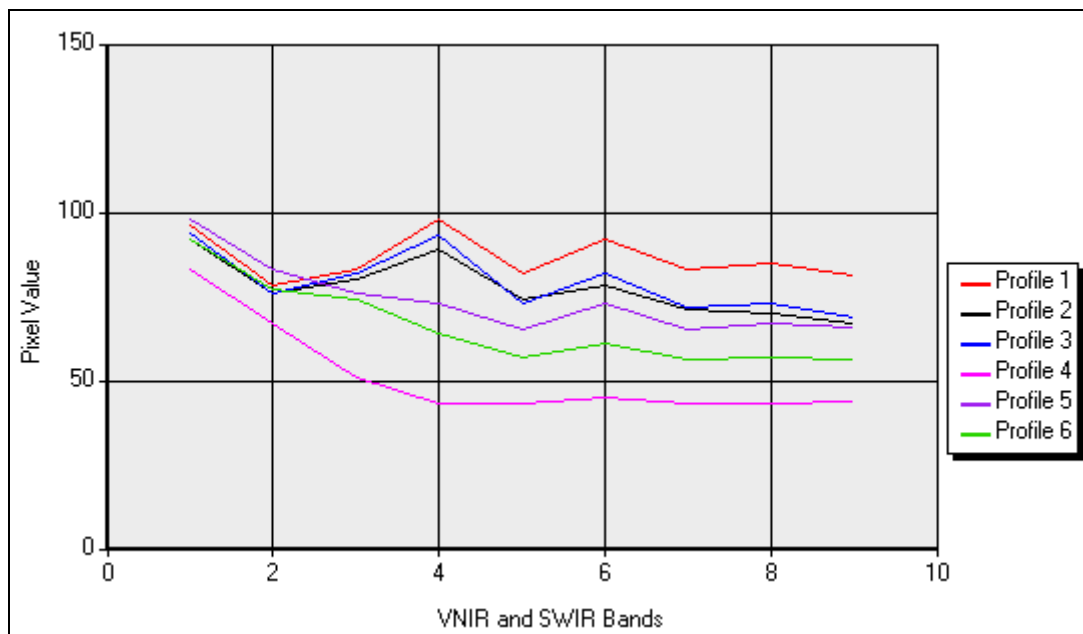


Figure 8: Spectral signature of selected areas.

As shown in the graph the spectral responses on the first two bands which are within the visible range of electromagnetic spectrum are bunched. Considerable contrasts are detected in the infra-red region which are bands 3, 4, 5, 6 and 7. Some band ratios are drawn out from the spectral curves which are believed to be significant for lithological discrimination. The basic principle is taking the ratio of bands of high DN value against low DN value

within a single spectral curve. By doing this some band ratios (4/2, 4/5, 6/7 and 6/3) are prepared to discriminate lithologies.

ASTER Satellite image rationing of bands (2/3) x (4/3) and a relief map is used to delineate the boundaries between basalt and sandstone in the northern part. Figure 9 shows the sharp distinction between the rock units both on the relief map and the above stated band ratio.

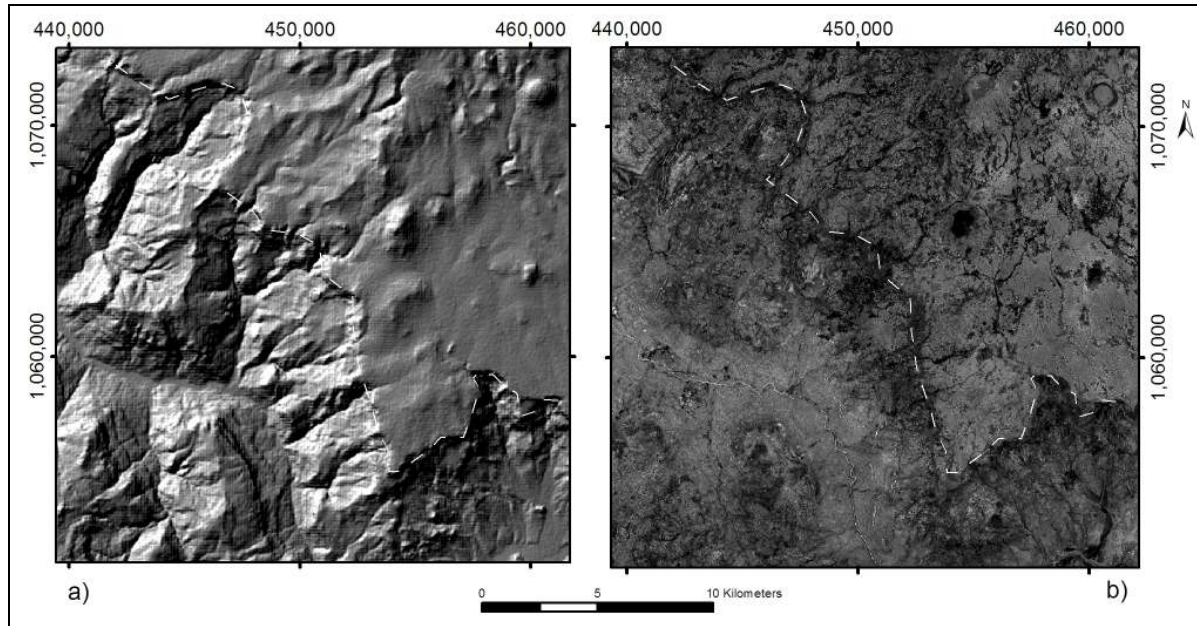


Figure 9: a) Relief map b) band ratio of (2/3) x (4/3) of selected area.

Most of the study area is covered by three types of basalt. These are Aiba basalts: flood basalt with rare basic tuff; Alajae Formation: transitional and sub-alkaline basalts; Tarmaber Megezez Formation: transitional and alkaline basalt. These basalts vary in their silica composition and alkali oxides (Na_2O and K_2O). Spectral signature of these units is believed to vary based on composition and degree of weathering.

Aiba basalt is distinct from transitional and alkaline basalt of Tarmaber Megazez Formation in band ratios of (5/3) + (1/2). This band ratio is sensitive for ferrous iron (Fe^{2+}). Basalt majorly composed of 45-55 wt% silica (SiO_2) also contains 5-14 wt% of FeO . Discrimination of the two types of basalt using the above band ratio may have resulted from different oxidation level of Iron. Reverse anomaly is detected in band ratio of 2/1 expected

to enhance Fe³⁺. Figure 10 shows the two types of enhancement used to discriminate the basalt types.

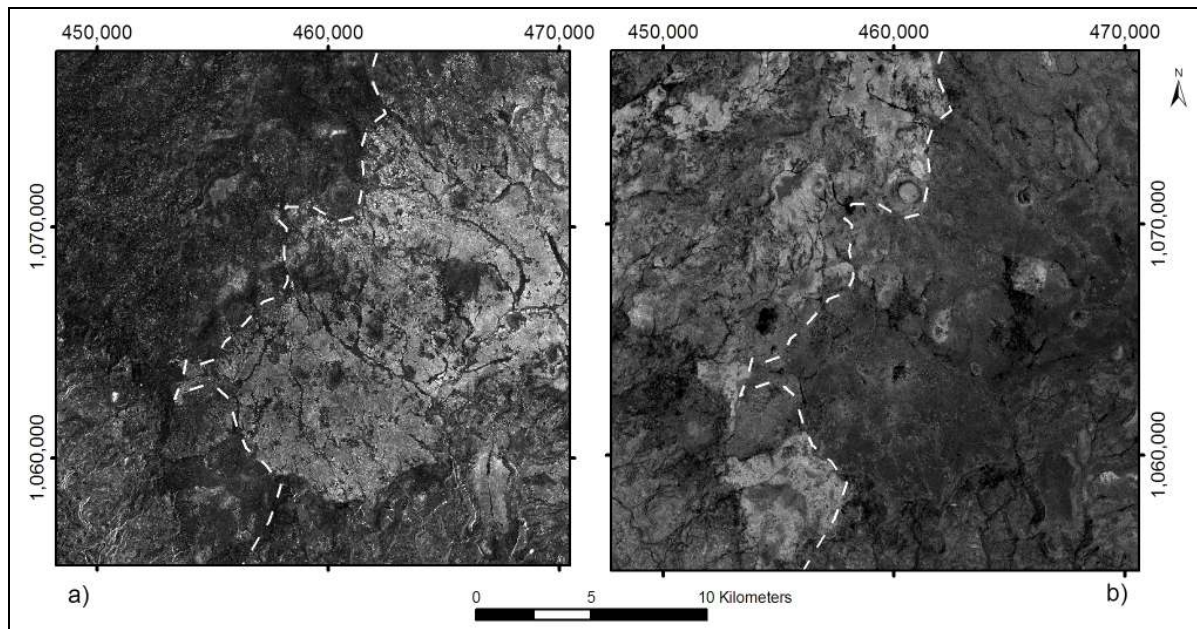


Figure 10: a) Band ratio of $(5/3) + (1/2)$, enhances Aiba Basalt b) Band ratio of $2/1$, enhances Tarmaber Megezez Formation

The upper boundary of sandstone is mapped using the above mentioned enhancements (figure 9) used to detect the basalts. The sandstone is overlaying the Antallo Formation which is majorly limestone. The contact between the limestone and overlaying sandstone is traced on band ratios of $13/14$ used to enhance carbonates. This band ratio makes the Antallo Formation and Abay Formation (also carbonate) very distinct from the overlaying sandstone. However it leaves challenge to discriminate the two types of carbonates. Abay formation underlying Antalo Formation is known to bear intercalations of shale and gypsum. Difference in texture and relief is used to delineate the Abay formation. Figure 11 shows enhancements for carbonate mapping and textural differences.

