EVALUATION OF LAND DEGRADATION AROUND DEBERE ZEYIT AREA USING RS AND GIS TECHNIQUES

BY

HANNA ENDALE



A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN GIS AND REMOTE SENSING

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ACKNOWLEDGMENT

My sincere thanks goes to Addis Ababa University, department of geology for allowing and supporting this work to be done.

I am greatly indebted to my Co-Advisor Dr Mohammed Umer for his guidance and instructive supervision of this thesis at its various stages. His close follow up; review and comments on the manuscript are highly appreciated. Moreover, the discussions I made with him on the results of this thesis and their interpretation were very important. I duly acknowledge his contributions to realize this study.

I am also grateful to all staff members of the Department of Geology and Geophysics for their various supports. A special thanks goes to Dr. Dereje Ayalew, the head, whose assistance in helping me to acquire financial support was crucial. Dr. Dagnachew Legesse and Dr. Tesfaye Korme whose instruction in the basic sciences of Remote sensing and GIS were paramount, and W/o Aynalem Gebeyehu was kind in helping with matters of administrative and secretarial services.

Special thanks to my parents W/O Almaz Tesfaye, Ato Endale Weldesselasse and I would also like to extend this special thanks to my sisters and brothers who gave me all the encouragement I needed to accomplish my study.

Finally, yet most importantly, I offer my deepest gratitude to my husband Zelalem Kubsa. He is the source of my strength and inspiration. His encouragement, support and love during both good and bad times were the pillars of my achievements. I would like to dedicate this work to my husband and the precious baby we are expecting soon.

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ABSTRACT

Gully development dynamics that occurred from 1971 to 2002 around the Debre Zeyit area were evaluated using remote sensing and GIS in addition to field verification. The study was conducted in about 694-km2 area with in the East Showa Zone of the Oromia Region.

The main objective of this study is to understand the rate, cause and extent of gully erosion around Debre Zeyit area in terms of change in landcover, development of infrastructure, soil type and geology of the area. Four sets of remotely sensed images, MSS-1973, TM-1986 & 1995 and ETM^{+} 2002 are used in evaluation of the change in landuse and landcover of the area with in of 13, 9 and 7 years gaps and Aerial photographs of 1971 as well as the 2002 ETM^{+} image are used in gully development rate mapping. In addition to this field measurement of gullies width and depth volume calculation is done to quantify the amount of soil lost by all gullies and rate of soil loss by new gullies with in 31 years gap.

Results of landcover change analysis show cultivated land increased from 50% in 1971 to 55% in 1986 and to 67 and 69% in 1995 and 2002 respectively. The overall increase in cultivated land is about 19%, which was mainly at the expense of grasslands and dense shrub covers. The area which was mainly covered by the dense shrubs is changed to open woodland and cropland. The size of urban and water bodies increased from 1.04% to 1.7% and 0.73% to 1.02% percent due to population increase and construction of dams respectively. The area covered by wetland also show minor differences in size due to evaporation.

New gullies are developing in areas where the original landcover is removed and where slopes are between 2 and 10 percent. In addition to this on the southern part of the study area construction of roads are important causes of gulling where the soil type and lithology are favoring erosion processes.

Based on the analysis done on the Arial photograph and the 2002 ETM^{+} image, gullies developed after 1971 are identified. The total length of the newly developed gullies is calculated as 101.9km with in a total of 269.2 km^2 of area.

The field measurements, on selected test sites on the north and southern part of the study area, are used in calculating the soil loss by gullies. Mathematical model, the Truncated pyramid model, is employed to calculate the amount of soil lost from all the gullies inventoried and the rate of soil loss for the new gullies. It comes up with the result that about 10 million m^3 of soil is lost from the gullies with in 12,000 ha of land out of which 1 million m^3 is from newly developed gullies with in 31 years. The rate of soil loss from the new gullies is calculated as 4.71 m^3/ha/yr and 1.34 m^3/ha/yr on the north and south test areas respectively.

Chapter One

Introduction

1.1 Background

Environmental degradation due to human pressure and land use has become a major problem in developing countries because of the high population growth rate and the associated rapid depletion of natural resources (Eswaran et al., 1998). Land degradation is an important issue because of its adverse impact on agronomic productivity, the environment and its effect on food security and quality of life (Eswaran et al., 1998). Degradation is the loss of actual or potential productivity as a result of natural and anthropogenic factors which reduce the yield of the land due to decline in the quality on site where degradation occurs and off site where sediments are deposited, and its beneficial effects on the environment; (FAO, AGL, 2000).

The direct causes of land degradation are apparent and generally agreed. These include production on steep slopes and fragile soils with inadequate investments in soil conservation or vegetative cover, erratic and erosive rainfall patterns, declining use of fallow, limited recycling of dung and crop residues to the soil, limited application of external sources of plant nutrients, deforestation and overgrazing. Underlying these proximate causes there are other factors such as population pressure, poverty, high cost and limited access to agricultural inputs and credit, low profitability of agricultural production and many conservation practices, farmers facing high risks, fragmented land holdings and insecure land tenure, short time horizons of farmers, and farmers' lack of information about appropriate alternative technologies. Affecting many of these factors are government policies relating to infrastructure development, market development, input and credit supplies, land tenure, agricultural research and extension, conservation programs, land use regulation, and local governance and collective action.

Ethiopia is characterized by a wide topographic range varying from a very low altitude of 116 meters below sea level to highlands with altitudes over 4,000m a.m.s.l. Those areas with altitudes above 1,500 meters cover about 500,000 km^2 accounting for about 45% of the land mass with climatic and ecological conditions of sufficient rainfall, moderate temperature and developed soils. Settlers are attracted to these favourable conditions over a long period of time resulting in high population pressure and scarce land for cultivation. Presently, the highlands are home for about 88% of the population, 95% of the cropped lands and 90% of the economic activities in the country (M.Saleem, 1995).

Therefore, in many parts of the highlands, agriculture has gradually expanded from gently sloping lands to the steeper slopes of the neighbouring mountains by removing the natural land cover. This change in Landuse-LandCover (LU-LC) along with unsustainable agriculture and other physical and socio-economic factors have been the driving factor to a series of land degradation problems.

Almost half of the soil loss on the Ethiopian highlands is from land under cultivation. In some areas soil loss from newly cleared forest lands for crop production is much higher. It is estimated that about 1.9 to 3.5 billion tones of topsoil is being removed from the Ethiopian highlands every year (EFAP, 1993). Consequently, some areas of the country are totally out of production where land is irreversibly damaged. The Ethiopian highlands reclamation study (EHRS, 1984) indicated that about 10 million farmers in the highlands could loose their farmlands due to land degradation.

Hurni (1985) indicates that Ethiopia is the most environmentally troubled country in the Sahel belt. Land degradation is most severe in the highlands (over 1500m altitude) which accounts for more than 43% of the area of the country, 95% of the cultivated area, 75% of the livestock and host about 88% of the population. The Ethiopian Highland Reclamation Study as quoted in Bojo and Cassels (1995) estimates that by the mid 1980^s about 50% of the highlands (27 million hectares [ha]) was significantly eroded while more than one-

fourth was seriously eroded. Hurni (1988) estimates that soil loss in cultivated areas averages 42 metric tons/ha per year (mt/ha per year), far exceeding the soil formation rate of 3–7 mt/ha per year. Stahl (1990) estimates that by the year 2010 the amount of total land incapable of supporting cultivation will reach to 10 million ha.

Among all the types of land degradation, the main concern of this study is gully erosion. Gully erosion is caused when run-off concentrates and flows at a velocity sufficient to detach and transport soil particles (FAO, AGL, 2000). A waterfall may form, with run-off picking up energy as it plunges over the gully head. Splash-back at the base of the gully head erodes the subsoil and the gully eats its way up the slope.

Gully development may be triggered by intensive cultivation or overgrazing of soils susceptible to gully erosion, increased run-off due to land use-land cover changes such as tree clearing in a catchment or construction of new residential areas. It also results from run-off concentration caused by furrows, contour banks, waterways, dam by-washes, stock pads, fences, tracks or roads, improper design construction or maintenance of waterways in cropping areas, poor vegetative cover, low flows or seepage flows over a long period, 'down-cutting' in a creek and diversion of a drainage line to an area of high risk to erosion.

Generally gullies are believed to be occuring only on highlands and mountainous areas and their damage is maximum if they are found on such places. Contrary to this general belief, this study tries to show the damage caused by gullies at low lands and the most triggering factors that made the gully to develop.

Improper construction of roads and associated engineering structures like culverts and bridges also initiate gullies as well as helps them to rapidly develop. In a case study along the road from Mekelle to Adwa, (Nyssen et al., 2002a) it has been indicated how road building, through the important enlargement of drainage areas and the concentration of

runoff can induce an artificial passing of the critical catchment size at which gulley heads are formed for a given slope gradient. Similar phenomenon has been observed and analysed in this study. The up stream part of this area is almost totally devoid of gullies while downstream they are numerous. Factors responsible for their formation such as the construction of culverts, the impact from Landuse-Landcover and land management as well as from lithology and soil development have been assessed.

1.2 Objectives

General objective

- To use integrated remote sensing and GIS techniques to evaluate the **Causes**, **Extent** and **Rate** of land degradation.

Specific objectives

- To identify the rate of land degradation (gully formation) in the study area for the past 31 years.
- To prepare land use-land cover map of 1973, 1986, 1995 and 2002 along with change detection over the three periods (i.e. 1973-1986, 1986-1995 and 1995-2002)
- To indicate the spatial and temporal environmental deterioration caused by natural and/or anthropogenic impacts.
- To quantify the amount of soil lost by gully formation.
- To recommend proper land use planning and utilization for sustainable land resource management.

1.3 Materials and Methods

To attain the above objectives different materials and methods were employed

1.3.1 Materials

- Topographic maps 1: 50,000 (1975), 1: 250,000 (1995),
- Aerial photographs of 1: 50,000 scale (1971).
- Satellite images were used as bases to map land use-land cover and gullies.

Types of Images	Date acquired	Bands
MSS	Jan 31-1973	1,2,3,4
TM	Jan 21-1986, Jan 30-1995,	1,2,3,4,5,7
ETM+	Feb 26-2002	1,2,3,4,5,7.8

Table1.1 descriptions of satellite images used in the study

- Software's used:

  CARTALINX- for digitizing and editing contours, roads and drainages

  ENVI 3.5 -for image processing

  ARCVIEW 3.2 -for editing the thematic maps of landcover classes imported from ENVI, detection of changes in land cover and perform analysis for gully development rate mapping.

- A GPS was used to map the position of the gullies.
- Gully sizes were measured using measuring tape.

1.3.2 Methodology

- **Pre-field laboratory Method**

1. Georeferencing of 2002 ETM^+ image for using as a base map for Landuse-Landcover mapping

2. Digital image processing of the 2002 image

- True and false color composite
- Enhancing and Filtering
- PCA (Principal Component Analysis)
-Unsupervised classification

- **Field Methods**

1. Gully Measurements

-In the field gullies were located with Meridian type Global Positioning System.

-The already existing gullies on the 1975 topographic map were noted and the newly developed gullies were traced.

-At different locations gully width and depth were measured using measuring tape.

-Additional measurements were taken whenever there is a variation in the width, depth or both.

2. Ground Truthing

-The land units obtained from unsupervised classification were checked and appropriate naming was given for each identified Land use –Land cover.

3. Section Description

- Stratigraphic sections exposed in the gullies were measured and described.

- **Post-Field Laboratory Methods**

1. Digitization of contours with 20 meters interval from 1:50.000 scale topographic map and generation of Digital Elevation Model (DEM)

2. Digitization of the old drainages which are mapped on 1975 topographic map and also observed in the field. In addition digitizing of newly developing gullies since then (In the last 31 years gap).

3. Georeferencing of the 1995-TM image, 'image to map' using well identified Ground Control Points (GCPs) and the rest of the images (MSS-1973,TM-1986) 'image to image' using the georeferenced 1995 image as a base.

4. Digital image processing of the three images (MSS-1973,TM-1986,and TM-1995) were done as that of the pre field laboratory work for the 2002 image

5. Supervised classification and accuracy assessment is done for the 2002 ETM^+ image based on training sites which are checked during field work.
   -to detect the landuse- landcover change

6. The panchromatic band of the 2002 ETM^+ image is georeferenced using 15 m pixel size.
   -to trace the gullies and approximate the time of initiation for the newly developing gullies and there by analyze the rate of their development

7. Georeferencing and mosiacking of 19 aerial photographs using Envi 3.5 software is done to trace gullies that were existing at that time. Resampling is done by taking 15m*15m pixel size in order to make it comparable with the panchromatic band.

8. Calculation of soil volume loss through gulling by using mathematical models.

9. Meteorological data (rainfall and temperature) of two stations (Air-Force and ILRI) were collected from Ethiopian Meteorological Station Agency (EMSA) to see the trend of land degradation with varying climate.

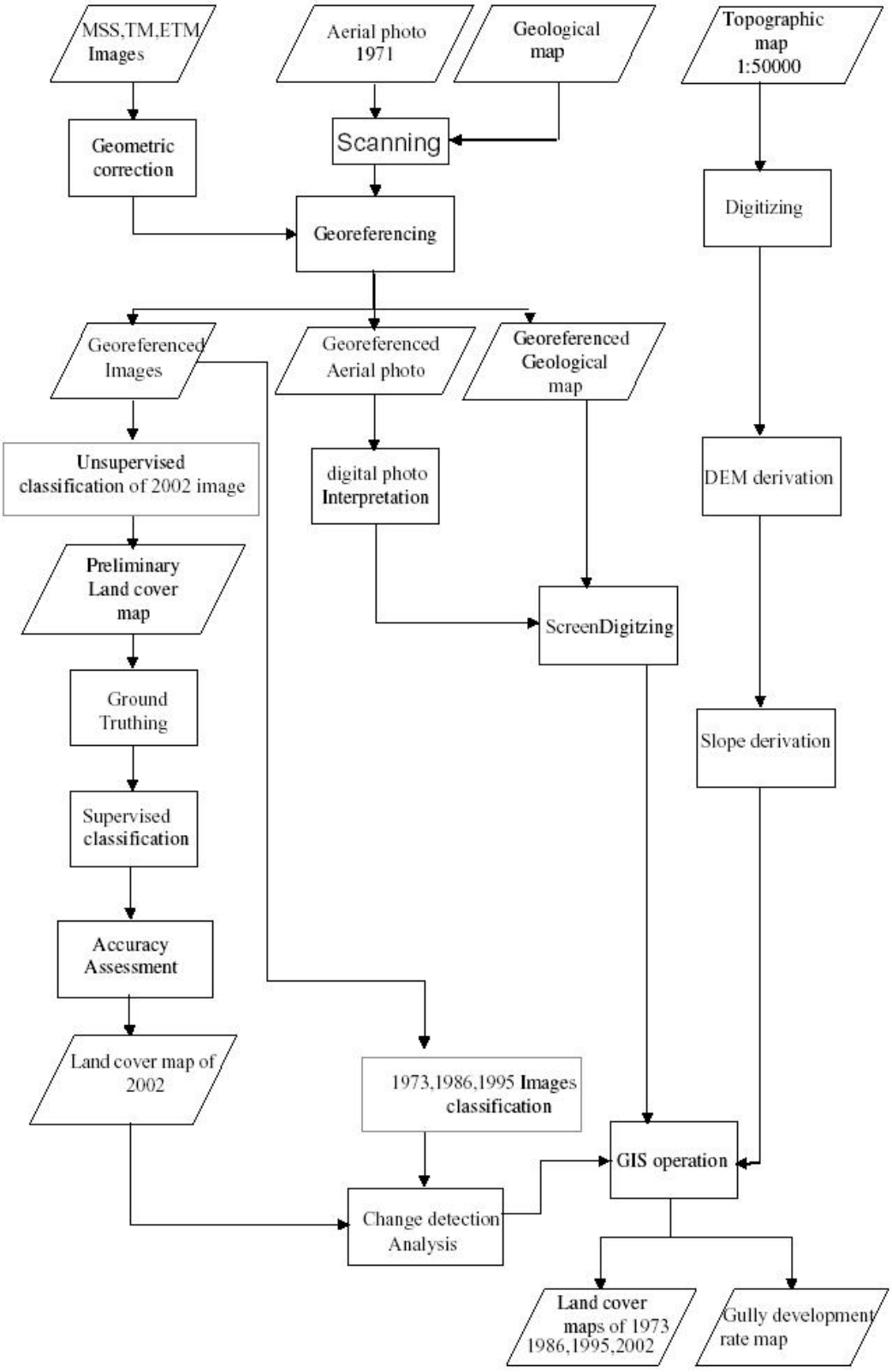


Figure 1.1 Flowchart showing the processes involved and the output produced

1.4 Literature Review

The principal environmental problem in Ethiopia is land degradation, in the form of soil erosion, gully formation, soil fertility loss and severe soil moisture stress, which is partly the result of loss in soil depth and organic matter. Ethiopia is very much affected by soil erosion processes, among them gullies play a very important role and the amount of soil loss due to gulling has become a very serious problem in recent decade as it was associated to remarkable depletion of cultivated land. The development of gullies has many negative impacts as it normally involves the loss and (in some cases) the deposition of a great amount of soil. In many countries, the loss of large soil masses by gully erosion often stands for the depletion of a basic natural resource. Gullies affect large areas with different morphological, pedological and climatic characteristics and once gullies are formed, they tend to develop further and this process is seldom inverted or halted naturally (Billi and Dramis, 2003).