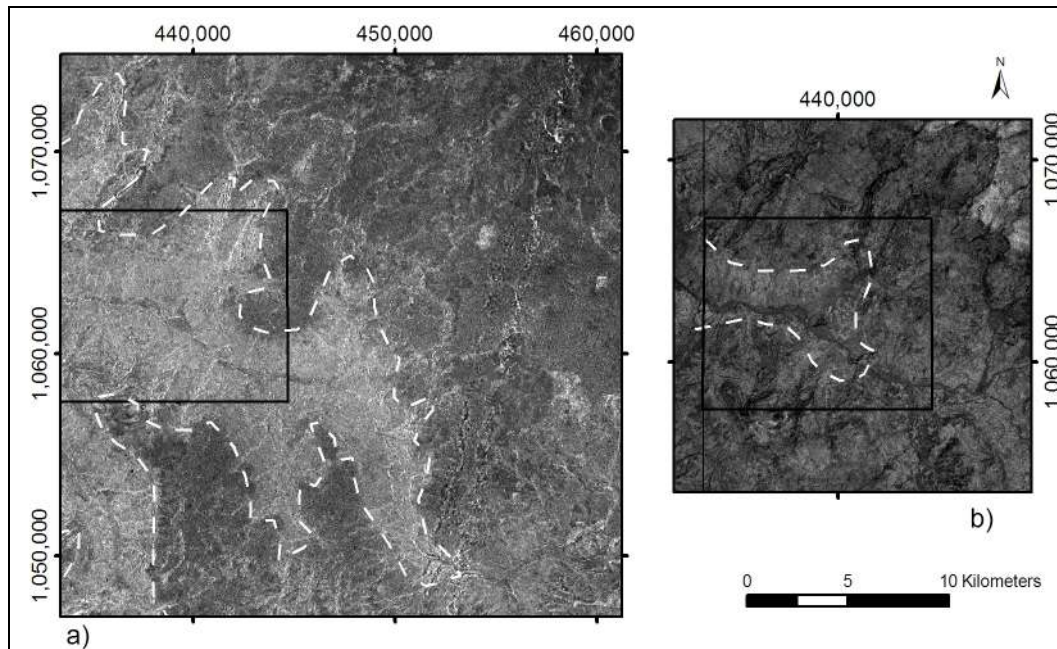


Figure 11: a) ASTER image 13/14, carbonate enhancement, b) Mapping Abay Formation using textural differences

Adigrat Formation, which is red sandstone underlying the Abay formation, terminates its extent out of study area. This unit is not mapped. Ashengi Formation and Alajae formation are similar in composition except in their intercalation and degree of weathering. Discrimination of the two units is also very difficult due to very small area coverage of Ashengi Formation. Figure 12 shows modified lithological map of the area.

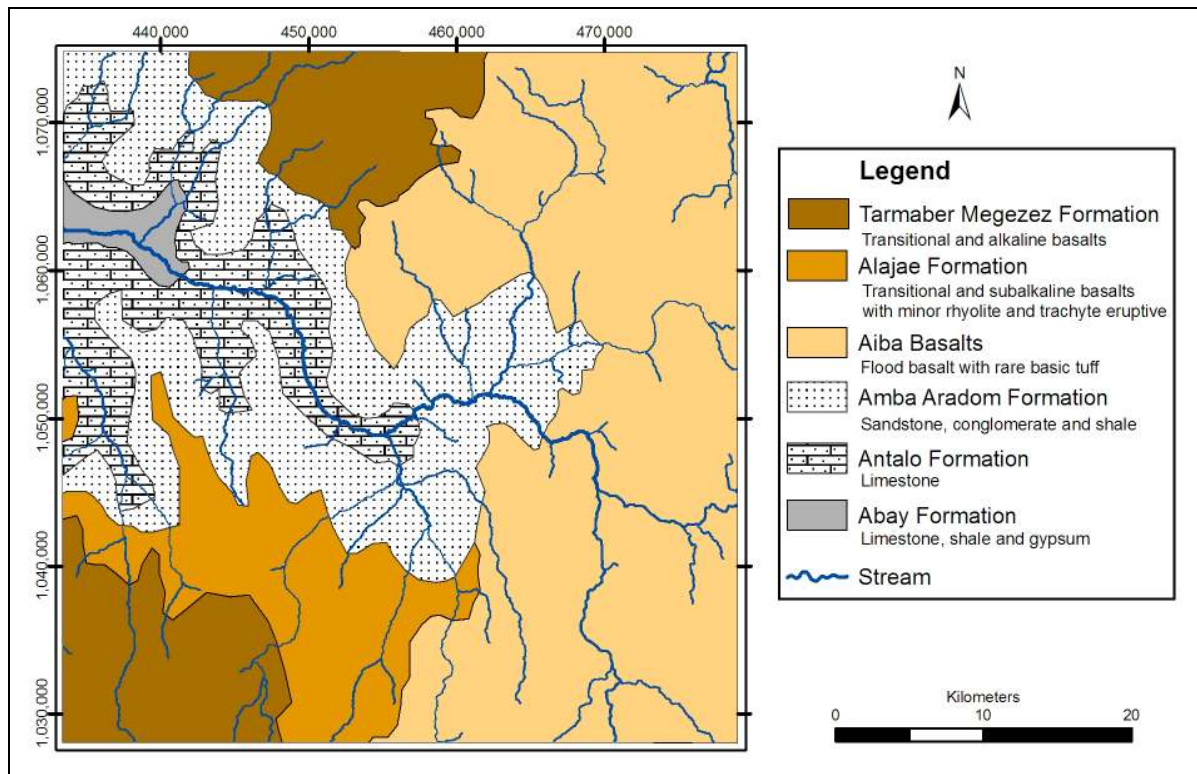


Figure 12: Lithological map shows modified boundaries of lithologies

4.2.Surface Deposit Mapping

4.2.1. Introduction

Geological process like erosion and deposition, chemical and physical weathering, leave remnants on the surface as well as create new surface deposits. These processes happen near the surface of the earth or at shallow depths. Erosion exposes fresh rock making geological mapping very easy. Contrarily depositions cover country rock and leaves challenge in geological mapping. Understanding the nature and distribution of this surface deposits is important to draw out the geomorphological processes of the area.

Recent deposits (Quaternary deposits) are of big interest concerning engineering geological applications and land use planning. Most of the times, these deposits, due to their occurrence near the surface, become foundations of structures or source of construction materials. Surface deposits are also focus of environmental concerns due to their vulnerability to pollution and degradation.

Physical and chemical breakdown of rocks form different varieties of soil. Laterite is very common deposit in tropical areas. Laterite can be defined as a highly weathered material rich in secondary oxides of iron, aluminum, or both (Thomas, 1974). It is nearly void of bases and primary silicates, but it may contain large amount of quartz and kaolinite. Nearly all laterites are rusty-red because of iron oxides. Figure 13 shows laterite deposit.



Figure 13: Laterite deposit

In steep slopes, weathering products (regolith), are transported and deposited down slope to form colluvium. Colluvium is the name for loose bodies of sediments that have been deposited or built up at the bottom of a low-grade slope or against a barrier on that slope, transported by gravity. In the area colluvial deposits occur in the valley faces.

Sand, gravel and coble deposits lay on the river bed of main rivers. These deposits are significant to this work due to the wideness of the river channels accommodating considerable volume. Typical river sand deposit is shown in figure 14.



Figure 14: River sand laying on river bed and colluvial material deposited at the river bank

A kind of chemical weathering called oxidation on basalts within the study area create yellowish to dark brown surfacial material called limonite. The occurrence of limonite sometimes can be referred with alteration. Limonite cover is expected in areas where high iron bearing rocks like basalt are available. Limonite occurrence may increase the weathering resistance of the rocks and create positive topography. Hence thin layer of limonite is expected in exposed rocks with high iron content (figure 15).



Figure 15: Limonite occurrence on basalt

Rivers flowing in gentle slope deposit clay and loam soil called Alluvium (Alluvial Soil). Alluvial soil is a fine-grained fertile soil deposited by water flowing over flood plains or in river beds. The fertility of alluvium and its occurrence near river makes it favorable for agriculture.

4.2.2. Enhancements for Surface Deposits

Surface deposits by their nature of occurrence are exposed which makes mapping easy with least enhancements. ASTER satellite image band ratios of 4/5 is known to enhance laterite deposits (Kalinowski and Oliver, 2004). This enhancement also helps to map colluvial deposits. Laterite and colluvial deposits have similar spectral reflectance. The two units vary in place of occurrence. Colluvium pulled down by gravity is expected at valley faces and bottom of slopes. This unit in most times is not covered. Laterite is found in gentle slope areas and can further decompose to create residual soil. Figure 16 shows laterite and colluvium differentiated by topography of depositional environment.

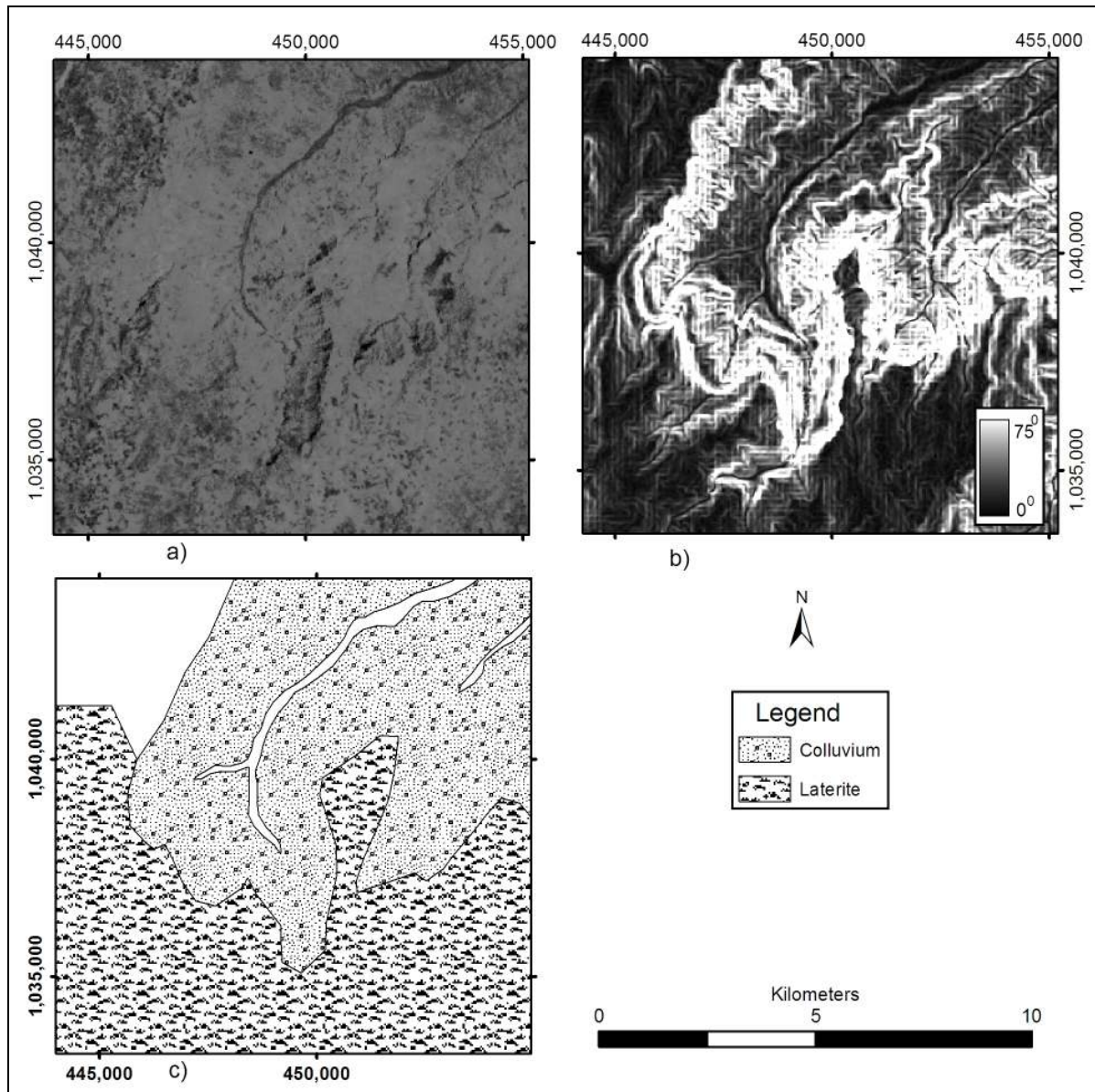


Figure 16: a) Band ratio 4/5 used to enhance laterite deposit. b) Slope map. c) Laterite and colluvial deposits.

Limonite forms at the surface of iron bearing rocks due to oxidation. Basalt is known to have high concentration of iron in oxidation state of +2 (Fe^{2+}). During oxidation thin layer of limonite composed of (Fe^{3+}) accumulates at the surface of the basalt. ASTER image band ratio of 2/1 is recommended to enhance Ferric iron (Kalinowski and Oliver, 2004). The band ratio shows positive anomaly on basalts specifically on the transitional and alkaline basalt found in the northern part of the study area. Figure 17 shows band ratio of 2/1 and corresponding limonite map of part of the study area.

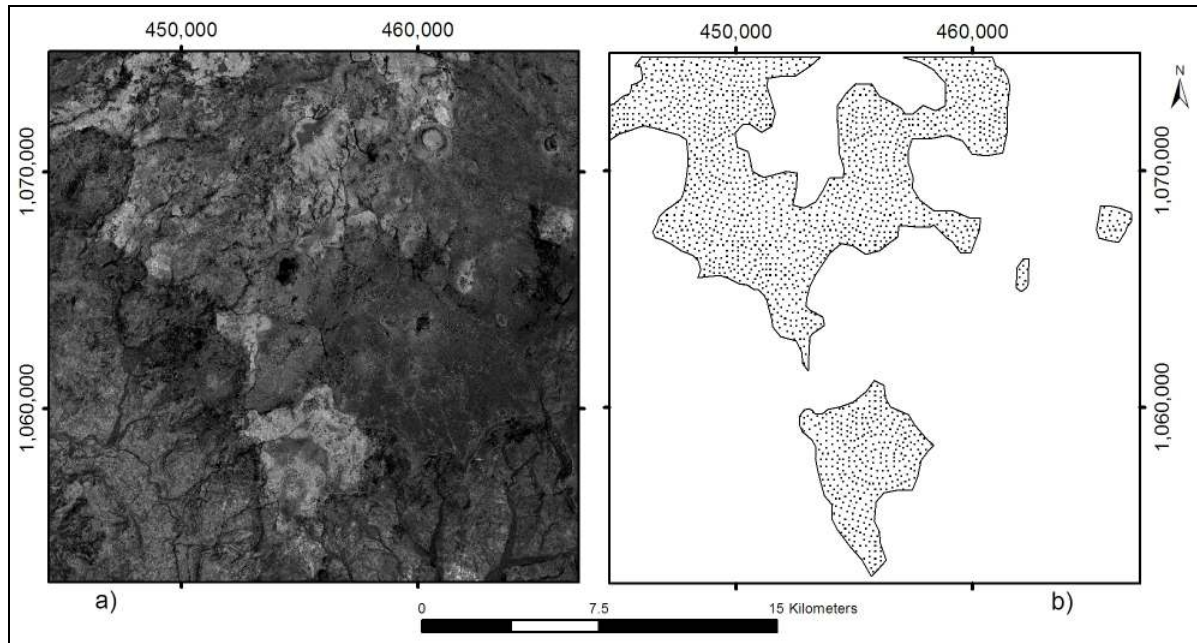


Figure 17: a) Band ratio of 2/1 for Fe³⁺ mapping. b) Traced anomalies of limonite

The main river Muger River crossing the study area has river bed width of up to 1 km. River sand is distinctively deposited throughout the river beds. This unit is easily visible in most false color compositions of ASTER Image. River sand is delineated following the river by comparing a number of band ratios and combinations.

Band ratio combinations of 4/1, 3/1 and 12/14 in RGB are suitable for discrimination of mapping (Kalinowski and Oliver, 2004). This combination shown in figure 18 has given big contrast between a number of features. Alluvial soil in the eastern and southern part of study area is delineated using this composition. Wet areas due to river within the alluvium are distinct.

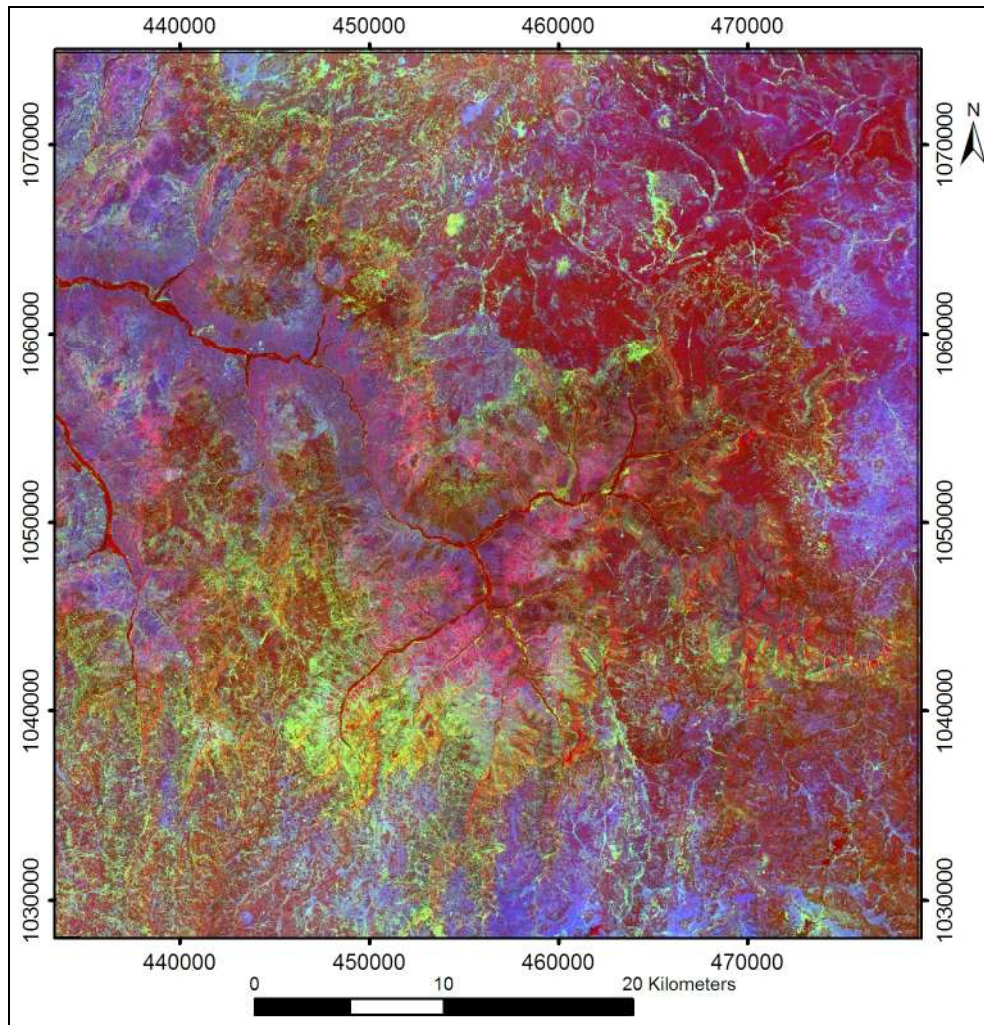


Figure 18: False color composite: 4/1, 3/1 and 12/14 in RGB

All the surface deposits enhanced and mapped using the above explained band ratios and combinations are compiled in one map as shown on figure 19. Most of the area is covered by either of the above explained surface deposits. Blank areas which are not mapped in this unit are exposed rocks with least or no surface deposit.