Gully erosion is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels and over short periods, removes the soil from this narrow area to considerable depths. Gully can be either ephemeral, permanent (classical) or bank gully. The term ephemeral gully erosion was introduced to include concentrated flow erosion larger than rill erosion but less than classical gully erosion that can be easily filled by normal tillage, only to reform again in the same location by additional run off events. Permanent gullies are often defined for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 to as much as 25-30m depth (soil science society of America, 2001). By definition, bank gullies develop whenever concentrated runoff crosses an earth bank. Given that the local slope gradient of the soil surface at the bank riser is very steep (i.e. subvertical to vertical), bank gullies can rapidly develop on top or below the soil surface by hydraulic erosion, piping (plate 5.4(5)) and eventually mass movement processes eventhough catchment areas are very small (Poeson and Govers, 1990). Once initiated, bank gullies retreat by

head cut migration in to more gentle sloping soil surface of the bank shoulder and further into low- angled pediments, rivers or agricultural terraces (Poeson et al., 2002)

1.4.1Contribution of gully erosion to soil loss and sediment production

Poeson et al., 2002 analyzed data collected in different parts of the world (in which Ethiopia is part of it, 4.7-12.1 t ha^{-1} yr^{-1} (30-35 %) Nyssen, 2001) and they showed that soil loss rates by gully erosion is minimum 10% to 94% caused by water erosion.

Spatial scales

Soil loss by gully erosion highly depends on the size of the study area considered. At runoff plot scale, inter rill and rill erosion dominate and soil loss by gully always equals 0%. However, once the study area considered exceeds a critical value ranging between 1 and 10 ha, gully erosion becomes very important and even becomes the dominant sediment producing process.

Poessen et al., 2002 explained the discrepancy between sediment production at the catchment scale and at the runoff plot scale as; at the catchment scale, sediment production processes other than inter rill and rill erosion such as gully and channel erosion also operate. Moreover, more sediment produced by inter rill and rill erosion in uplands is often deposited at the foot of hill slopes or in depressions within the landscape and therefore does not reach the river channel. Hence, other sediment generation processes in catchments such as gully or channel erosion must play an important process in the production of sediments which are transported by rivers and cause reservoir infilling. This hypothesis is confirmed by Bedmar et al., 1997.

In Ethiopia, gullies can be found everywhere, no matter the climate, the top soil characteristics, the physiography or the lithology of the substratum. Normally, they develop on low gradient slopes that seldom exceed 10^{o} (1–5^{o}on average) (Billi and

Dramis, 2003). Gully systems in Ethiopia can often be considered as discontinuous ephemeral streams (Bull, 1997) comprising a hillslope gully, an alluvial–colluvial cone at the foot of the hill and renewed incision with gully head formation further downslope in the valley Vertisol. Pediments dissected by gullies are a common feature in many areas (Riche´ and Se´galen, 1971; Ogbaghebriel and Brancaccio, 1993; Ogbaghebriel et al., 1997; Billi and Dramis, 2003). In valley bottoms, initial gully heads often coincide with sinking polygonal structures in Vertisols (Nyssen et al., 2000a).

Different causes of gully erosion in the highlands of Ethiopia are discussed by many researchers.The rapid expansion of gullied areas that seems to have occurred in Ethiopia during the recent decades has been associated to deforestation and overgrazing (Sagri, 1998), Hurni (1983) critically discussed land degradation, famine and land resource scenarios in Ethiopia and characterized Hararghe highlands as areas very seriously affected (60–80%) by land degradation due to soil erosion, without specifying the role of gully erosion. Krüger et al. (1996) have stated that the common occurrence of gullies and shallow soils with rock outcrops are prime indicators of the severity of soil erosion. Hurni and Tato (1992) have reported the severity of gully erosion while Krauer (1988) emphasized the overall severity of soil erosion problems in Ethiopia.

Recent tectonically induced gulling was analysed in the Rift Valley (Williams, 1981; Belluomini et al., 2000). It should be remembered that ongoing rift widening at a rate of 0.5 mm per year (Mohr, 1974, quoted by Williams, 1981) causes cracks to develop. Though not a primary cause for gulling in Ethiopia, it can certainly be important at a regional scale. Near Dessie, a 300-m-deep gully was created after river capture (Asfawossen et al., 1997).

Bocco et al. (1990), studied dynamics of gully erosion using GIS and geomorphology and reported that areas with severe gully erosion risk could be predicted. Assessments of gully erosion volumes in Ethiopia are rare. Using photogrammetric techniques, Shibru et al.,

(2003) estimated that between 1966 and 1996, about 700,000 t of soil was lost due to gully erosion from catchment of 9-km^2 in the eastern highlands at the rate of 26 t ha^{-1} $year^{-1}$. Using monitoring and interviews to establish average long-term soil loss rates by gully erosion in Central Tigray, Nyssen (2001) obtained 5 t $ha^{-1}year^{-1}$ and De Wit (2003) 6.2 t ha^{-1} $year^{-1}$ (average of 65 year in a 18-km^2 catchment).

Flooding risks can be aggravated by the presence of gullies. Gully erosion can generally be described as the most catastrophic and usually impressive form of rainfall-induced erosion (El-Swaify, 1983).

1.4.2 Landuse dynamics and Land degradation.

Even though, natural processes contribute to change in landcover, the major driving force is human induced landuses (Allen and Barnes, 1985). In order to understand the various implications of landcover change, understanding of landuse change is essential. Different human driving forces mediated by the socio-economic setting and influenced by the existing environmental conditions, lead to an intended landuse of an existing land cover through the manipulation of the biophysical conditions of the land (Turner et al., 1995)

As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas and depends directly on the land for its livelihood. This rural population is currently growing rapidly, and consequently inducing many effects on the resource base. One such effect is on dynamic landuse and landcover. This has been confirmed by empirical studies carried out in different parts of the country (Solomon, 1994; Kebrom and Hedlund, 2000; Gete and Hurni, 2001). A common concern addressed by many of these studies is the resource degradation brought about by the decrease in the area under natural vegetation and its conversion into other types of land use and land cover that are human managed systems. The underlying simple assumption is that de-vegetation leads to deterioration in the physical and chemical properties of soils and degradation of the land (Bewket and stroosnijder, 2003).

Hurni (1990) has shown that even though it cover only 13 percent of the country, soil erosion is greatest on cultivated lands from where almost half of the soil is lost. Billy and Dramis (2003) explained the effect of gradual increase of population and adoption of new methods of land use as well as modern management practices producing both qualitatively and quantitatively change in land use system and again this leading to episodes of land degradation in the lakes region.

Removal of vegetation cover due to expansion of agriculture on the steep lands enhances gulling which in turn promotes ecosystem instability due to both the on-site and off-site effects of soil erosion. An important off-site effect of gully erosion leading to ecosystem instability is siltation (Poesen et al., 1996) of valuable lakes and reservoirs as gullies carry a sizeable amount of sediment in a given watershed.

Different studies, were carried out using remote sensed data of different years, in parts of Ethiopia, indicate that croplands have expanded at the expense of natural vegetation, including forest and shrub lands (Selamyehun kidanu, 2004; Girmay Kassa, 2003; Belay Tegene, 2002; Gete Zeleke and Hurni, 2001; Solomon Abate, 1994 in the central highlands of Ethiopia). While Kibrom Tekele and Hedlund, (2000) reported increase in the size of open areas and settlements at the expense of shrub lands and forests. Open areas increased by about 333% while urban and rural settlement increased by 192 and 57%, respectively in 28 years (between 1958 and 1986), in Kalu area of Wello.

Other studies made in the central highlands, homesteads were reported to increase, during 1957 and 1986 (Woien, 1995), which may indicate increasing population density. Girmay Kassa (2003) in his study in southern Wello, reported the decline of natural forests and grazing lands due to conversion to croplands. Similarly, Feoli, et al., (2002) reported the expansion of bush land and ever green vegetation with population increases. However, such expansions of cultivation, commonly in to steeper slopes and marginal areas, may

have been done with out appropriate soil and water conservation measures. As a result these lands become unproductive in short period of time leading to soil erosion.

Shibiru Daba et al., 2003 also reported the effect of landuse and landcover changes in causing major gullies and quantified the expansion rate of these gullies and there effects on the livelihood of people in eastern Ethiopia. Similarly, Selamyihun Kidanu, (2004) reported that increases in surface area of gullies from 16.6 to 36.2 ha, from 1957 to 1994, in the central highlands of Ethiopia.

1.4.3 Engineering structures and Land degradation

Increased gully erosion after road consruction results in loss of soil and yielding, decrease in cropped area, obstruction of tillage operations and lowering of the water table. The road induces surface runoff concentration, changes catchment sizes and shapes and diverts concentrated runoff to nearby catchments.

According to Nyssen, 2002a, many rural communities in Ethiopian Highlands are located more than 25 km away from any road. As part of the development strategy, many feeder and rural access roads were built recently to increase the accessibility of theses areas. Although obvious in the field and a recognized problem (Chaddocar, 2000), the impact of road building on hydrology and gulling in Ethiopia has recently been analyzed.

In his studies, Nyssen et al., 2002(a), along the road Mekelle-Adwa, built in 1994, analyze how road building, through the important enlargement of drainage areas and the concentration of runoff, induces an artificial passing of the critical catchment size at which gully heads are formed for a given slope gradient. Active gulling induced by road building on pediments is also described by Ogbaghebriel et al., (1993). Elsewhere in East Africa, Rwanda; Moeyreson (1991) monitored and analyzed progressive gully formation after road building.

Montgomory (1994) found that the main causes of gulling, after road building, are overland flow concentration by establishment of artificial drains and increased catchment area. Harden (1992) studied the influence of foot paths on runoff concentration in rural areas in Equador and Tennessee and stressed the necessity in incorporating roads and paths in hydrologic and soil erosion models at the catchment scale.

CHAPTER TWO

GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location and Accessibility

The study area is located in the central Ethiopia. It is situated about 45 km south east of Addis Ababa. The area is bounded between $8^{o}35'30''$- $8^{o}51'50''$ N latitude and $37^{o}49'05''$- $39^{o}05'30''$ E longitude (Figure 2.1). The study area covers 694.4 Km^2 both to the north and to the south of the town of Debre Zeyit bounded by the Yerer Mountain on the northern side. The town of Debre Zeyit is located on the western flank of the Main Ethiopian Rift (MER) and is known by its crater lakes: Hora, Babogaya, Kuriftu, Bshoftu, Arenguade and Zikuala.

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The road networks with in the study area have facilitated access (Figure 2.2). The area is accessible by a main road that goes from Addis Ababa to the south eastern part of the country joining other towns such as Mojo and Nathereth. In addition to trails which join the villages in the study area, all weather roads starting from the town of Debere zeyit to Dire-Bekejo-Adulala in the southern part of the study area and to Ginde Gorba-Godino-Chefe Donsa , to Koftu as well as to Rob Gebya were used to access the northern part of the study area.