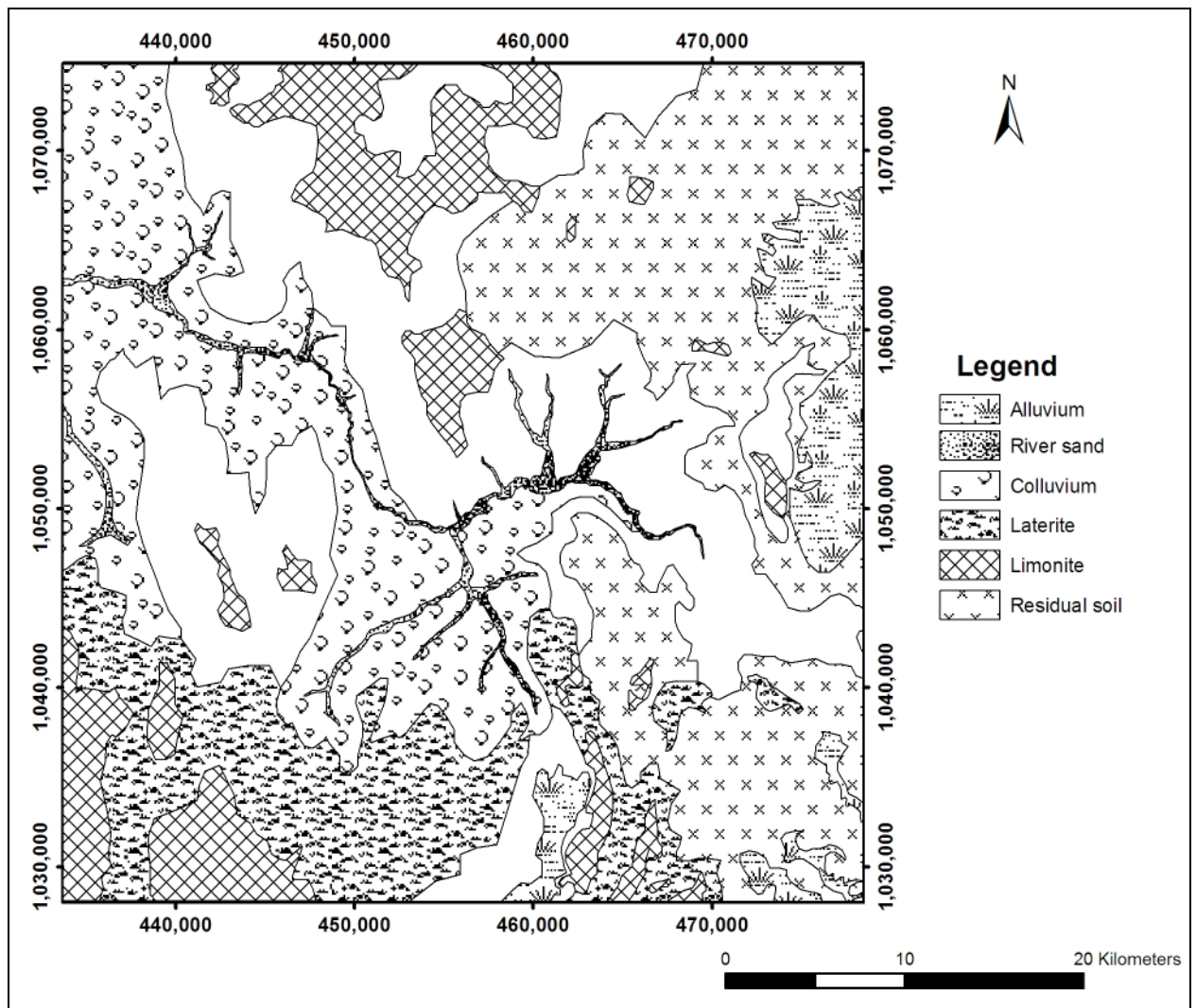


Figure 19: Distribution of surface deposits map.

4.3.Mapping Linear Features

4.3.1. Introduction

Due to the advancement of remote sensing and GIS technologies, land form mapping is aided by computer visualization of digital Elevation Model (DEM). Land forms were originally mapped directly in the field; however the advent of remote sensing technologies has meant that larger areas can be mapped by fewer people in less time (Mike and Chris, 2005).

Land form mapping has been a primary method of data collection across a wide range of earth sciences. Satellite imagery and DEMs are the main remote sensing technologies and these have been used extensively to map landforms over a wide range of applications. DEMs can be enhanced to produce map layers for land form mapping. Relief maps, slope maps and slope curvature maps are outputs of DEMs used to map land forms. In this unit landforms are enhanced and visualized and linear features are mapped.

The land forms in the study area are influenced by the most dominant geological phenomena, erosion. Extensive erosion is observed in the bare land valley and mountainous mixed land use physiographic zones. Deep valleys, cliffs, steep mountains and escarpments are observed. The agricultural flat land is found on the elevated plateaus and shows small elevation difference and gradient. Relatively extent of erosion is least in this zone. Linear features of tectonic origins are thought to be preserved in this zone.

4.3.2. Image Enhancements for Linear Features Mapping

Extensive erosion in the study area has left deeply incised canyon, steep cliffs, escarpment and plateaus. Escarpments mark boundary between plateaus and valley faces. Escarpments are susceptible to mass wasting due to gravitational pull. Slope map produced from DEM shows topographic gradients. Slope curvature map is produced by conducting 3x3 high pass convolution on the slope map. Two different levels of escarpments are mapped from the original slope map and 180 meters resolution resampled image as shown in Figure 20.

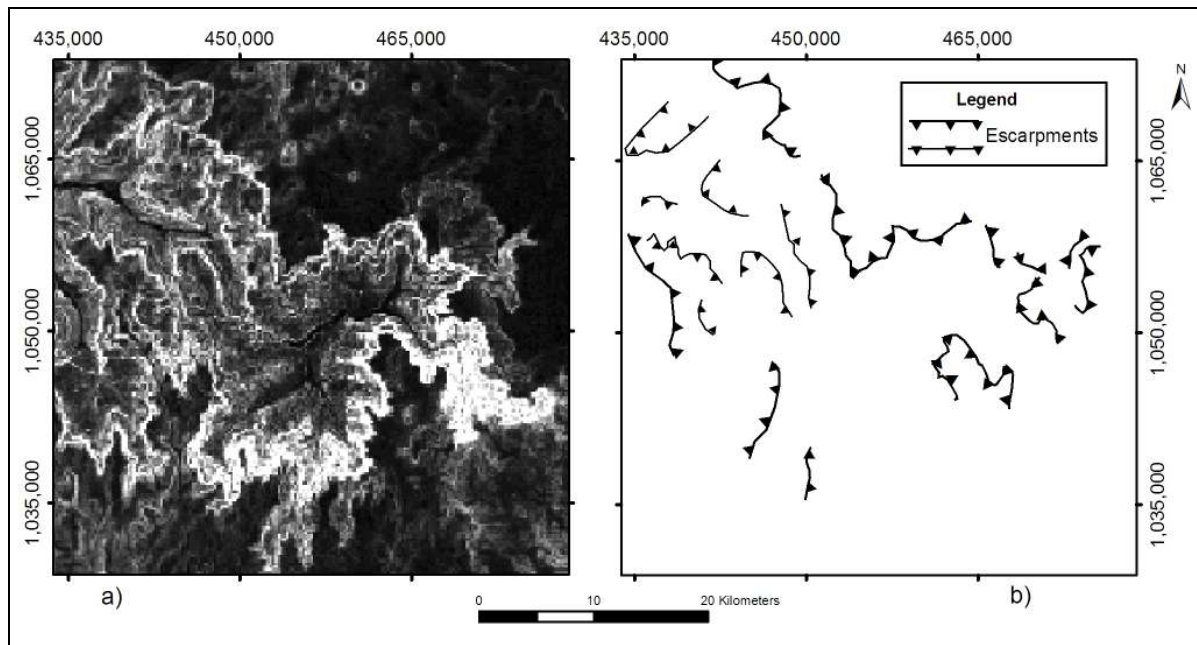


Figure 20: a) Slope map. b) Escarpments digitized from slope maps.

One of the outputs of DEMs is relief shading. Relief Shading is the use of light and dark tones to depict the form of land; it makes the map appear as if illuminated by the sun from imaginary azimuth and solar elevation angle. This process makes the land look three dimensional by the use of graded shadow effect. Relief shading is popular because it highlights subtle variation in the surface and allows their realistic depiction and interpretation. Features can be enhanced or suppressed by manipulating the illumination direction. Landforms are more clearly depicted when illuminated from a direction at right angles to the lineament trend (Mike and Chris, 2005). Linear landforms shaded from certain azimuth are less visible. This is called azimuth biasing.

Three relief maps of azimuth angle 100, 190 and their intermediate are produced to map linear features. Each relief shading prepared is known to enhance linear features of similar orientation; that is perpendicular to azimuth angle. Due to these composite images of the three relief maps and their principal component analysis is used to trace linear features within the highland plateaus. Figure 21 shows the stacked relief map and it's PCA.

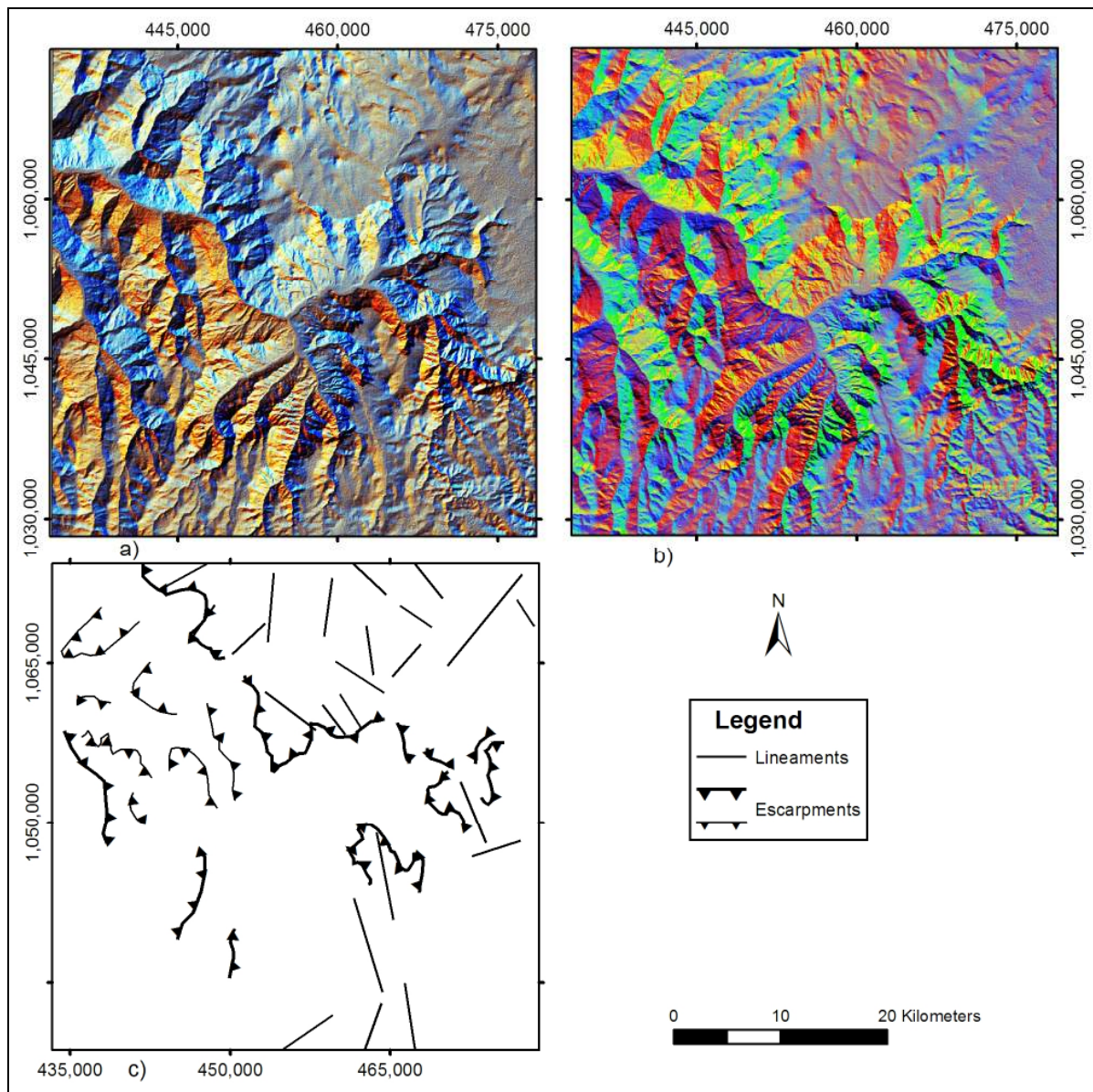


Figure 21: Composite Image of three relief maps, azimuth angle: 100, 145 and 190. b) PCA of the relief composites. c) Traced linear features and escarpments.

The relief map uniquely also showed circular erosion remnant in the highland plateaus shown on figure 22 a). These circular features are observed only on the basaltic terrain found in the northern part. Erosion remnants within the main valley incision are visible on the relief maps as shown in figure 22 b). Most land forms like valley, cliffs and mountains are easily visualized using the relief maps.

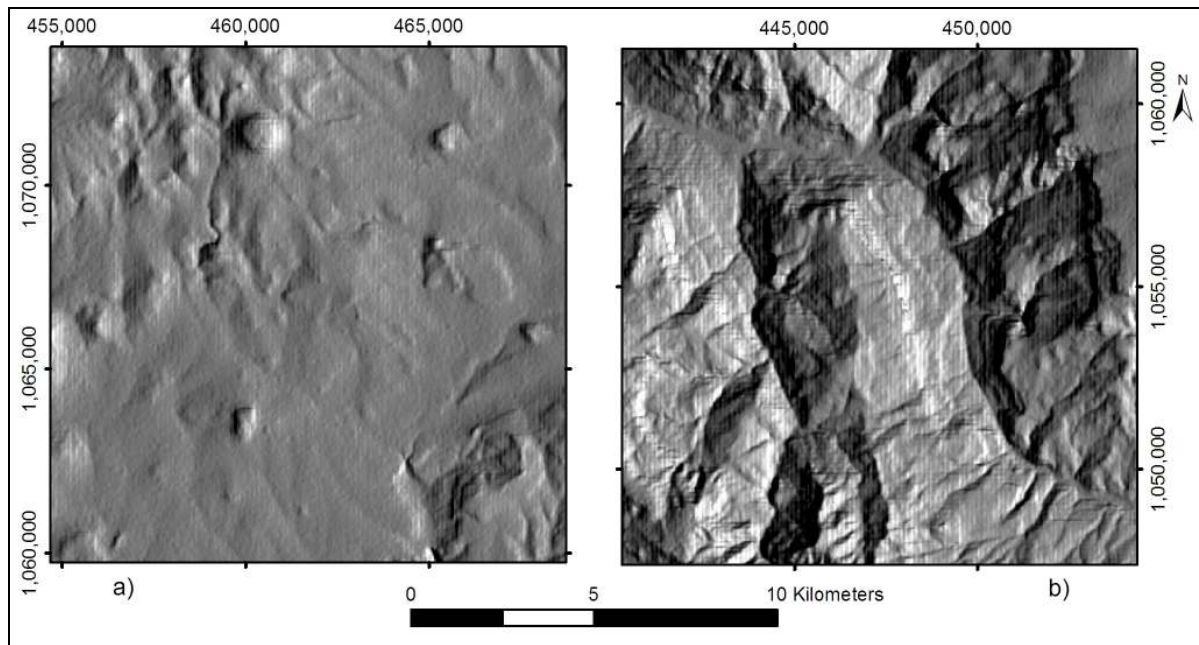


Figure 22: a) Relief map showing circular erosion remnants on the basaltic terrain. b) Land form called mesa formed by erosion.

5. Morphological Dynamics and Visualizations

5.1. Erosion Volume Estimation

The occurrence of deep canyons in the study area and exposure of section of underlying lithologies makes incision volume estimation big interest. The last sedimentary succession Amba Aradom Formation is evidence for flatness of the area during late Cretaceous. Series of flood basalt eruption occurred in the area also assured the formation of nearly horizontal surfaces during the epoch of Oligocene. These formations have gone through some geological processes changing the semi-horizontal terrain during their formation. Occurrence of flood basalt unconformably over upper sandstone evidences rough topography caused by erosion on the upper sandstone. The flood basalt has also lost its semi-horizontal surfaces due to the occurrence of recent volcanisms and deep erosions.

Topographic contrasts formed by deep erosion are easily visible from the digital elevation model. There is about 2000 meters of elevation difference between the lowest point at the mouth of the main River Mugger and mountain picks in the northern part. The topographic variations are formed by extensive erosion.

By inter-connecting the locations and elevations of remnants of erosion, it possible to construct the then (before deep incision has occurred) digital elevation model of the area termed as Paleo-DEM. Six mountain picks within and outside the study area are taken as remnants of erosion since the occurrence of basalts. By interconnecting the mountain picks valuing their elevation, using spline interpolation, Paleo-DEM of the area is constructed. The Paleo-DEM, taken as least possible elevation of the area just after the occurrence of flood basalt, looks like flat within the study area showing least variation. This constructed DEM is taken as the minimum possible elevation of the area had there been no erosion since the occurrence of Oligocene flood basalt.

Modern digital elevation, ASTER DEM of 30 meters, is subtracted from Paleo-DEM to show possible depth of incision at every point. Figure 23 shows the modern DEM and depth of incision of locations. The figure shows that minimum of 250 meters thick land mass has

been eroded from the highland plateaus. The incision goes even up to about 2147 meters in the deepest valley in the western part.

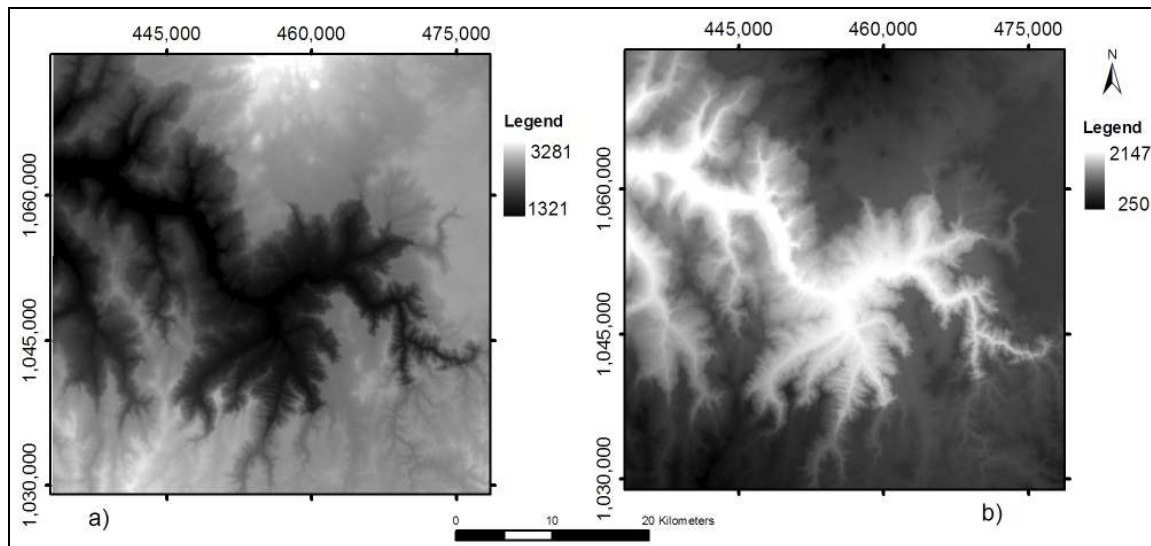


Figure 23: a) Shows modern DEM. b) Estimated depth of incision.