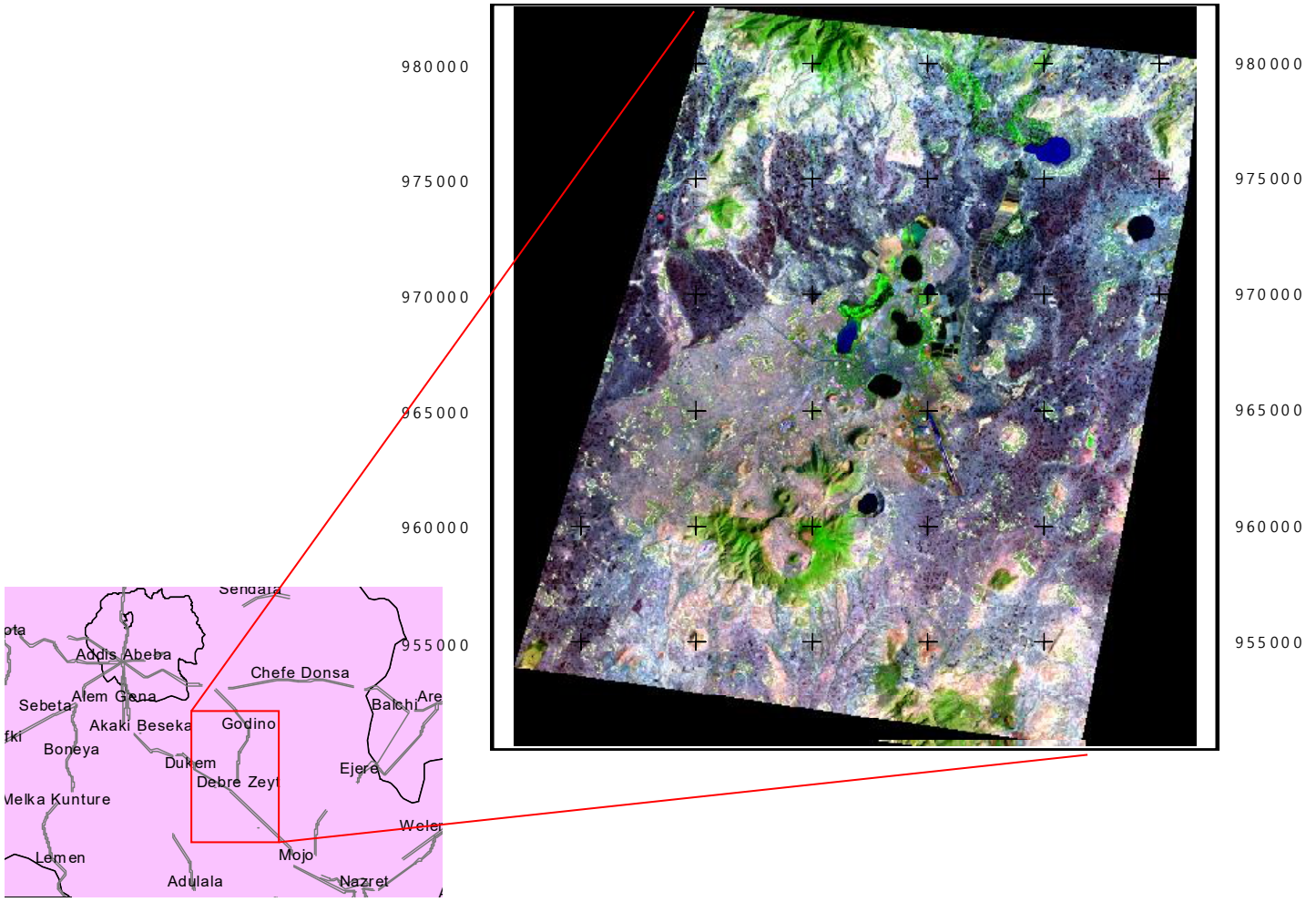


Figure 2.1 Location map of the study area

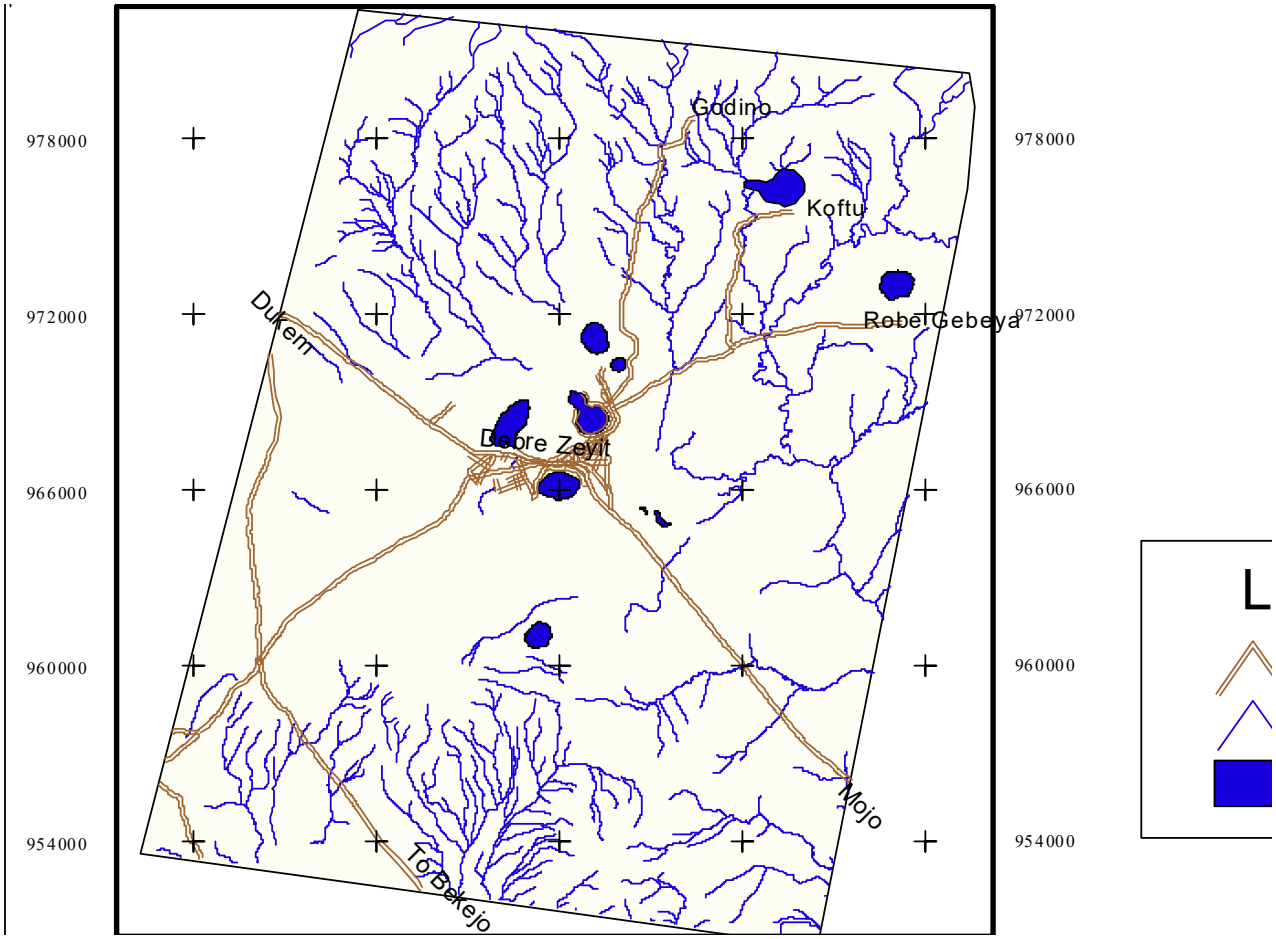
2.2 Physiography and Drainage

The physiography of the study area is the result of Tertiary volcanic and tectonic activities as well as Quaternary soil formation and later erosions by sheet, rill and gully. The exposed rocks are of volcanic origin. Volcanic scoracious cones are found scattered here and there in the area. There is about 1260 m difference in elevation between Lake Kuriftu (1840m) and the top of the Yerer Mountain (3100 m) in the northern part of the study area. The main rivers are Wedecha, Gende Gorba, Mojo, Belbela, Kofele and Mekana in the northern part of the study area and Kilicha and Hade-Were in the southern part.

The principal drainage patterns of the study area are dendritic on the flat lands and radial on the volcanic cons and on the steep mountains sides (Figure 2.2). Kofele and Mekana rivers disappear in the Chelekeleka swamp which is covered by water in the rainy seasons.

The area is highly dissected by gullies, which expose alternating layers of volcanic materials and paleosols. As Derose et al., 1998 sited on Poesen et al., 2002 there is no clear cut definition that exist to describe the upper limit for gullies size. Based on this all the ephemeral river channels found in this study are considered as gullies.

Both in the northern and southern parts, volcanic surge deposits are found bracketing paleosoils. By comparing a topographic map of the 1975 with the ground truth during the field visits, it was possible to observe gullies, which were not traced on the map or even if some were traced they then had small sizes, implying the land has severely been degraded during the last 31 years (plate 5.4). On the contrary, people are rehabilitating some of the gullies in quite very small places on the northern part of the study area near Godino and in some places around Babogaya Lake along the road.


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2.3 Climate

Ethiopia is situated within the tropics and therefore is subject to comparatively small seasonal variations in temperature, but experiences considerable diurnal fluctuations in temperature (Gamachu 1977). However the present study area shows great seasonal variation in rainfall and humidity. Most of the annual rainfall occurs between late June and mid September. During this period, the large low pressure zone located over the Indian Ocean and the Arabian Sea dominates the airflow and there is a strong movement of moist air from Southwest to Northeast, i.e. from the high pressure center over the Gulf of Guinea (Atlantic Ocean) towards the low pressure center of Arabia. This movement carries warm, moist, unstable air masses from the Congo basin to Ethiopia and is the largest source of rainwater. The driest time of the year is usually the months of November to January, when the prevailing winds are the northeast trades, bringing dry air from central Asia. The lowest daily minimum temperatures usually occur during this period. In most years a shorter period of fairly heavy rainfall (the little rains) can be distinguished sometime between February and May. But in some years this scarcely occurs, and in other years there is no very obvious interruption between the rains of the main wet season and the period of the small rains. The weather throughout the Ethiopian highlands may vary considerably from one year to another. This is due to the passage of the Inter tropical Convergence Zone over Ethiopia.

Rainfall and Temperature

Rainfall is one of the most important elements in characterizing the climate of a region. In Southern Ethiopia the main dry season is shorter (December – February) unlike in Northern Ethiopia (November - February); and, conversely the main rainy season is longer in the south (May – November) and shorter in the north (June – August) (Suzuki, 1967).

In Ethiopia, fourteen rainfall regions are recognized based on whether the rain months are continuously distributed (type I) or there are two rainy “seasons” (type II) (Gamachu, 1977).

The study area is characterized by two rainy seasons (i.e. Type II rainfall region). Like most of the regions on the western escarpment of the Rift system Debre Zeyit and it’s surrounding is located in regime IID. Regime IID is characterized by six rainy months from March to April and June to September. The small rains are in March, and April and the big rains are from June to September with very high concentrations in July and August (Gamachu, 1977).

From the long-term rainfall data of the study area the precipitation of the area shows large seasonal and inter annual variability. The record of precipitation is available since 1953. The precipitation is recorded in the Agricultural Research Institute and the Air Force stations located in the town of Debre Zeyit. There is a minor difference in record of rainfall between the two stations which are located in less 3 Km distance from each other. The average of 44 years mean annual rainfall for the Air force station is 887 mm/yr**.** The 10 years mean annual rainfall at the Agricultural research station is 880 mm/yr. For this work the record from the Air force station is considered. The general trend of precipitation is a decrease until 1962, with a little increase up to 1966 then a decreases up to 1973, (the driest year), followed by a small increase and slight fluctuations up to 2002 (relatively dry) and a general increase starting this year up to present. The five years moving average trend shows that the rainfall has a rising trend between late 1950's and late 1960's and a general decreasing trend since 1960. (Figure 2.3)

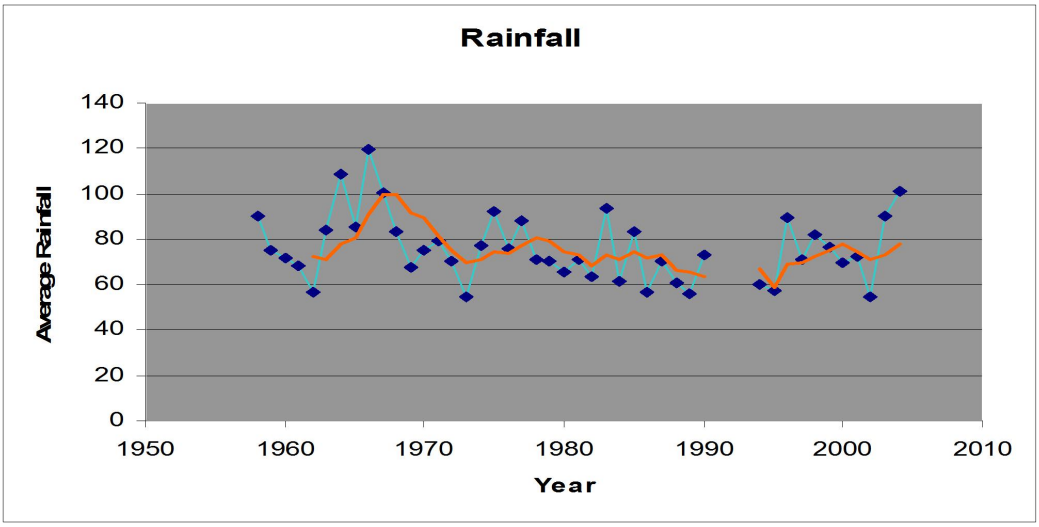


Figure 2.3- Annual variability in rainfall at Air force station, Debre Zeyit

Although rainfall data is available from 1958 to 2004, the record at Air force station is not complete. Data were missing between 1991and 1993.

The rainfall distribution from this recording station shows high rainfall in the months of June, July, August and September and small rain in March, April and May (Figure 2.4). There is a slight decrease in rainfall in the month of May which is the period of transition from the small spring rains to the big summer rains.

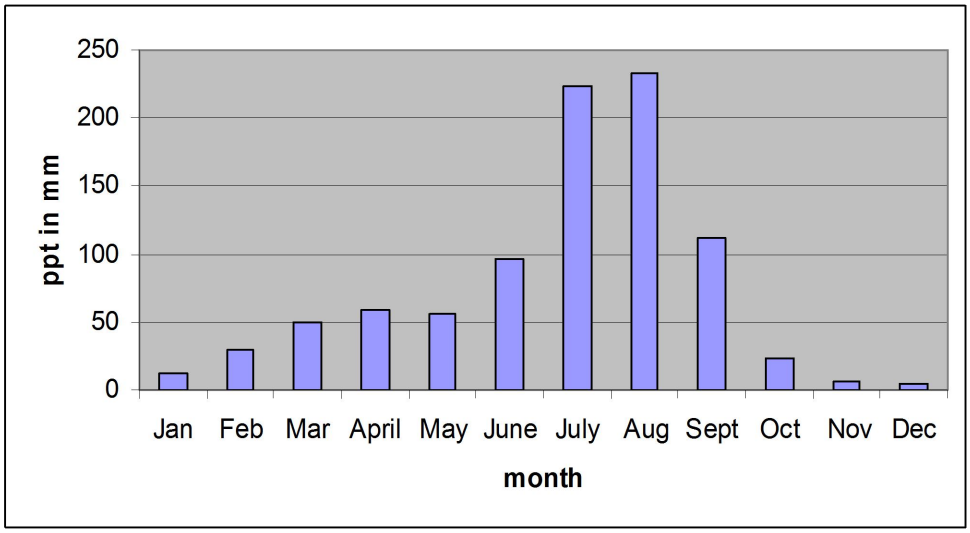


Figure 2.4-Rain fall pattern of Debre Zeyit at Air force station

Mean monthly average temperature values for the Air force station are shown in figure 2.5. Generally, months of March, April, May, and June, have the highest average temperatures while November, December and January have the lowest. The maximum temperature reaches as high as 28.56 ^{o}C, in May while the minimum temperature gets as low as 8.8^{o}C, in December.

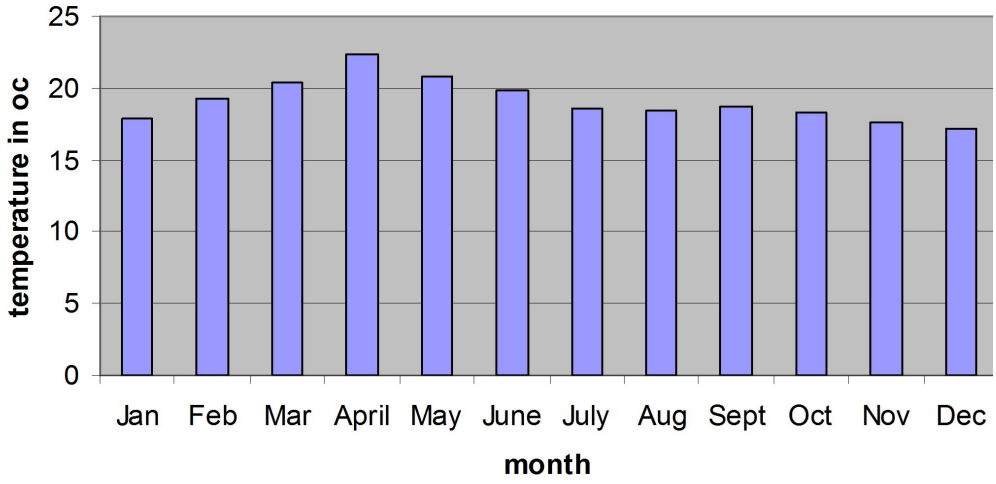


Figure 2.5 Mean monthly average temperature of Debre Zeyit at Air Force station

2.4 Regional Geological Setting

The Debre Zeyit area represents a transition zone between the Ethiopian plateau and the Main Ethiopian Rift (MER). In this area the rift escarpment is not well defined, and the MER intersects the important E-W structures (Abebe et al., 1998). Due to its accessibility, this area was studied by several researchers (Mohr, 1961; Justin-Visentin et al., 1974; Kasmin and Berhe, 1978; Morton et al., 1979; Gasparon et al., 1993; Abebe, 1995; Welde, 1996; Chernet et al., 1998). This region is mainly covered by volcanic rocks and the sedimentary rocks consist of alluvial cover and lacustrine sequences. Volcanic activity in the area has given rise to central composite volcanoes as well as to monogenic apparata as

domes, spatter cones and maars. Emission centers of lava and ignimbrite are observed only for youngest volcanic products.

The different mapped rock bodies are named as units that are grouped in to complexes. Three complexes, ten volcanic and two sedimentary units were distinguished. The names of the complexes have been attributed mainly on the basis of the morpho-structural features and their relation with the Main Ethiopian Rift.

1. Western Rift Margin Complex

This complex exhibits ages ranging from 7.5 to 2 Ma. It is constituted by four volcanic units dominated in the lower part by basaltic lava flows (Addis Ababa basalts unit), followed by a pyroclastic sequence, mainly formed by ignimbrites (Addis Ababa ignimbrites unit) and, finally, by central composite volcanoes and small spatter cones an lava flows (Akaki unit).

Addis Ababa basalts unit: extensively crop out along the gorges of Akaki, Kebena and Dukem rivers at east- southeast of Addis Ababa, and represent he oldest unit of the area ranging between7.5 and 4.5Ma.

Addis Ababa ignimbrites unit: this unit is exposed close to Addis Ababa and along the Akaki and Kebena rivers. It rests on the Addis Ababa basalt and locally covers the products of the composite central volcanoes of wechacha and Furi. The sequence is constituted by different flow units, consisting of pale-green to pale-yellow welded and crystal rich ignimbrites having age of 5.1 and 3.3 Ma.

Yerer represents the largest volcanic edifice of the region, with a relief of 1000 m from plain. It is 14 km wide along the E-W direction. Ridges and Domes are NE-SW aligned. Products consist of mainly of lavas, even if pyroclastic are widespread mainly in the central and eastern sector. Overall, the volcano is strongly eroded, especially at the

southern slope, where 200m escarpments occur. The highest part of the Yerer volcano was affected also by a more recent volcanic activity that produces spatter cones and associated basaltic lavas, ascribed to the Akaki unit. The lavas are mainly trachytes.

Akaki unit: it crops out East of Addis Ababa and consists of scoria and spatter cones with associated lava flows.

2. Intra Rift Complex

In this complex upper Miocene-Quaternary products which constitute the floor of the main Ethiopian rift and its successive filling are included. The Nazareth unit which is the basal unit forming the floor of the rift is recognized as part of this complex.

Nazereth unit: it is mainly exposed in the north-eastern and eastern sector and it consists of sequences of welded peralkaline rhyolitic ignimbrites. Maximum number of observed flow units is four with thickness variable from 5-15 m. The unit comprises also numerous rhyolitic and trachytic domes.

Tulu Rie Basalts unit: this unit covers the Nazareth unit and forms the upper part of NE trending escarpments. The age ranges between 2.7-1.8 Ma. It consists of Sub-horizontal or slightly tilted tabular lava flows. And covers about 3% of the Debre Zeyit area; the maximum observed thickness is 20m.

Chefe Donsa Unit: the volcanic rocks of the Chefe Donsa unit are exposed mainly along the boarder of the central plain. They consist of fall deposits and poorly welded ignimbrites of rhyolitic composition. In the south western area, Chefe Donsa unit rests upon the Addis Ababa basalt and is covered by the lacustrine deposits, where the eastern and north- eastern area, they cover the Nazareth and Tulu Rie Basalt and Yerer products.

3. Rift Axis Complex

It is made up by a quaternary to Holocene sequence consisting of young central volcanoes, lacustrine deposits and basaltic cinder and spatter cones, aligned NNE along the axis of secondary rift.

Zikwala Volcano Unit: Zikwala is an isolated, well preserved composite cone standing 1300 meter above its regional base. Lavas are the dominant products with pyroclastics mainly occurring at south-eastern foot of the volcano, it is slightly elongated along the NE-SW direction and has a summit caldera 1.5 km wide, partially filled by water the age ranges from 1.28 Ma-0.85 Ma lavas are dominated by per alkaline trachite.

Bede Gebabe Volcano Unit: is a volcanic complex with a quasi-circular, slightly NNE elongated and with a maximum relief of 400 m above surrounding topography. Lacustrine deposits rest above this unit all over its marginal portion. Furthermore, spatter cones and basaltic lava flows are present in the central part of the volcanic complex. Pumices and lavas show a composition ranging from rhyolites to minor trachites.

Bishoftu Volcanic Unit: this unit forms a NNE trending belt outcropping mainly in the central flat area of Debre Zeyit. In this unit two groups are distinguished represented by spatter and cinder cones with associated lavas and phreatomagmatic deposits respectively. These latter, consisting mainly of surges and highly fragmented deposits, are associated with maars and tuff ring. The maars are chiefly concentrated in the central part of the central sector where the highest thicknesses of lacustrine sediments frequently intercalated with the phreatomagmatic products are found (Abebe, 1995).

Lacustrine deposits: this unit is developed on a relative, NE elongated depression in the central sector of the area. These fine grained deposits are generally brown to yellowish, thinly stratified and often contain abundant volcanic matrix. In these successions volcanic layers are frequent and become predominant and coarse grained in the neighboring of the maars. Lacustrine environments started after the Bede Gebabe volcanic unit and

continued during the eruptive activity of Bishoftu Volcanic unit. Therefore, an upper Pleistocene-Holocene age is proposed for lacustrine deposits.

4. Alluvial Cover

The alluvial cover mainly outcrops above the products of the western rift margin complex and consists of regoliths, red soils, talus and alluvium with maximum thickness of about 2 m.

Tectonic Framework

A widespread brittle deformation consisting of fractures, joints and faults can be recognized during field survey in the area. Structures are extensional and affect chiefly the rocks of the Intra Rift Margin complex and partially those of the western Rift Margin Complex. These structures can be grouped in to four main fracture systems consisting mainly of joint sets and some faults**.**

The N-S/NNE-SSW fracture systems strikes 20^{o}W to 20^{o}E, clustering mainly around 15oE; it is considered analogous to the so called Wonji Fault belt along the axial part of the MER (Mohr, 1967; Di Pola, 1972). It consists of steeply dipping joints and normal faults, more than 70% of them with dip angle >85^{o}.

The NE-SW fracture system parallels the regional trend of the MER. Again deformation leads to almost vertical joints and some high angle normal faults with maximum thrown of about 1m (about 65% with dip angle>85^{o}). It is widespread especially in the Nazareth unit where the most important physiographic features are NE trending ridges and escarpments.

The E-W fracture system is mainly concentrated in zones close to the Yerer volcano or just east of Addis Ababa; it parallels the trend of the YTVL (Yerer-Tullu Wellel volcano-

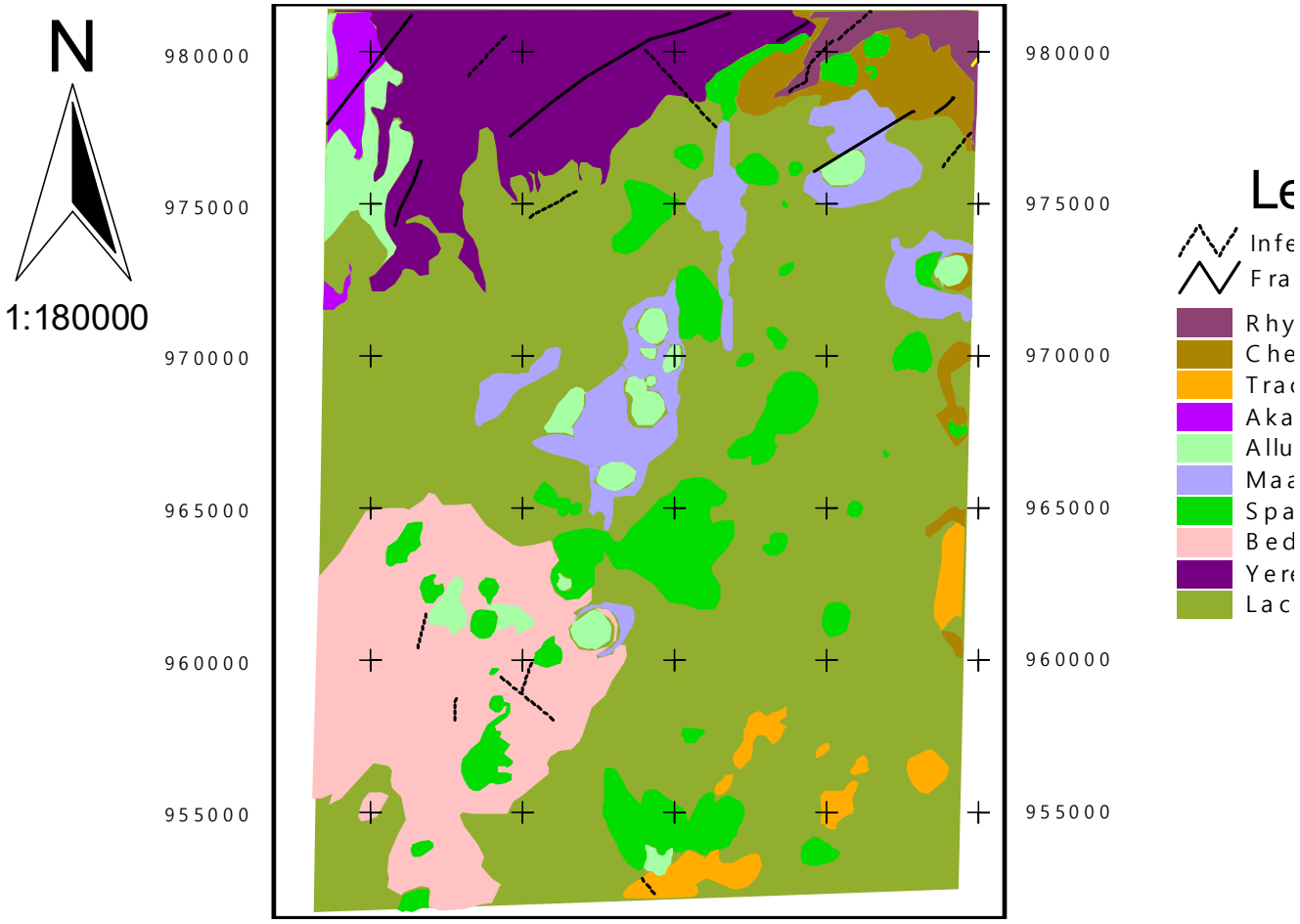
tectonic lineaments) structures. It consist of sub vertical to vertical joints (about 70% with dip angle >85^{o}).

The NW-SE fracture system represents more than 65% of joints with dip angle >85%. Few high angle normal faults have been observed with high morphologic evidence. This system affects mainly the oldest units of the Western Rift Margin and Intra Rift Complexes.

Local Geology

The local geology of the study area has not been done in detail due to the availability of recent and detail works on the study area and the surrounding.

The Yerer volcanic unit, covers the northern most part of the study area. This unit is not exposed much on the surface due to the deep soil and vegetation covers. Surge deposits which belong to Bisheftu volcanic unit are exposed on the flat lands below the Yerer volcanics. They are exposed on those places that are cut by deep and powerful gullies. The lacustrine deposits covering almost 60-75% of the study area with some alluvial deposits which is found on the central part of the study area covering the flat land extensively. The Bede Gebabe unit with its pumice deposits on the southern part of the study area and here and there scattered spatter cones are also observed (Figure 2.6).


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2.5 Soils of the Debre Zeyit area

According to F. Itanna, 1992 the soils at Debre Zeyit are identified as Vertisols associated with other soil types mainly Andisols. FAO/UNESCO, (1988) describes the Vertisols as follows: Vertisols are characterized by their high clay contents. They are often dark colored. Due to their smectite clay mineralogy, they are very hard and crack when dry, but become sticky and plastic (often impassable) when wet. These are chemically rich soils, but they may develop on an undulating micro relief which hampers mechanization. Vertisols have great agricultural potential, but special management practices are required to secure sustained agricultural production. Unless mechanization or irrigation is feasible, they are best suited for grazing.

The study of vertisols in relation to the adjoining soils in a geomorphic unit, supplies a comprehensive knowledge of their pedogenesis and nutrient status. Hall (1983) and Schlichting (1986), in this connection describe that geomorphology plays a major role in processes governing the distribution of soils in the landscape and Pedologic processes are considered as an integral part of landscape formation. Malo et al., 1974, report that soil properties follow systematic patterns of distribution on the landscape. They point out that properties such as organic matter content, bulk density, texture and pH all vary with landscape position.

In Ethiopia, several soil groups have been reported as forming associations with Vertisols. Valentine (1970) has reported on a Lithosol-Cambisol-Vertisol association in Harrar plateaus. Ahmed (1986) describes an association of Entisols (on steeper slopes), Alfisols on central highlands of Ethiopia. A similar report by Allen and Fanning (1983), is that Vertisols are sometimes associated with ustic great groups of Alfisols and Mollisols in semi arid regions and with Aridisols in arid regions. Fikiru (1985) broadly delineates areas in Ethiopia where Vertisols are found in association with other soils. According to

his report, Vertisols are associated quite often with Eutric Nitosols, Eutric and chromic cambisols, Lithosols, Andosols and chromic Luvisols to a low extent.

The major soil parent material is weathering olivine basalt of Tertiary age. Ahmed (1986) noted the presence of volcanic materials of recent age like tuffs, cinders and finer ash of basic nature as well. The soils at Debre Zeyit locally are known as Gombore (light soils occupying upper topographic positions), and Koticha (the vertisols). Meticulous morphological field observations reveal the presence of soils derived from volcanic ash and other recent materials on the uppermost topographic positions, Mollic Andosols at mid slopes and vertisols at bottom lands. The upper soils contain more sand and silt material and high pH values compared to the vertisols at bottom lands. The vertisols at Debre Zeyit have more of grayish color probably due to the influence of the ash material on the upper topographic positions which certainly is eroded down to the vertisols.

The soil identified as vertisols fulfill the requirements of clay content (>30%) up to 50cm, formation of cracks, silkensides, structural aggregates and other properties as specified by the FAO/UNESCO system of classification for vertisols (1988). They also undergo self mulching and self swallowing properties common for most vertisols.

In Debre Zeyit, Andisols are the associated soils which are derived from quaternary pyroclastic deposits. They commonly have a very dark grey brown moist color to at least 1m depth (mostly deeper). The vertisols have mostly clayey horizons, while the associated soils are dominantly loam, with admixtures of sand and clay loams. Clay increase downslope is more regular: increasing from summit position (weighted average of 8.7%) to toeslope position (weighted average of 67.7%). Surfcial clay fractions of the vertisols at foot slope and toeslope positions are about twice as much as surficial clay fractions at mid slope positions and these fractions in turn are about twice as much as the surficial clay content of the summit position.

Indurated silica layers occur with in the Andisols between 32-90 cm at summit position and below 140 and 153 cms at shoulder and backslope positions, respectively. Due to the volcanic ash influence sand and silt fractions dominate, almost equally, especially at shoulders and backslope positions. The presence of finer material below 104 cm at summit position is an indication of young quaternary material depositing over older weathered soil. The finer material is not a result of illuviation but rather of in situ soil development. Downward transport of ash material as a result of erosion has influenced the vertisols close by, in some morphological properties like color alteration (modifications).