The map shows at least 250 to 2147 meters depth of erosion. Volume of erosion is estimated using Cut and Fill analysis of Arc GIS 9.2. About 2,491 km³ volume of rock is eroded from the area. This shows that an average of 1167 meters depth surface material is removed from the area since Oligocene (ca. 29 Ma).

5.2. River Bed Morphology Change using Aerial Photos

5.2.1. Introduction

Aerial photography is the taking of photograph of the ground from an elevated position, usually from planes and balloons as a platform. Aerial photographs are used in cartography, land use planning, geological mapping, landform mapping, environmental studies and so on.

Even though advancement of remote sensing provides high resolution multispectral satellite images, still analog aerial photos are important for their availability in hard copy and good resolution. The 1:50,000 aerial photos provided by EMA have much better spatial resolution than the commonly available satellite images. Aerial photo of 1957 and 1986 available

today can be taken as historic Aerial Photographs. Visualization and spatio-temporal variation assessment of landforms is possible using these aerial photos.

One of the specific objectives of this work is identifying suitable GIS and remote sensing techniques for geomorphological mapping. The analyses made in this unit does not cover the whole study area, rather is made on selected aerial photos.

5.2.2. Orthorectification

Aerial photographs are originally acquired in hard copies. Camera information like lens focal length, flight height, scale, ground control points, fiducial points and corresponding attributes should be acquired accompanying the aerial photos. Some of the information mentioned above can be indirectly derived from other images or topo-maps. Digitizing (scanning) these aerial photos, with appropriate scanning resolution, is the first task of data preparation. Aerial photos do not have orthogonal projection; they have radial distortion induced by perspective view of cameras. Terrain topography also introduces distortion to the aerial photograph. These distortions are removed by an analysis called orthorectification. The topographical variations in the surface of the earth and the tilt of the aerial sensor, affect the distance with which features on the aerial image are displayed. Figure 24 shows original aerial photo and orthorectified one. Orthorectified aerial photo is sometimes referred to as orthophoto.

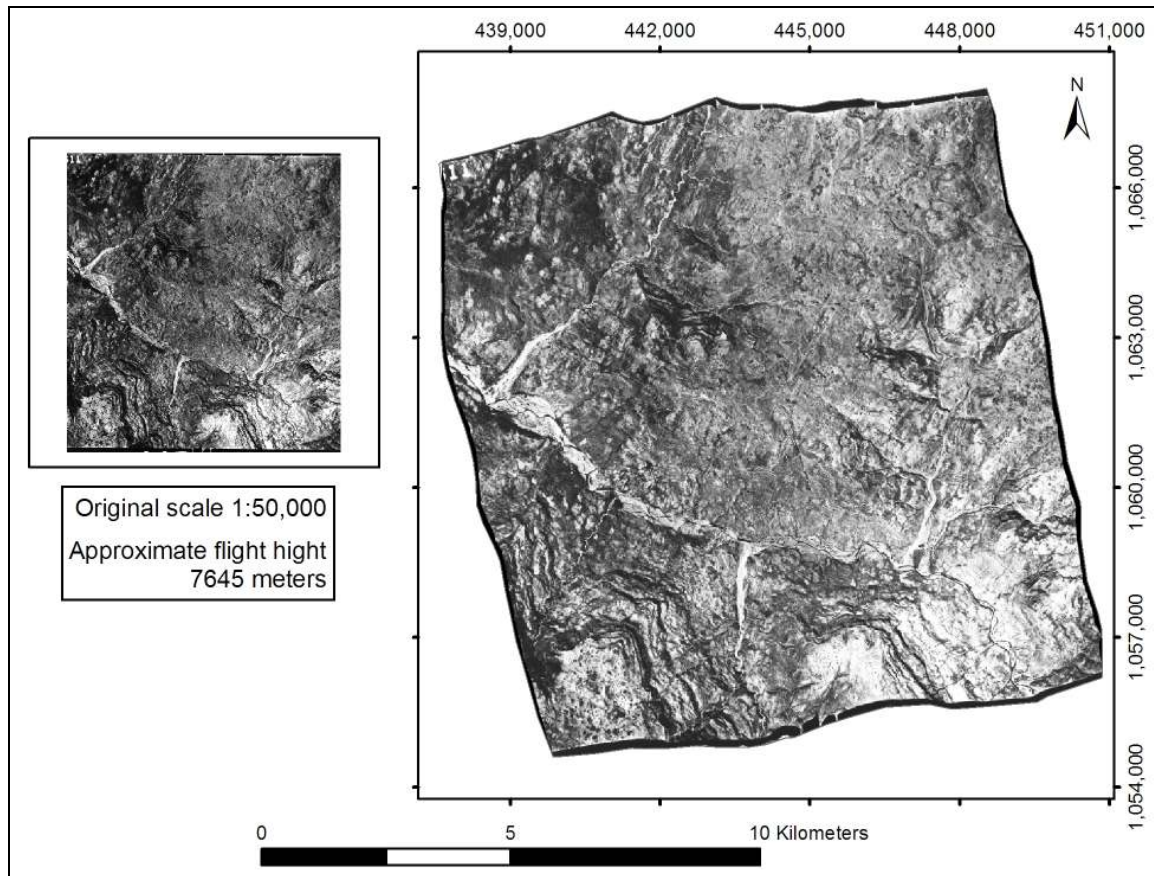


Figure 24: Original aerial photograph and orthophoto.

5.2.3. River Morphology

The term river morphology is used to describe the shapes of river channel and how they change over time. In geomorphologically active area, shape of river channel is not preserved for long time. Erosions and depositions change the shape of depositional features within the channel, shape and dimension of the channel and the path of active flowing water.

Availability of 1957 and 1986 historic aerial photographs is a big asset for assessment of dynamics of river morphology. In conjugation, the 2006 google earth image is also used for comparison with the aerial photographs. Subjective river morphology evaluation is conducted for two selected locations using the above datasets as shown in figure 25.

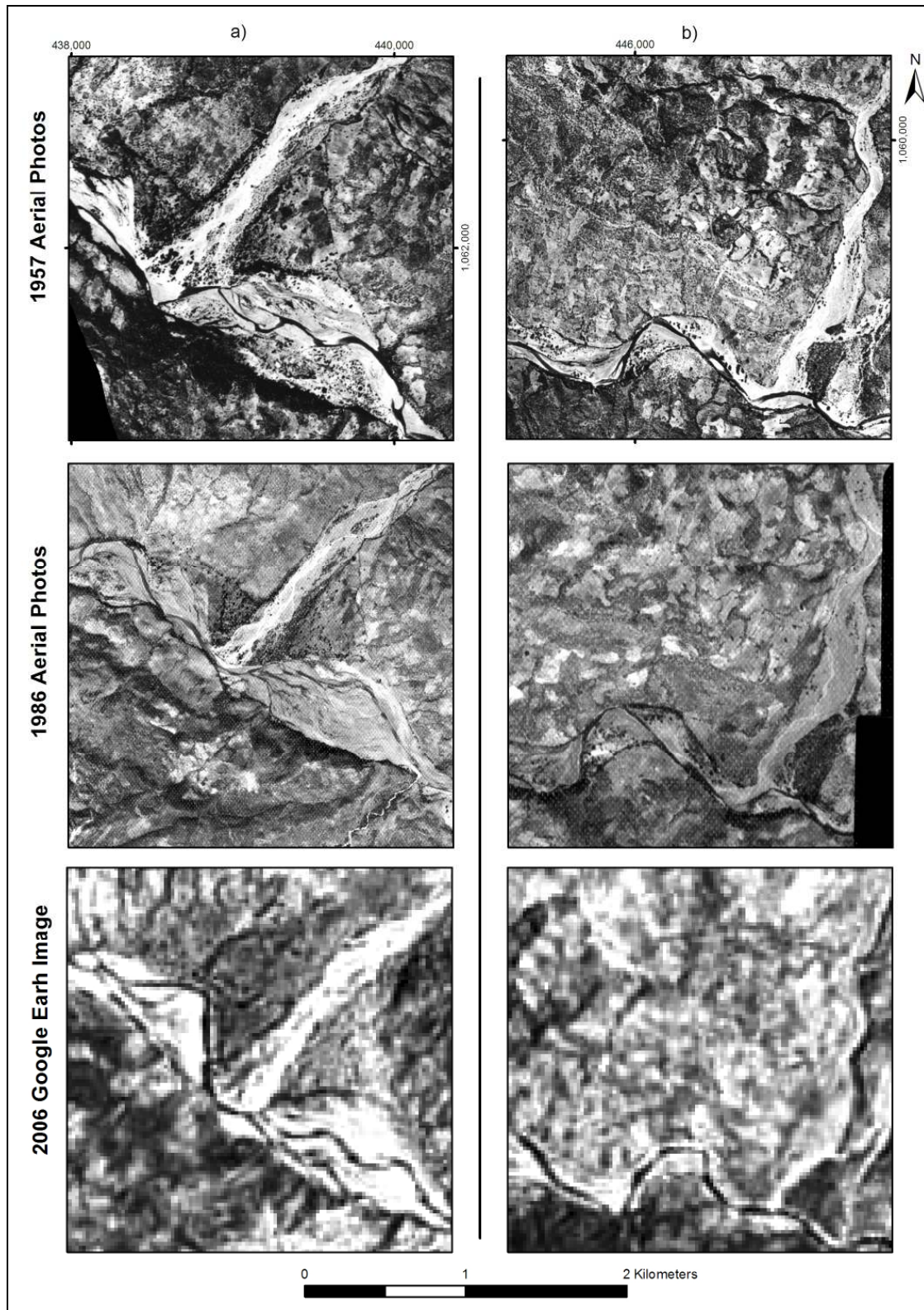


Figure 25: Aerial photographs and Google Earth image showing river morphology change on two selected locations.