The surface soils between summit and backslope position in Debre Zeyit, contain more than 30% sand and silt fractions to at least 40 cm depth. According to morphological field observations and oxalate Fe and Al values, the volcanic glass composition is close to 30%. Since they fulfill a certain set of andic properties they are classified as Andisols. The pendon at shoulders and backslope positions meet the requirements set for Mollic Andosols, but the one at the summit position is classified as vitric Andosol because it lacks the depth and organic carbon value ascribed for a mollic Andosol. It lacks also the requirement for the other Andosols except Vitric Andosols.

CHAPTER THREE

REMOTE SENSING TECHNIQUES

3.1 Back ground

Remote sensing has long been recommended for its potential to detect, map and monitor degradation problems (Hellden and Stern, 1980; Sabins, 1987; Pickup, 1989; Frederiksen, 1993; Mohammed, 1993; Raina et al., 1993; Tripathy et al., 1996; Sujatha et al., 2000) including their spread and effects with time (Sommer et al., 1998). Use of remotely sensed imagery evolved on the basis that traditional survey became expensive and time-consuming. It is especially useful in areas that are not accessible.

Hoosbeek et al. (1997) grouped methods of mapping land degradation into 2 broad categories. One of which is the Qualitative Extrapolation Model which includes delineation of degraded soils using topographic maps, remotely sensed imagery and selection of soil mapping unit. In this category, the Soil Survey Manual (USDA, 1993) and GLASOD framework (Oldeman et al., 1991) are recommended in describing and classifying soil degradation. The other method focused on the application of geo-statistics.

The most accurate method for detection of land degradation is the direct measurement and observation at individual sites. This demands many observations as the area of mapping coverage becomes large. Consequently, stratification is done and examination of representative sites are employed which lead to subjective and non-rigorous selection (Pickup, 1989). In most cases, such a technique fail to produce detailed mapping outputs due to budget constraints, inaccessible areas, insufficient standardization and repeatability (Hill et al., 1995a). With such a constraint, remote sensing becomes an alternative to map land degradation (King and Delpont, 1993; De Jong, 1994). Remote Sensing has high potential for land degradation data collection due to large area coverage, regular time interval, spatial and spectral resolution which facilitates detection of degraded areas (De Jong, 1994).

Pickup (1989) stressed the importance of the spectral-temporal model of analysis in assessing land degradation. It is because of the differences of soil and vegetation reflectance at the different wavelengths and the temporal components giving a trend idea on the pattern at which land degradation occurs. Hill et al. (1995b) pointed out the importance of monitoring soil conditions including vegetation regime and recovery over time in understanding the process of land degradation from their spatial context. They claimed that the incorporation of terrain parameters improved the classification not only for the current degradation but also for erosion risk analysis.

Remote sensing provides a convenient source of information but the data collected by these instruments do not directly correspond to the information we need (Hill et al., 1995b). They emphasized that changes in albedo and/or reflectance do not necessarily mean changes or worsening of degradation problems. This could be attributed to other changes in land surface characteristics such as clearing of woodlands, maturing cereals and dry vegetations. In a temporal aspect of analysis, Hill et al. (1995a) stressed that change detection should also be given extra care due to the radiometric effects that would mislead the analysis at different times of acquisition such as state of the atmosphere, illumination and drifts in sensor calibration. Singh (1989) considers soil moisture as an important factor affecting land degradation change detection analysis and thus proposes to be taken into account.

3.2 Digital image processing techniques

Image processing technique for this work is performed in 3 steps:

1. Image rectification and restoration
2. Image enhancement and Interpretation
3. Image classification and out put preparation.

3.2.1 Image rectification and restoration

In their raw form, as received from imaging sensors mounted on satellite platforms, remotely sensed data generally contain flaws or deficiencies (Mather, 1999); some of them are radiometric distortions, geometric distortion and noise. Such errors can be corrected by using pre processing techniques like radiometric corrections, geometric correction and noise removal which should be applied on the raw image. All the images that are used for this study are found from different sources. And the above mentioned pre processing techniques were carried out before they were available for this study except for the 1973 MSS image. In this particular image, bands 3 and 4 showed a dropped lines error which occurs when there are missing scan lines. This error can be corrected by averaging the neighboring pixel values in a raw format of the image before any kind of geographic projection applied. Since the 1973 image was found already georeferenced in UTM, 37N-WGS-84 projection in prior, we couldn't do any thing to minimize the problem and is used as it is.

In a preprocessing stage, it is usually necessary to georeference the images on desired projection and datum. Specially, if remotely sensed data are to be used in association with other data within the context of a geographic information system, then the remotely sensed data and the products derived from such data will need to be expressed with reference to the geographical coordinates that are used for the rest of the data in the information system. All the images that are used for this study were georeferenced with one or other projection except the ETM^+ 2002 image which is found in its raw format.

So, all the images (MSS, TM and ETM^+) were brought to the same geographic coordinate which is UTM, 37N-Adinden, using ENVI 3.5 software applying both 'image to map' and 'image to image' registration options. First the 2002 ETM^+ image was georeferenced using the topographic map of 1975. Well distributed 26 ground control points were used for this process. Then the rest of the images were georeferenced taking the 2002 ETM^+

image as a base using again well distributed GCP's. The 1973-MSS image (pixel size=57*57m) is registered to the TM images (pixel size=28.5*28.5) in addition to being georeferenced.

3.2.2 Image enhancement

These techniques are applied to images in order to more effectively display or record the data for subsequent visual interpretation. A number of enhancement and transformation techniques were performed on the images to improve the descriminablity of land cover classes as well as newly developing gully and ephemeral drainage systems.

Contrast Enhancement

For any particular area that is being imaged it is unlikely that the full dynamic range of the sensor will be used and the corresponding image is dull and lacking in contrast or over-bright. Not much detail can be seen on such images, which are either under exposed or overexposed in photographic terms (Mather, 1999). Contrast stretching is a technique to expand the narrow range of brightness values typically present in an input image over a wider range of gray value (Lillesand and Kiefer 2000). The visual interpretability of the images used in this study is enhanced by using histogram equalization stretch, in this type of contrast enhancement image values are assigned to the display levels on the basis of their frequency of occurrence.

Color composites

For the color composition many combinations were checked. The common result of several combination studies has resulted that combination including TM band 4 and band 5 were highly ranked for effective channel selection. In this case the one that allows identification of most of the categories of land cover classes were the color composite red 4, green 3 and blue 2 which is false color composite.

Principal component analysis

Adjacent bands in multispectral remotely sensed imagery are generally correlated. The presence of correlation among the bands of a multispectral image implies that there is redundancy in the data (Mather, 1999). If DN of one band are plotted against those from another band near to it in the electromagnetic spectrum, the majority of points lie on, or near to, a diagonal line passing through the origin of the graph. A means of improving the spread of data is to redistribute them about another set of axis in multi dimensional space, which maximizes the separation of differences in the data.

Principal component analysis is a technique designed to serve the purpose of reducing redundancy in multi spectral data by compressing all of the information contained in an original *n*-band data sets in to fewer than *n*-new bands or components using eigen vectors (Lillesand and Kiefer 2000).

For channels of multispectral data, the first principal component includes the largest percentage of the total scene variance and succeeding components (pc_2, $pc_3 \ldots pc_n$) each contain a decreasing percentage of the scene variance.

For all the images used in this study principal component analysis have been done and the resulting images are used to visually interpret the images according to the objective of the research. It is well observed that $\mathbf{pc_1}$ from the 1973 MSS image and $\mathbf{pc_2}$ from the other TM and ETM^+ images were useful in the identification of linear features like roads, drainages and older gullies (Figure 3.1).

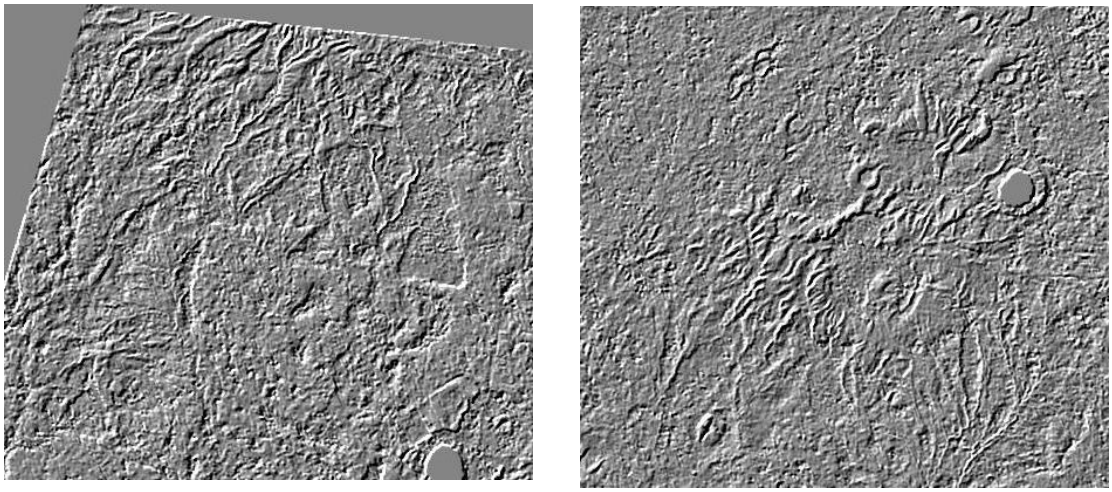


Figure 3.1 a principal componenent-2 image of TM- 1986 with directional filtering at 45^0

Filtering

Filtering is a method to selectively emphasize or suppress information at different spatial scales over an image using a moving window. The moving window contains an array of coefficients or weighting factors called kernels which are normally odd number of pixels in size. The kernel is moved throughout the original image, and the DN at the center of the kernel in a second (convoluted) output image is obtained by multiplying each coefficient in the kernel by the corresponding DN in the original image and adding all the result products (Lillesand and Kiefer 2000). For this work directional filtering is used. Directional filtering emphasizes those features normal to the direction of filtering and deemphasizes those parallel to the direction of filtering. Filtering at 45^0 has shown the best result in the identification of linear features of gullies since the flow direction of most of the rivers and newly developed gullies is NE-SW (Figure 3.1).

Normalized Difference Vegetation Index (NDVI)

A vegetation index is a common spectral index that identifies the presence of chlorophyll. It is composed of reflectance in the red spectral region (0.62 to 0.7 um) and a portion of the near infrared spectral region (0.7 to 1.1 um). Chlorophyll has a relative low

reflectance in the red part of the electromagnetic spectrum and a relative high reflectance in the near infrared part.

Vegetation indices are empirical formulae designed to emphasize the spectral contrast between the red and near infrared regions of the electromagnetic spectrum. They attempt to measure biomass and vegetative health, the higher the vegetation index value, the higher the probability that the corresponding area on the ground has a dense coverage of healthy green vegetation (Gibson & Power, 2000). Spectral vegetation indices permit clear discrimination between bare soil surfaces, water bodies, and vegetation. Several vegetation indices, NDVI, DVI, PVI, SAVI, and others, have been developed in order to improve specific analyses.

NDVI is one of the most widely used vegetation indices. Its strength is the vegetation cover, and it is tailored to give desirable characteristics for various parameters associated with vegetation growth, type and ecosystem environment. Its value ranges between –1 and +1 (Gibson & Power, 2000).

$$\textbf{NDVI} = \frac{\textbf{Near infrared} - \textbf{Visible red}}{\textbf{Visible red} + \textbf{Near infrared}}$$

NDVI is used in this study as one parameter in the identification of ground cover classes for preliminary check during the unsupervised classification of the 2002 ETM^{+} image before field work. It is used as a color combination with the other bands and principal component outputs. Those areas with permanent vegetation throughout the year are easily identified. Since the time of image acquisition is on the harvesting and near harvesting time crops can’t be represented as vegetation on this index.

3.2.3 Image classification and out put preparation.

Classification

Image classification is the process of creating thematic maps from satellite imagery. A thematic map is an informational representation of an image that shows the spatial distribution of a particular theme (Verbyla, 1995).

The computerized interpretation of images from remote sensors is known as a quantitative analysis due to its ability to identify pixels based in the numerical properties. For quantitative analysis usually different procedures of classification are used (Richards, 1993). Classification is a method that assigns categories to different pixel groups according with the spectral character. There are two main spectrally oriented classification procedures for land cover mapping: unsupervised and supervised classifications.

A. Unsupervised classification is more computer-automated. It enables user to specify some parameters that the computer uses to uncover statistical patterns that are inherent in the data. These patterns are simply clusters of pixels with similar spectral characteristics. In some cases, it may be mere important to identify group of pixels with similar spectral characteristics than it is to sort pixels into recognizable categories (Diday, 1994).

B. In supervised classification the image analyst supervises the pixel categorization processes by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of known cover type, called training areas are used to create the parametric signatures of each class. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it ‘looks most like’ (Lillesand and Kiefer 2000). There are different algorithms under this classification type in which minimum distance, variance and covariance of the classes are considered during

classification. Of these algorithms the best is maximum likelihood classifier. It quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel. In this study the ML classifier is adopted to differentiate the different land cover classes in each image of the different years. Field work was done using the thematic map of the 2002 classified image and training sites were selected on this map representing all landcover types.

Post classification smoothing

Classified data often manifest a salt-and-pepper appearance due to inherent spectral variability encountered by a classifier when applied on a pixel by pixel basis (Lillesand and Kiefer 2000). This problem can be adjusted by applying post classification smoothing algorithm. One means of classification smoothing involves the application of a majority filter. The idea behind this procedure is: a moving window is passed through the classified data set and the majority class with in the window is determined. If the center pixel in the window is not the majority class, its identity is changed to the majority class. If there is no majority class in the window, the identity of the center pixel is unchanged. This operation is done on the classified images of the landuse-landcover classes iteratively.

CHAPTER FOUR

LANDUSE AND LANDCOVER DYNAMICS

4.1 Back ground

Landcover refers to the vegetation (natural and planted), water bodies, bare rock, and similar surface and also man-made construction occur on the earth's surface. While Landuse refers to a series of operations on land, carried out by humans, with the intention to obtain products and/or benefit through using land resources including soil and vegetation resources which is part of land cover (FAO 1995). Thus, land use often influences land cover. Milne (1993), defined change as an alteration in the surface component of the landscape and is only considered occur if the surface has a different appearance when viewed on at least two successive occasions.

Landuse and landcover change has become a central component in current strategies for managing natural resources and monitoring environmental change. Since the late 1960's, the rapid development of the concept of vegetation mapping has lead to increased studies of landuse and landcover change worldwide. Providing an accurate assessment of the extent and health of the world's forest, grassland and agricultural resources have become an important priority.

The importance of investigating landcover dynamics as a baseline requirement for sustainable management of natural resources has been highlighted by many researchers involved in global change studies (Brandon *et al*, 1998; Chen, 2002; Jansen *et al*, 2002; Mertens, 1999; Mertens *et al*, 2000; Petit *et al*, 2001; Primack, 1993; Read *et al*, 2002; Serneels, 2001; Serneels *et al*, 2000). These scientists have argued that a more focused management intervention requires information on the rates and the impacts of landcover change as well as the distribution of these changes in space and over time.

Also, the importance of spatial models as useful tools for describing processes of landcover change in quantitative terms and for testing our understanding of these processes have been highlighted. Models of landcover change can be used at predicting the spatial pattern of changes or the rate of change (Pontius & Schneider, 2001 in Serneels, 2001). So they should aim in addressing at least one of the following questions: (i) which environmental and cultural variables contribute most to an explanation of landcover changes: why?; (ii) which locations are affected by landcover changes: where?; and (iii) at what rate is land cover change progressing: when? (Mertens et al, 2000).