The boundaries of the river channel on figure 26 a, change gradually as shown from 1957's aerial photo to the 1986's. In the north-western part of the map the bank of the river is further eroded widening the river channel. The path of active water flowing within the river channel has gradually changed on the three images displayed. Figure 26 b shows representative image where the shape of depositions within the river bed gradually changes. The triangular shaped sand deposition pointing southward at the contact of the two rivers changes its shape and becomes elliptical in the second image. This sand deposit appears in triangular shape again pointing northward in the google earth image. Generally shape of the river channel, depositions within it and active flowing water path changes gradually within the time frame discussed.

5.3.Pan-Sharpening and 3D Visualization

Pan-sharpening is a process of merging high resolution panchromatic and lower resolution multispectral imagery to create a single high resolution color image. Pan-sharpening is sometimes called resolution merge. It is customary to conduct such kind of analysis using gray scale high resolution satellite image layer with low spatial resolution colored satellite image to produce colored high spatial resolution image. In this unit 5 meter spatial resolution orthorectified aerial photo is used as a panchromatic layer and 15 meters spatial resolution ASTER VNIR stack image as multispectral image to conduct pan-sharpening. The resulting image is colored 5 meters resolution image with distinct contrasts suitable for geomorphological mapping.

The pan-sharpened image is then dumped on digital elevation model of the area to visualize 3-Dimensional features as shown in figure 26 using ERDAS IMAGINE Virtual GIS tool. IMAGINE Virtual GIS is a powerful yet easy-to-use visual analysis tool that offers GIS functions and capabilities in a 3D environment.

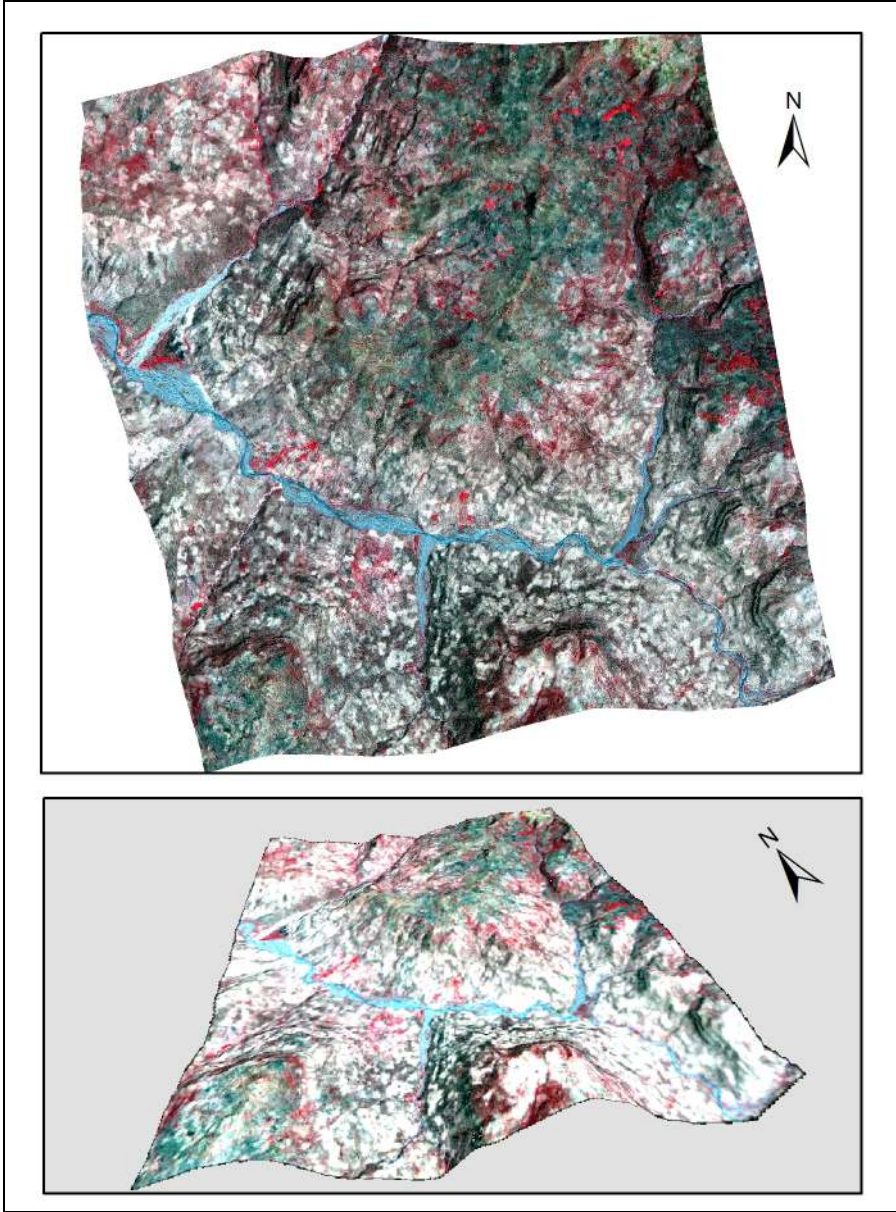


Figure 26: Pan-sharpened image and 3-Dimensional view dumped on DEM.

6. Result and Discussion

The Blue Nile Gorge for long time has been used as natural laboratory to understand the geodynamics of continental rifting and evolution of hominis (Gani, 2007). Elevated plateaus of about 3,200 meters a.s.l and valley bottom of about 1,300 meters a.s.l. caused by incisions of the Muger River has brought big topographic contrasts visible in the digital elevation model. The incision has also caused the exposure of section of sedimentary strata underlying the Tertiary basalt. Currently the area is known by its high erosion rate making geomorphological study big interest.

In this study physiographic zoning is taken as a preliminary approach to hypothesize the geomorphological setup of the area. Three physiographic zones prepared considering the DEM and Relief map, land cover map and existing lithological map gave general over view of the area. Agricultural flat land zone situated on highland plateaus overlaying basalt is extensively used for agriculture due to the availability of residual soil. Mountainous mixed land use zone found in the southern side of the main river extending to north east falls in the gentler valley faces. This zone is relatively denudational; the agriculture land use and vegetations partially depend on colluvial deposits. The bare land valley zone is highly degraded area falling on the steep side of the valley. The deepest incision is found in this zone. The clear association between the physiographic zones and the surface deposits has helped mapping. The three physiographic zones are also used to subjectively select and tune image enhancement techniques.

The boundaries of lithologies extracted from 1:2,000,000 geological map of the area are modified by conducting a number of enhancements on ASTER satellite image. Band ratios and combinations recommended by previous researchers and PCA helped to enhance lithological variations for appropriate mapping. The following table (table 2) shows list of enhancements used on ASTER image for lithological mapping.

Table 2: Selected enhancements for lithological mapping

Enhancements	Suggested For	Differentiated Units
ASTER (2/3) x (4/3)	Discrimination	Basalt Vs Sandstone
ASTER (5/3) + (1/2) ASTER 2/1	Ferrous iron, Fe ²⁺ Ferric iron, Fe ³⁺	Aiba basalt Vs Alajae Formation
ASTER 13/14	Carbonate enhancement	Limestone Vs Sandstone

Lithological boundaries are distinctive using the above mentioned enhancements. The boundaries are considerably modified and are consistent with the topography and river.

Geomorphological processes like weathering, erosion and depositions leave remnants on the surface or new surface deposits. By assessing the physiography of the area deposits like laterite, limonite, colluvium, alluvium, residual soil and river sand were targeted to be mapped. The following enhancements listed in the table are proofed to be suitable to map surface deposits.

Table 3: Selected enhancements for surface deposits

Enhancements	Suggested For	Differentiated deposits
ASTER 4/5 slope Map	laterite enhancement Terrain visualization	laterite and colluvial deposit
ASTER 2/1	Ferric iron, Fe ³⁺	Limonite mapping
Composite 4/1, 3/1, 12/14 in RGB PCA	Discrimination	Alluvial soil, River sand and Residual soil

The surface deposits are mapped showing specific trend with the river and topography. River sand is accumulated in river bed, alluvial soil on the highland plateaus, colluvials on slopes and valley bottoms and limonites on plateaus of basalt.

Land forms are well visualized in ASTER 30 meters resolution DEM, three relief maps of different illumination azimuth, stacked in to one composite image, showed subtle topographic variations. Linear features are easily mapped from composite relief maps displayed in RGB. PCA prepared from composite relief map also show feature contrasts. Slope maps were used to map escarpments.

The output of much of analysis conducted so far give rise to the Geomorphological map of the area displayed in figure 27. The terrain is classified in to different landforms. Elevated gentle slope area in the northern part is labeled highland plateau. Remnants of erosion on the highland plateaus are categorized as residual hills. The plateaus in the southern part are highly eroded and are called dissected plateau. Steep and gentle valley faces, valley bottom and flood plains are also zoned.