Over the past two decades, data obtained from Remote sensing satellites have become important in mapping the earth's features and infrastructure, managing natural resources and studying environmental change (Brandon R. Bottomley 1998).

Remote sensing and Geographic Information Systems are providing new tools for advanced ecosystem management. The collection of remotely sensed data facilitates the synoptic analyses of earth-system function, pattern and change at local, regional and global scales over time. The mapping of landuse and landcover is one of the most important application areas of remote sensing (Clawson and Stewort, 1965).

The main aim of this study is to generate spatial information on landcover dynamics and prepare a link between these changes and land degradation problems specially their relation to gully erosion.

4.2 Landcover change detection, qualification and quantification

Landcover change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, landcover change detection involves the ability to quantify temporal effects using multitemporal data sets. Remotely sensed data obtained from earth orbiting satellites is an important data source

for landcover change detection because of repetitive coverage at short intervals and consistent image quality (Singh, 1989).

The objective of analyzing the spatio- temporal dynamics of the landcover is to monitor the evolution of the natural vegetation cover of the study area. This was based on post classification comparison of independently classified landcover maps of 1973, 1986, 1995 and 2002. The technique used for change detection is GIS overlay in Arcview 3.2. In this technique, the out put table from the overlay of maps of the different dates was used to qualify and quantify the landcover changes. Landcover changes were investigated for the sub periods 1973-1986, 1986-1995 and 1995-2002. This was to determine if there is a difference in the rate, the trends and the factors that cause landcover change in the three periods.

Landcover classes

Seven types of landcover classes were identified in this study. These are:

Dense shrub land and remnant trees: in this class woody perennial plants with persistent and woody stems being less than 5m tall and remnant *Junipers procera* and *Acasia albida* are included.

Open woodland with shrubs: this class corresponds to plants which has undergone modifications from man's influence. It is composed predominantly of secondary vegetation indicative of a recovery stage from past disturbance. It occurs mostly on the outer most parts of the dense shrub land, around settlements and along roads. It consists of the *Eucalyptus* and *Acasia* trees.

Grassland: this class consists of all areas with less than 10% tree and/or shrub canopy cover and greater than 0.1% total vegetation cover.

Cultivated Land: areas of land that are ploughed and/or prepared for raising crops. The category includes areas currently under crop, fallow land and land being prepared for

planting it also includes settlements of the rural farmer because it was impossible to identify the dispersed rural settlement as a separate landcover type.

Water bodies: this category includes natural and man made surface water bodies (lakes).

Wetlands: areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered in either herbaceous or woody vegetation cover and with cultivation during the non rainy season.

Urban area: An area where there is a permanent concentration of people, buildings, and other man-made structures and activities, from small to large city scale. Where mapping scales permit, the limits of the urban boundary are delineated to exclude open areas within the built up region.

Five landuse categories were identified with in the study area. These are: Agriculture, pasture, forestery, water bodies, and urban areas.

Agriculture: this class includes those areas used for cultivation of crops and holticulture plantation.

Pasture: this class includes the grassland area which is used by the settlers to feed their cattles.

Forestery: this class is composed of the trees found on top of those hilly and mountaneous areas and those planted near towns.

Water bodies: these are those artificial lakes constructed by diverting rivers for the use in agriculture and for those areas where holticulture plantations are developed. In addition those seasonally wetlands are included in this class.

Urban areas: these are where settlers concentrated and different infrastructures are developed .

Changes are observed on the above discussed landcover classes with in the the years 1973,1986,1995 and 2002. Table 4.1 discusses the change in area within the each class both in hectare and percentage.

Landcover classes	1973		1986		1995		2002	
	ha	percent	ha	percent	ha	percent	ha	percent
wetland	171.920	0.25%	195.63	0.28%	185.75	0.27%	256.89	0.37%
Water bodies	507.860	0.73%	739.01	1.06%	812.17	1.17%	705.46	1.02%
Dense shrub	4337.510	6.25%	3825.11	5.51%	3292.16	4.74%	2359.45	3.40%
Grassland	24257.800	34.93%	19612.67	28.24%	11459.34	16.50%	10902.08	15.70%
Open woodland	4833.510	6.96%	5606.16	8.07%	5994.79	8.63%	6345.22	9.14%
Cultivated land	34611.180	49.84%	38446.77	55.37%	46584.3	67.08%	47694.86	68.68%
Urban	721.270	1.04%	1015.7	1.46%	1112.54	1.60%	1177.09	1.70%
Total	69441.050	100.00%	69441.05	100.00%	69441.05	100.00%	69441.05	100.00%

Table 4.1 Areal coverage of landcover classes in hectares and percentage

Slope classes

The digitized contour maps with 20 m elevation interval are used to derive the DEM of the study area. This is used again to derive the slope of the area. Slope derived from the DEM is classified based on the classification system by FAO, 1990 (Table 4.2).

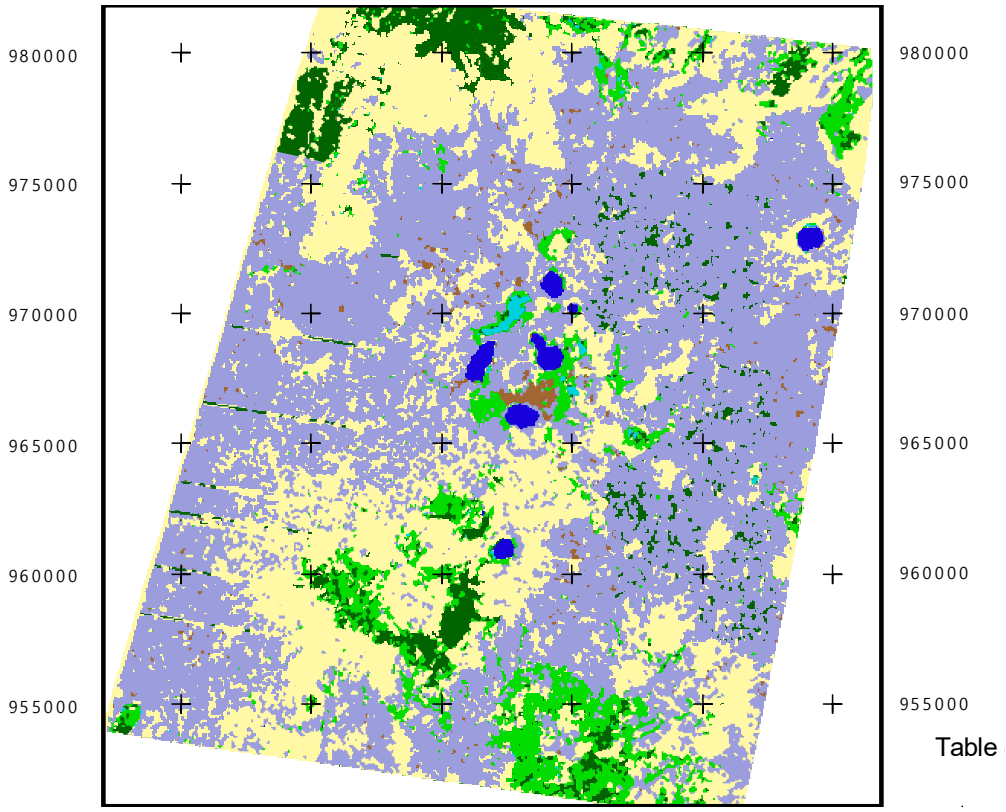
Slope in percentage	Class name
0-2	Flat to almost flat Terrain
2-10	Gently undulating to Undulating Terrain
10-15	Rolling Terrain
15-30	Hilly Terrain
>30	Steeply dissected to mountainous Terrain

Table 4.2 slope classification (FAO,1990)

Classification of the study area in to different slopes showed that around 88% is found with in slope less than 10% of which the majority is with in slope less than 2% . The rest 12% is found on slopes >10%. This indicates that the study area is dominantly covered by lower topography (figure 6.

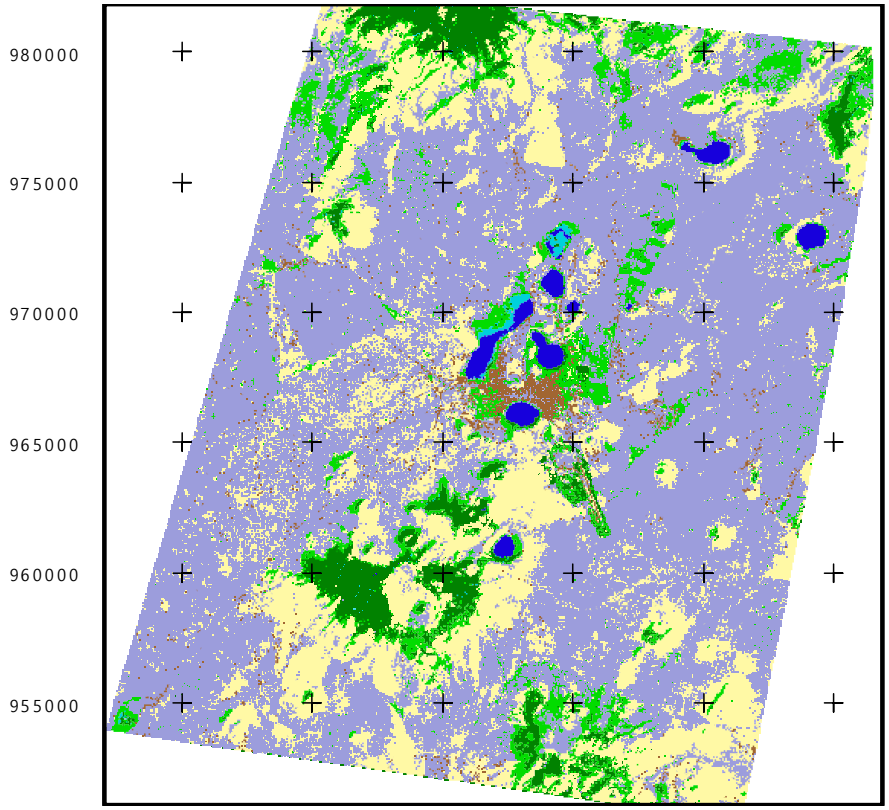
slope class	%slope	Area (ha)	Area percentage
Flat	<2	41353	59.55%
Gently undulating	2-10	19433	27.98%
Rolling	10-15	2059	2.97%
Hilly	15-30	5938	8.55%
Mountainous	>30	658	0.95%
	Total	69441	100.00%

Table 4.3 area covered by each slope class



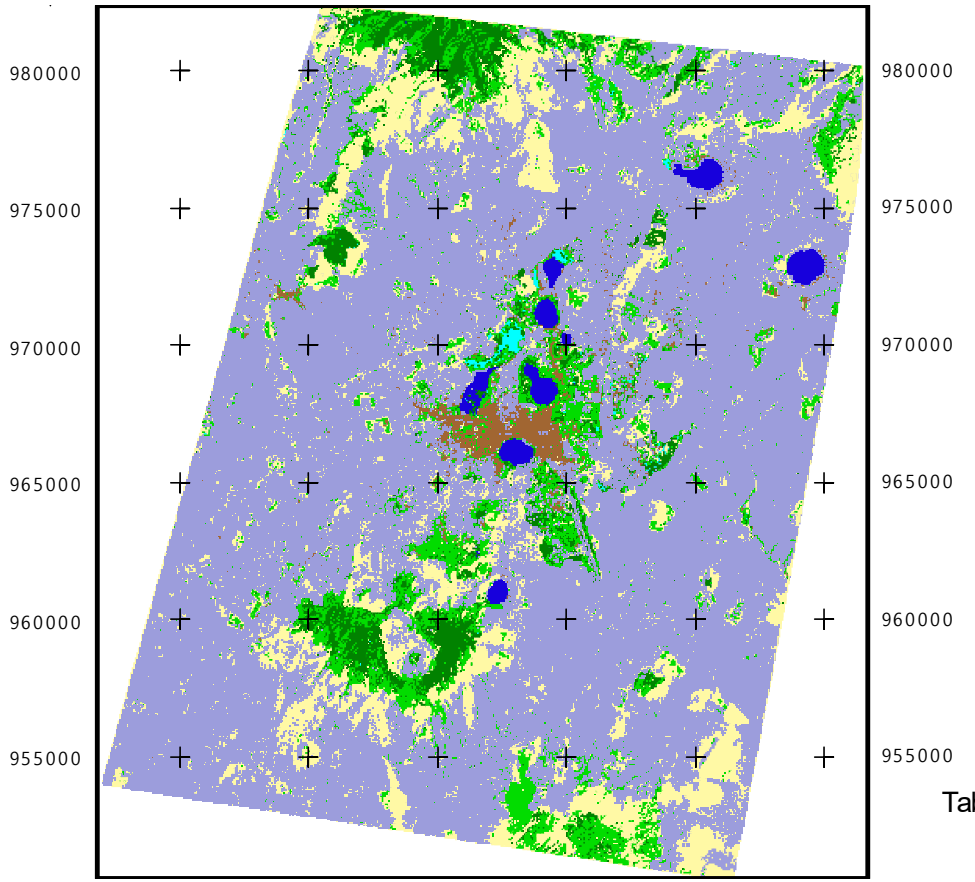
Table

LC class	0-2% Flat	2 -10% Gently Undul.	10 -15% Rolling	15-30% Hilly	>30% Mounta.	Total
DS	1246	659	889	1217	326	4337
OW	1643	1123	676	1275	116	4833
GL	10245	11415	283	2195	120	24258
CL	27209	5856	205	1247	95	34612
WB	403	105	0	0	0	508
WL	168	4	0	0	0	172
U	439	271	6	4	1	721
Total	41353	19433	2059	5938	658	69441



Table

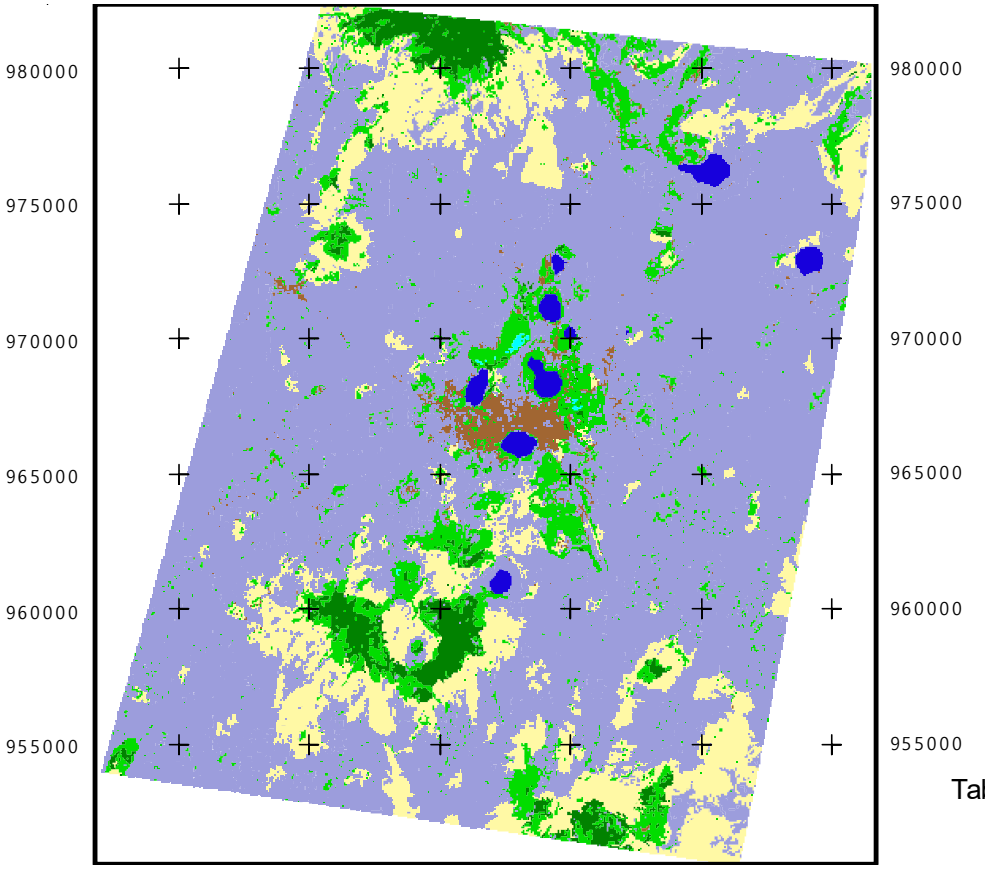
LC class	0-2% Flat	2 -10% Gently Undul.	10 - 15% Rolling	15-30% Hilly	>30% Mount.	Total
DS	1131	740	544	1112	298	3825
OW	1378	1833	836	1388	171	5606
GL	9040	8244	343	1912	74	19613
CL	28386	8144	301	1502	113	38446
WB	578	161	0	0	0	739
WL	179	17	0	0	0	196
U	661	294	35	24	2	1016
Total	41353	19433	2059	5938	658	69441