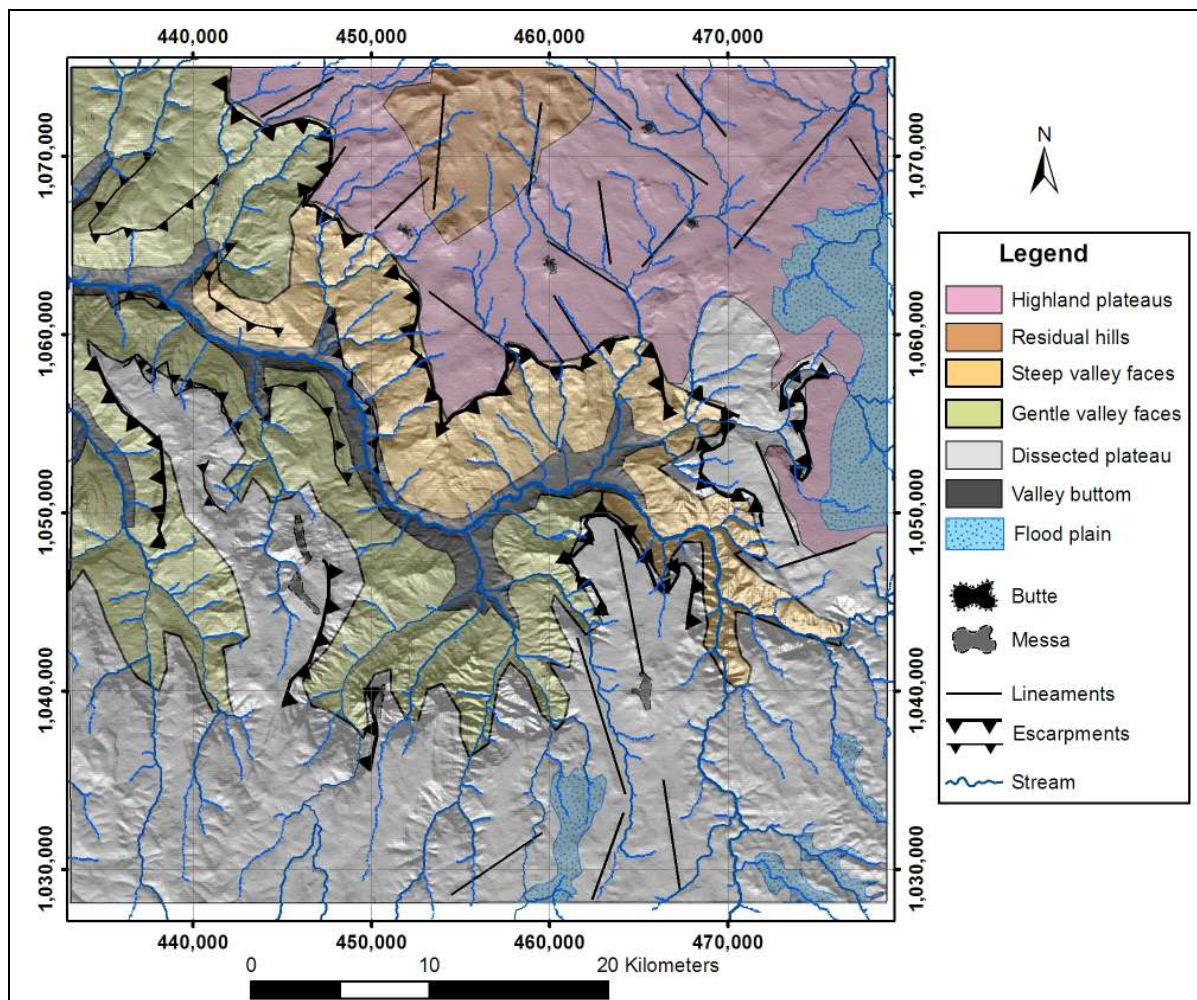


Figure 27: Geomorphological map

The highland plateau gave rise to surface deposits limonite, laterite, residual soil and alluvial soil. Limonite is associated with composition of basalt; laterites and residual soil occurred due to the flatness of the basaltic terrain. Low coarse rivers have deposited alluvial soil. Surface deposits exposed within the valley are colluvials and river sand. Steep faces of the valley and elevated areas in the north are denudational surfaces with least or no occurrence of surface deposits.

As one of the objectives of this work is identifying appropriate remote sensing and GIS techniques for geomorphological studies. Incision volume estimation, river morphology evaluation and 3 Dimensional visualization of digital aerial photograph with satellite image are conducted.

Incision volume determination used the concept of constructing paleo-DEM (Digital Elevation Model of known geologic time) by using erosion remnants within and around the study area. Modern DEM subtracted from paleo-DEM has shown depth of incision throughout the area. It is also known that more than 2,400 km³ volume of rock is eroded from the area since Oligocene, bringing average depth of erosion throughout the study area to be 1,167 meters. Previous works has stated that average depth of incision throughout Blue Nile River basin is about 370 meters; this shows that the study area is severely affected by erosion even compared with other areas in the Blue Nile River Basin.

Dynamics of river morphology is well understood by comparing aerial photographs of 1957, 1986 and 2006 Google earth image. This analysis is demonstrated in two selected areas only. The progressive river channel shape change and shape of deposits within the river channel depicted active river morphology.

High spatial resolution multi spectral image, produced using pan-sharpening or resolution merge is found suitable for landform mapping. Pan sharpening is proofed possible using orthorectified aerial photo as panchromatic layer with mutispectral satellite image. The output image also dumped on DEM using virtual GIS tool of Erdas Imagine showing 3 Dimensional views of the area.

7. Conclusion and Recommendation

Conclusions

- Even though the area is known by its severe erosion, considerable coverage and verity of surface deposits are revealed. These deposits have intern influenced the land use/cover of the area.
- The occurrence of surface deposits showed the presence of high rate of physical and chemical weathering, and active transportation of loose materials.
- The high spectral resolution (14 bands) ASTER satellite imagery is powerful for both lithological mapping and surface deposit mapping due to its ability to create a number of band combination and rationing options.
- Physiographic assessment helped mapping in providing bases to hypothesize geomorphological setups and delineate zones for different image analysis.
- Relief maps of different illumination azimuth, which are produced from DEM, stacked in to composite color images are suitable for topographic feature mapping at single view.
- Pan sharpening is proofed possible using orthorectified aerial photograph and multi spectral satellite image.

Recommendations

- Geomorphological maps should be prepared and applied for effective land use planning, geohazard mitigation and environmental protection.
- The availability of aerial photos of 1957 and 1986 is valuable asset for morphological analysis and change detection. Hence researchers in this area should experience the importance of this dataset.
- Large scale geomorphological map can be produced using ASTER satellite imagery if enough ground truthing can be carried out.

References

- Abdeen M. M., EL-Kazzaz Y. A. H. A., Attia G. M., Yehia M. A., Hassen S. M., (2009), Mapping Geological Structures in Wadi Ghoweiba Area, Northwestern Gulf of Suez, Egypt, using ASTER-SPOT Data Fusion and ASTER DEM, Egypt. *Journal of Remote Sensing and Space Science* Vol. 12, Pages 101 – 126
- ASTER's User's Guide, Ver. 4.0, (2005), Earth Remote Sensing Data Analysis Center
- Beaulieu Alexandre and Gaonac'h Helene, (2002), Scaling of differentially eroded surfaces in the drainage network of the Ethiopian Plateau, *Remote Sensing of Environment*, Vol. 82, Pages 111–122
- Gani N. D., Abduselam M. G, Gera S., Gani. M. R, (2008), Stratigraphic and Structural Evolution of the Blue Nile Basin, Northwestern Ethiopian Plateau, *Geological Journal*, Vol. 44, Pages 30 – 56
- Gani N. D., Gani. M. R. and Abduselam M. G., (2007), Blue Nile Incision on the Ethiopian Plateau: Pulsed Plateau Growth, Pliocene Uplift, and Hominin Evolution, *GSA Today*, Vol. 17
- Giles, P. T., (1997), Geomorphological Signatures: Classification of Aggregated Slope Unit Objects from Digital Elevation and Remote Sensing Data, *Earth Surface Process and Landforms*, Vol.23, pages 581-594
- Jozef Minar and Ian S. Evans, (2007), Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping, *Geomorphology*, Vol. 95, Pages 236 to 259
- Kalinowski A, Oliver S., (2004), ASTER Mineral Index Processing, Remote Sensing Applications, *Geoscience Australia*
- Kamal A.S.M. and Midorikawa S., (2004), "GIS-based geomorphological mapping using remote sensing data and supplementary geoinformation, A case study of the Dhaka city area, Bangladesh", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 6, Pages 111 to 125, Elsevier
- Mengehsa Tefera, Tadiwos Chernet and Workineh Haro, (1996), Explanation of the Geological Map of Ethiopia, Second Edition, Geological Survey of Ethiopia (unpublished)
- Small R. J., (1983), *The Study of Landforms*, Cambridge University Press, Cambridge, London

Smith M. J., Clark C. D., (2005), Methods for the Visualization of Digital Elevation Models for Landform Mapping, *Earth Surface Processes and Landforms*, Vol. 30, Pages 885 – 900

Thomas M. F., (1974), *Tropical Geomorphology*, The Macmilan Press LTD., London

http://disc.sci.gsfc.nasa.gov/geomorphology/GEO_11, accessed on 10/12/09

<http://www.geomorph.org/wg/wgagm.html>, Working Group on Applied Geomorphological Mapping - AppGeMa, accessed on 9/12/09

D E C L A R A T I O N

I hereby declare that the thesis entitled “**Geomorphological Mapping in the Upstreams of Muger River, Blue Nile River Basin, Using Geospatial Tools**” has been carried out by me under the supervision of Dr. K. V. Suryabhagavan, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2010 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Yafet Birhanu Gebremariam

Signature: _____

Addis Ababa, Ethiopia

Date: June, 2010

CERTIFICATE

This is certified that the dissertation entitled “**Geomorphological Mapping in the Upstreams of Muger River, Blue Nile River Basin, Using Geospatial Tools**” is a bonafied work carried out by Yafet Birhanu Gebremariam under my guidance and supervision. This is the actual work done for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa, Ethiopia.

Dr. K. V. Suryabhagavan

Assistant Professor

Department of Earth Sciences

Addis Ababa University

Addis Ababa, Ethiopia