1:

Table

LC class	0-2% Flat	2 -10% Gently Undul.	10 -15% Rolling	15-30% Hilly	>30% Mounta.	Total
DS	975	670	500	946	201	3292
OW	1200	2286	898	1413	198	5995
GL	3629	6190	205	1394	41	11459
CL	34036	9756	420	2156	216	46584
WB	609	203	0	0	0	812
WL	169	17	0	0	0	186
U	735	311	36	29	2	1113
Total	41353	19433	2059	5938	658	69441



1:

Table

LC class	0-2% Flat	2 -10% Gently Undul.	10 - 15% Rolling	15-30% Hilly	>30% Mounta.	Total
DS	691	281	299	933	156	2360
OW	1146	2582	1012	1390	215	6345
GR	3855	5712	186	1110	39	10902
CL	34134	10329	521	2473	237	47694
WB	571	135	0	0	0	706
WL	198	59	0	0	0	257
U	758	335	41	32	11	1177
Total	41353	19433	2059	5938	658	69441

Changes of classes within the years 1995 and 2002 (values in hectares)								
CLASS_ID	**wetland**	**Lakes**	**Dense shrub**	**Grassland**	**Open woodland**	**cultivated land**	**Urban**	**1995 Total**
Wetland	**116.59**	1.98	11.86	0.00	9.88	51.38	3.95	185.75
Lakes	0.00	**673.85**	7.90	11.86	29.64	82.99	5.93	812.17
Dense shrub	7.90	11.86	**1446.50**	231.20	1183.68	409.05	9.88	3292.16
Grassland	0.00	0.00	254.92	**7104.04**	750.91	3274.38	75.09	11459.34
Open woodland	13.83	1.98	616.54	744.99	**2974.01**	1403.02	254.25	5994.79
Cultivated land	224.95	11.86	31.62	2798.14	1272.60	**42116.37**	282.58	46584.16
Urban	0.00	5.93	1.98	11.86	134.38	409.05	**549.35**	1112.54
2002 Total	256.89	705.46	2359.45	10902.01	6345.22	47693.86	1177.09	69440.91
Changes of classes within the years 1986 and 1995 (values in hectares)								
CLASS_ID	**Wetland**	**Lakes**	**Dense Shrub**	**Grassland**	**Open woodland**	**Cultivated land**	**Urban**	**1986 Total**
Wetland	**49.40**	45.45	33.59	5.93	47.43	11.86	1.98	195.63
Lakes	27.67	**626.42**	29.64	0.00	13.83	33.59	7.90	739.06
Dense Shrub	1.98	23.71	**1592.73**	413.00	1638.18	140.30	1.98	3824.87
Grassland	15.81	9.88	604.68	**8698.74**	1229.13	8935.87	118.57	19612.67
Open woodland	47.43	45.45	588.87	746.96	**1697.46**	2260.65	219.35	5606.16
Cultivated land	27.67	51.38	262.82	1592.73	1211.34	**34822.62**	478.21	38445.77
Urban	11.86	0.00	21.74	61.26	88.92	521.69	**310.25**	1015.71
1995 Total	185.80	812.29	3292.08	11458.62	5995.29	46583.58	1113.23	69440.87
Changes of classes within the years 1973 and 1986 (values in hectares)								
CLASS_ID	**Wetland**	**Lakes**	**Dense shrub**	**Grassland**	**Open woodland**	**Cultivated land**	**Urban**	**1973 Total**
Wetland	**61.26**	11.86	23.71	5.93	53.36	15.81	0.00	171.92
Lakes	7.90	**484.14**	11.86	0.00	1.98	1.98	0.00	507.86
Dense shrub	19.76	1.98	**1357.57**	580.97	918.88	1448.47	9.88	4337.51
Grassland	47.43	33.59	1037.45	**13218.05**	1845.67	7734.41	169.94	24257.54
Open woodland	49.40	47.43	1209.37	857.62	**1444.52**	1108.59	116.59	4833.51
Cultivated land	9.88	156.11	118.57	4793.99	1304.22	**27625.71**	602.71	34611.18
Urban	0.00	3.95	3.95	25.69	31.62	535.52	**120.54**	721.27
1986 Total	195.63	739.06	3824.47	19613.25	5606.23	38445.48	1015.66	69440.79

Table 4.8 changes detected between classes with in the three periods.

4.3 Description of changes in each landcover class

Tree cover of the area (Dense shrub lands & remnant trees and open wood land and shrubs):

The area under tree cover, which includes both trees on the hilly parts of the study area and trees planted around homesteads and which constituted only 13% of the total size of the study area in 1973 showed a decrease over the study period. The area under dense shrubs cover decreased by about 1% (40 ha/year) on both the 1973-1986 and 1986-1995 periods and showed a decrease of 133 ha/year on the next period. On the other side the open woodland and shrub cover of the area increased through out the time. It is believed that the increase is attributable to the afforestation program of the Derg regime. As in many places throughout the country, the community undertook some afforestation during the Derg's rule. Most of the tree species planted at that time were varieties of Juniper and Eucalyptus. On the third period (1995-2002) there is an increase of 50 ha/year with in the 7 years gap. This is assumed to be due to forest management programs held by the local community to plant trees around their homesteads. Other changes with in these periods are mostly from tree cover to cultivated land and some to grass land.

Grassland

This land cover class shows a constant decline in size through out the study period. In 1973 grassland covered 35% (24257ha) of the total size of the study area. This was reduced to 28% (19612ha) by1986 and further diminished to 17% (11459ha) and 16% (10902ha) by the years 1995 and 2002 respectively. From the thematic result of the change detection it is observed that 65% of the grassland on 2002 has been preserved unchanged through out the study period and the rest 35% has been transformed to cultivated land, open wood land and other classes.

Cultivated land

This class is the most dynamically increasing class with out any interruption. As it is shown on the table 4.8 the size of the cultivated land covers about 50% of the total land mass of the study area in 1973 and this further increases to 69% in 2002.

From thematic change detection map of the different years, cultivated land has shown no change in 88% of its total aerial coverage in 2002 and 12% has shown change to different classes out of which 6% is to grass/degraded land, most probably assumed due to repeated cultivation and loss of its nutrient content and capacity to give good/expected yield.

Lakes and wetlands

This class shows different areal coverage on different periods due to the amount of rainfall at that rainy season and amount of sun intensity. The wetlands adjacent to lakes area are sometimes filled with water due to the heavy rainfall until late months of the year and it is difficult to distinguish between the lakes and the wetlands. Overall evaluation of these classes shows an increase in area due to the construction of artificial lakes, Belbela and Wedecha dams to facilitate irrigated cultivation.

Urban\Built up area

On this class the two main towns Debre Zeyit and Dukem and settlements that were identified from the satellite images are evaluated and their size increased from 721 ha to 1177 ha overall with small increase in between.

4.4 Landcover changes and slope

If we take the starting time of this study 1973 and the year 2002, on the starting year; of the 34611 ha of cultivated land 33065 ha was found on slope range betweewn 0-10% . Less than 5% of the cultivated land was found in slope >10% indicating that what was then cultivated was only on those places suitable for agriculture.

On the year 2002, 44463 ha was found on slopes between 0-10, of which 34134 ha was on less than 2% slope. On the slopes greater than 10 %, 3231 ha of cultivated land is found. From this we observe that the settlers used most of the agriculturally suitable flat slope area and are now migrating to the sloppy areas by removing the natural vegetation covers.

Although they are migrating to the less convenient and management demanding area, most of the cultivated lands are with out any kind of erosion controlling mechanisms (field observation). This leads to intensified soil erosion and flooding on the mid and flat lands of the study area eventhough the amount of seasonal rain is not heavy.

In general, it is observed that the area coverage of dense shrub land decreased with time on those slope classes which are relatively steeper and the size of the cultivated land on those slopes increases. In addition the grassland found on the steeper lands has decreased in area with in the periods evaluated. The area covered by the open woodland and shrubs has increased in account to the decrease in dense shrubs.

4.5 Landcover change and population pressure

Landcover changes are caused by a number of natural and human driving forces (Meyer and Turner, 1994) where as natural effects such as climate change are felt only over a long period of time, the effect of human activities are immediate and often radical (Bewkwet, 2002) population growth is the most important of the human factors in Ethiopia (Hurni, 1993).

Changes are observed almost on all types of the landcover classes within the study area when evaluated at different years. This change mostly shows expansion of agricultural land and relative reduction on the other landcover classes. The major reason for the decrease in the aerial extent of the other cover types is the increase in population pressure and the ultimate increase on the demand of the cultivable land that cause much of the open grass land to be transformed in to cropland. According to a report from central statistics of Ethiopia (CSA) the total population of the major towns on the study area, Debre Zeyit and Dukem was about 59,150 in the year 1984 and this number has been doubled (133,433) on the projected amount from the next census which is held on 1996 (Annex4). Thus, population growth is the most important factor causing change in the observed landcover dynamics.

CHAPTER FIVE

LAND DEGRADATION-GULLY EROSION

5.1 Gully mapping

According to Graf (1977), natural drainage system are close to a situation of equilibrium in which erosion, transport and deposition are adapted to the existing geomorphologic and climatic conditions. This steady state may be disturbed by human impacts (e.g. changes in landuse). The steady state in the case of gulling can be represented by topographic threshold values. The threshold value corresponds to those places in the landscape where gulling could occur. Vandaele et al, (1996), Poesen et al, (1998) and Vandekerckhove et al, (2000), among others, report topographic threshold values for incipient gulling in a range of landuse conditions.

Horton (1945) was the first person to state the threshold concept of erosion by overland flow. He said incision only occurs where a threshold of soil resistance to flow shear stress is exceeded. Horton defined the 'length of overland flow' as the distance over which runoff will flow before concentrating in to permanent drainage channels. This topographical characteristic of drainage system can be interpreted as a measure of surface resistance to concentrated flow erosion. Gully initiation occurs above a threshold value of the shear stress indicator within uniform geomorphic and hydrologic conditions but different threshold values are expected where geology, soil, climate and vegetation are different.

In order to test the effect of soil, geology, vegetation and landuse characteristic on topographical threshold levels, the effect of climatic conditions has to be excluded as much as possible by looking at differences within the individual data sets (Poesen et al., 2002). This approach is expected to be more effective when investigating permanent

gullies resulting from longer term rainfall conditions, which can be considered to be homogeneous within one study area.

5.1.1 Topographic Threshold

The topographic threshold concept is based on the assumption that in a landscape with a given climate and landuse, there exists for a given slope gradient of the soil surface and a critical drainage area necessary to produce sufficient runoff which will cause gully erosion. As slope steepens, this critical drainage area decreases and vice versa (Patton and Schumn, 1975).

The topographic threshold concept for gully initiation permits one to predict, for a given landuse, the location in the landscape where gully channels may develop by providing a physical basis for initiation of gullies (Poesen et al., 2002). Vanderkerckhove et al., 2000 found that vegetation type and cover are far more important than climatic factors in explaining differences in topographic thresholds for different areas.

As it is presented on table 4.3 the study area is dominated by a flat slope covering about 60% of the total size. Gullies are seen on all slope classes at different proportions dominating on the slope class ranging between 2 and 10% and then on the flat lands.

5.1.1.1 Pedologic and lihologic controls

Soil type

Soil type and, in particular, the vertical distribution of the erosion resistance of the various soil horizons largely controls the size and more specifically, the depth and cross-sectional morphology of gullies (Poesen et al., 2002). Less permeable soil horizons can induce positive pore water pressure in the overlying soil layers which in turn lowers the erosion

resistance of these soil horizons, particularly when seepage conditions and (return flow) occurs (Moore et al., 1998). This inturn may alter the topographic threshold for gully head initiation (Vandekerckhove et al., 2000)

According Morgan (1995), erodibility varies with different soil characteristics such as soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content. Large particles are resistant to transport because of a greater force required to entrain them, fine particles such as clay are resistant to detachment because of their cohesiveness and silt and fine sands are the least resistant. Sand and silt tend to increase erodibility while clay decreases it. Soils with a high content of minerals are more stable as these contribute to the chemical bonding of the aggregates. On the other hand, wetting of the soil weakens the aggregates because it lowers their cohesiveness, softens the cements and causes swelling as the water is absorbed on the clay particles. However, some clay under moist but unsaturated condition regains strength over time. Rapid wetting can also cause collapse of the aggregates especially if the soils are very dry.

The shear strength of the soil is a measure of its cohesiveness and resistance to shearing forces exerted by gravity, moving fluids and mechanical loads. Increases in the moisture content of a soil decrease its shear strength and bring about changes in its behavior. At low moisture contents the soil behaves as a solid and fractures under stress but with increasing moisture content it becomes plastic and yields by flow with out fracture. When there is excess of water and drainage takes place the soil is more likely to remain bellow the plastic limit and retain higher shear strength. Infiltration capacity, the maximum sustained rate at which soil can absorb water, is influenced by pore size, pore stability and the form of the soil profile. Soils with stable aggregates maintain their pore spaces better while soils with swelling clays or minerals that are unstable in water tend to have low infiltration capacities. The organic and chemical constituents of the soil are important because of their influence on aggregate stability. In addition, soil erodibility decreases linearly with increasing organic content over the range of 0 to 10 per cent and detachment

of soil by raindrop impact decreases exponentially with increasing organic content over the range of 0 to 12 percent.

Vertisols in association with Andisols are present in the Debre Zeyit area. The Andisols are developed in volcanic ash, tuff pumice and other volcanic ejects of various compositions. The rapid weathering of the porous parent material results in the accumulation of amorphous clays with high specific surface (FAO/UNESCO, 1988). These properties are seen on the southern part of the study area. The soil is developed from the pumice deposit which covers the upper part of Bede Gebabe. The vertisols which are characterized by their high clay content, plasticity and happen to develop on an undulating micro relief are observed on the northern part of the study area in association with the Andisols which are the result of quaternary volcanic activities.

Lithology

Lithology controls the initiation, density and size of gully development under cropland. Poesen et al., (2002) described the presence of unconsolidated or poorly sorted materials such as shales, gypsiferous and silt marl sand silt-clay deposits of Tertiary and quaternary age in the Mediterranean strongly controls the occurrence of landscapes heavily dissected by gullies. The presence of hard unweathered bed rock nearby plays a major role in reducing the power of the water and the amount of sediment it carries during its course. In addition to this the type of rock unit at different places has its own impact on the size of gullies.

As it is described on local geology the study area is outcropped by major lithologies which are trachytic lava flows of the Yerer volcano and pyroclastic surge deposits on the northern side and the southern part is dominated by rhyolitic to minor trachytic lavas and pumice deposits that is used as a raw material for Mugher cement factory. The types of gullies observed on the areas covered by these different rock units are also different on their development vertically, laterally and on density.

Soil is highly developed in thickness on the northern area covered by the trachytic unit due to the weathering and the presence of vegetation near by and these made it easy for the formation of deep gullies in addition to other factors. On the other hand the pyroclastic surge deposit which is found at the base of the trachytic layer made it difficult the down cutting of the gullies and it is observed that those gullies which have cumulated runoff has only the power to cut through this layers and expose the down laying paleosol and other surge deposit below it. The pumice deposit which is dominating the southern part of the study area has played a major role in the formation of the gullies. Since the pumice is easily erodable, the water collected from the above lying highland of Bede Gebabe can easily disrupt and carry it to low lying areas further down. It is observed that there is high density of gullies on this area relative to the northern part. Rate of incision is low in this area due to the presence of the trachyitic bed rock. The central part of the study area is covered with the lacustrine deposit and it is almost devoid of gullies.

5.1.2 Landuse Thresholds

In its natural condition, land is covered by forest trees and natural vegetation. Trees leave control the speed of the raindrops and allow them to go down to the land surface slowly.

The effectiveness of a plant cover in reducing erosion by raindrop impact depends upon the height and continuity of the canopy, and ground cover density. The height of the canopy is important because water drops falling from 7m will reduce its terminal velocity in ten percent (Morgan, 1996). On the other hand, raindrops intercepted by the canopy may coalesce on the leaves and form larger drops which are more erosive. However, if ground cover vegetation exists the effect of falling larger water drops formed on the leaves would be minimized and an adequate soil protection could be achieved. A vegetation cover dissipates the energy of running water by imparting roughness to the flow, thereby reducing its velocity. On the contrary, when trees are felled and the root

mats are destroyed, the infiltration rate of the water decreases and there is direct impact of the raindrops on the soil. So the soil is subject to soil erosion by full force of rain.

Vegetation cover generally helps to protect the land against mass movements partly through the cohesive effect of the tree roots. It also contributes to slope stability as a result of evapo-transpiration producing a drier soil environment; higher intensity and longer duration rainfall are required to induce slope failure compared with an unvegetated slope.

5.1.2.1 Natural Controls

Climate

The climatic factors that influence runoff and erosion are precipitation and temperature. Temperature has an effect on runoff by contributing to changes to soil moisture between rains. Precipitation is obviously by far the most important. Raindrop erosion is controlled by the resistance of the soil and the amount, intensity and duration of the rainfall. During a storm the rain is made up of drops of all sizes but low intensity rain is usually made up of small drops and high intensity rainfall has a greater proportion of medium and large drops. The velocity of fall of raindrops depends on the frictional resistance of the air; larger raindrops achieve higher terminal velocities than small ones.

5.1.2.2 Anthropogenic Controls

Deforestation

Gradual or sudden shift in landuse has significant impact on triggering of gulling or increase in gully erosion rate. Removal of vegetation cover due to the expansion of agriculture on the steep lands enhances gulling which in turn promotes ecosystem instability due to both the on-site and off-site effects of soil erosion. Because of rapid population growth, large forests and crop areas are required to satisfy the needs of the population. Traditionally cropland on steep slopes is ploughed several times, which results in the breaking up of soil aggregates and causes soil erosion (Constable and Belshaw, 1989). As it is discussed on the landuse–landcover dynamics section the landcover of the study area is constantly changing from time to time and the original cover is decreasing in size and secondary covers with the influence of human being are alarmingly increasing.

Overgrazing

Mwendera and Mohamed saleem, (1996) has shown that water infiltration rate decreases and sediment production increases as vegetation cover declines under heavy stocking rates. The foot paths used by human and cattle, in time, develop in to rills and then into gullies. Even with limited or control grazing the concentration of animal traffic in watering areas or through gates or lanes often becomes the site of initial wind erosion that may spread to other parts of the field. Gullies are used as trails on some parts of the study area. On these places it is well observed that bank erosion is easily undertaking on climbing spot (Plate 5.1).



Plate 5.1 Gully used for foot path

Development of Infrastructure

Infrastructures such as irrigation canals or roads in catchments can induce formation of gullies and an increase in gully erosion rate due to inappropriate drainage of surface water (Nyssen, 2001). Gully incision is significantly more likely below culverts on steep slopes with longer than average contributing ditch length (Wemple et al., 1996; Nyssen, 2001).

On the road that goes from Debre Zeyit to Bekejo through the town of Dire and from Debre Zeyit to Godino, there are several culverts constructed to collect runoff from the highlands. The down stream part of the gullies as observed on the field has significant difference as compared with the size of the same gully upstream. The road that goes to Bekejo is built on early 80's and as the settlers described those gullies that are found below the culverts were very small before the construction. Concentration of runoff through these culverts caused the downstream part to be incised vertically as well as laterally (Plates 5.2 and5.3).



Plate 5.2 vertical and lateral erosion after culvert construction

In addition to the bank erosion and down ward incision some gullies are affected by head ward erosion. The culvert on the road Debre Zeyit-Dire, (Plate 5.3) concentrate runoff and it leads in the back ward erosion. It damages the culvert and narrows the 8 meter wide road to 5 meters.



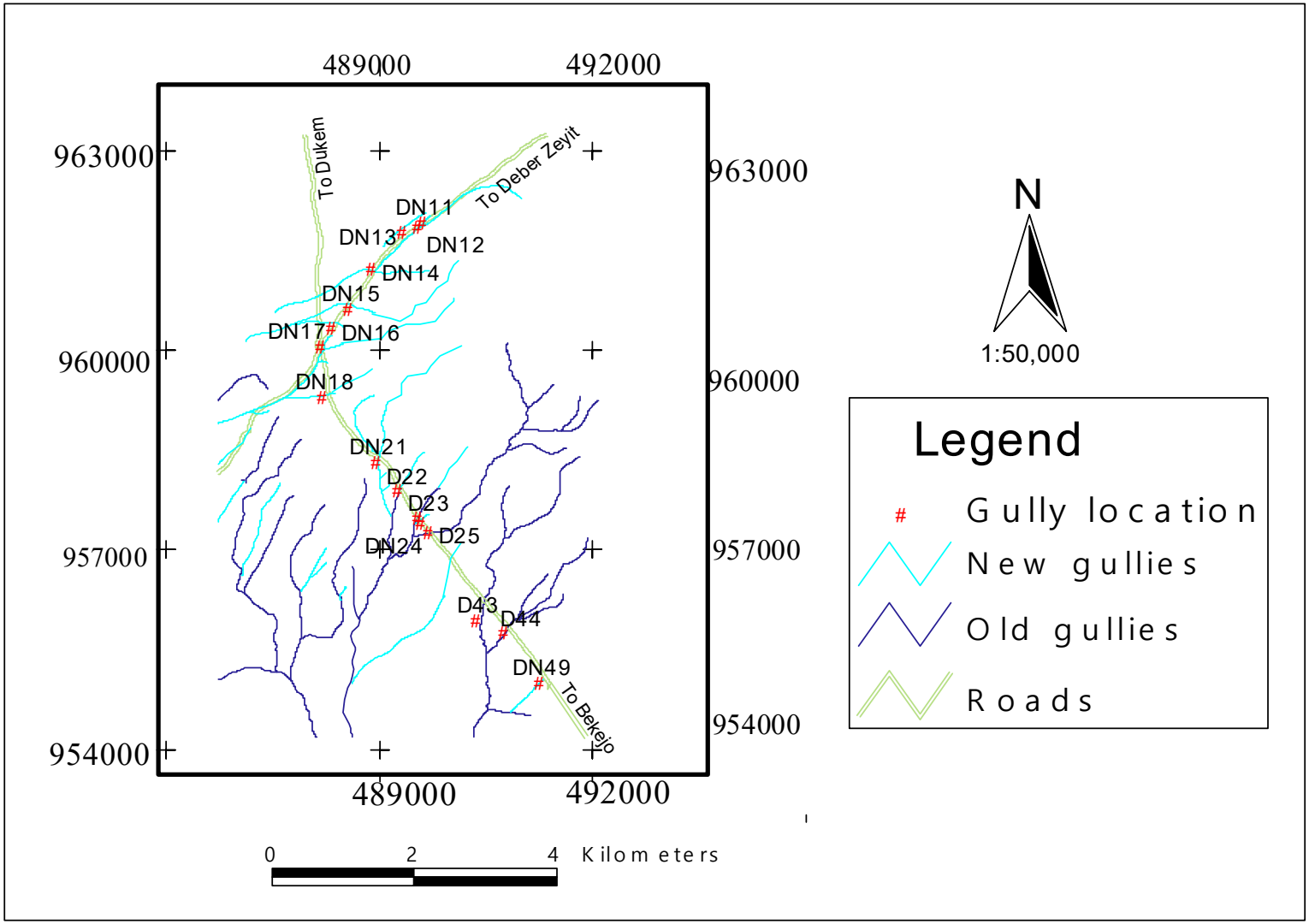
Plate 5.3 headward erosion by the same gully A= 8m. B=5m. C=3m and D=3.5m

To compare the volume of these gullies formed and modified by these culverts, readings are taken on both the upstream and downstream part of the gullies found on the road to Bekejo (Table 5.1).

Gully Name	Gully Location X	Gully Location Y	Altitude	Gully width (m)		Gully depth (m)	
				upstream	downstream	upstream	downstream
DN16	488363	960380	1966	1.1	2	2.4	4.7
DN17	488205	960087	1970	0.9	6	1.6	4.2
DN18	488227	959339	1992	3	5	2.8	11
DN21	488986	958351	1936	5	10	1.2	2.9
D22	489285	957913	1907	5	14.8	3.8	6.2
D23	489568	957511	1897	4.7	8.2	3.2	4.6
DN24	489613	957447	1999	2.5	5.1	1	2.6
D25	499716	957301	1897	1.5	2.3	1.1	6.4
D43*	490635	950560	1892	0	17	0	19.2
D44	490787	955787	1859	7	9	5.2	6.3
DN49	491282	955035	1663	0	4	0	2

*measurement taken 300m downstream

Table 5.1 Upstream and downstream measurement for gullies caused by road building.



Fgure 5.1-map showing location of gullies developed after road building

















Plate 5.4 pictures showing different features of gullies on the study area.1,2&5 piping and iner-rill formation, 3&4 potholes , 6&7 headward erosion by gullies, 8 bankside erosion.

5.2 Gully Development Rate mapping

Methodology

Two test sites, one on the northern part of the study area at the foot of the Yerer Mountain and the other on the southern part near the town of Dire (Figure 5.2), are selected in the field for detail mapping of the gullies. On these sites the location of newly developing and the already existing gullies is identified and plotted on the 1:50,000 topographic map of the area. Detail description of both the new and old gullies is noted down. The detail description includes, measurements of depth and width of each gullies and detail stratigraphic section of representative gullies. The test sites are selected based on there accessibility and for having unique features like gullies caused by road building.

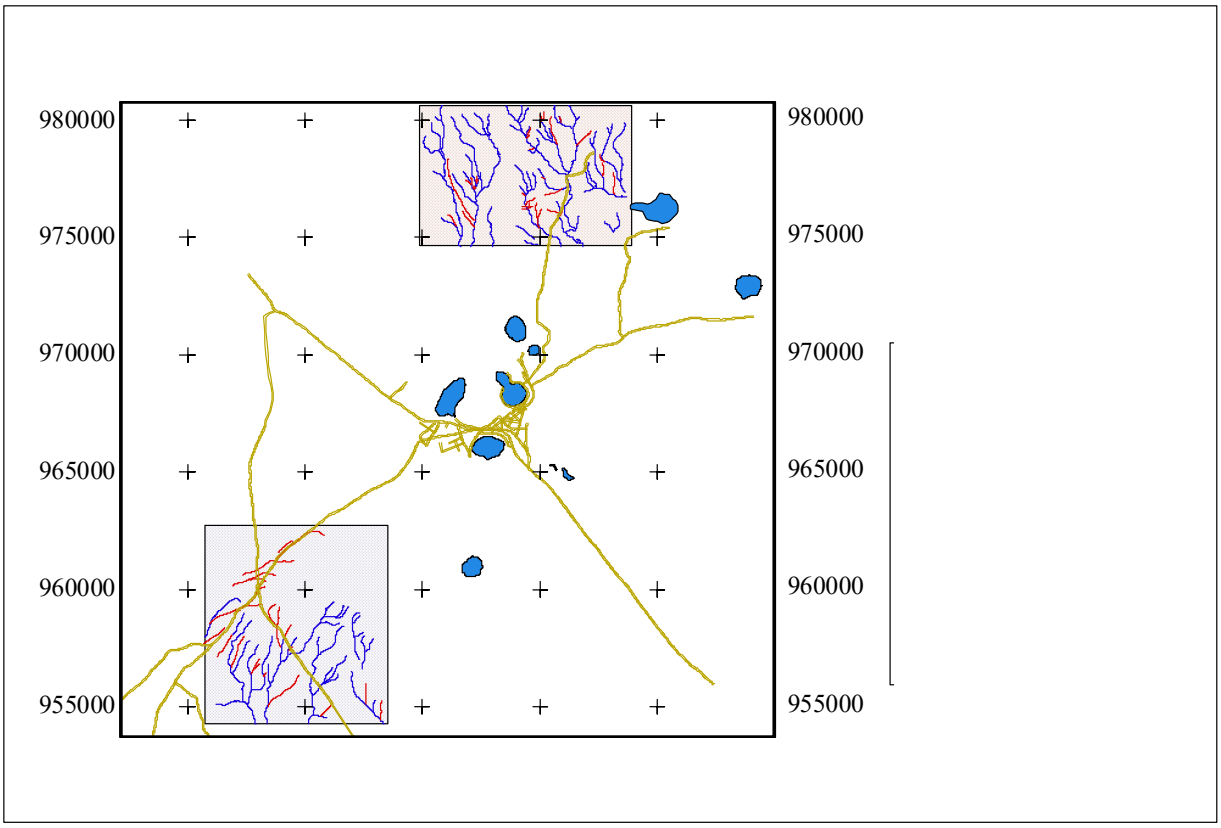


Figure 5.2 - location of the two test sites

Gully rate is determined from satellite image by utilizing different image enhancement techniques. It was proposed to do the rate analysis by taking images from different years, 1973, 1986, 1995 and 2002 and calculate the rate with in these time intervals. But it was difficult to identify the newly developing gullies from those images which have 30m resolution and are without panchromatic band. Every digital image processing technique was employed but the result was discouraging.

The solution to this problem was to use aerial photographs of the year 1971 and the panchromatic band of the 2002 ETM^{+} image. The aerial photographs were scanned and georeferenced with 15m x 15m pixel size using cubic convolution resampling method and the existing gullies were screen digitized. From the 2002 panchromatic image it was less difficult to identify both the already existing and the newly developed gullies. To make sure, the image was enhanced using directional filtering at different angles and the separability of other linear features with the gully is checked. The image was exported to Arcview environment and those gullies that are existing on the 1971 aerial photo are overlaid on the image and those which are new and the extensions of the old gullies are traced. (Figure5.3 and Figure 5.4)

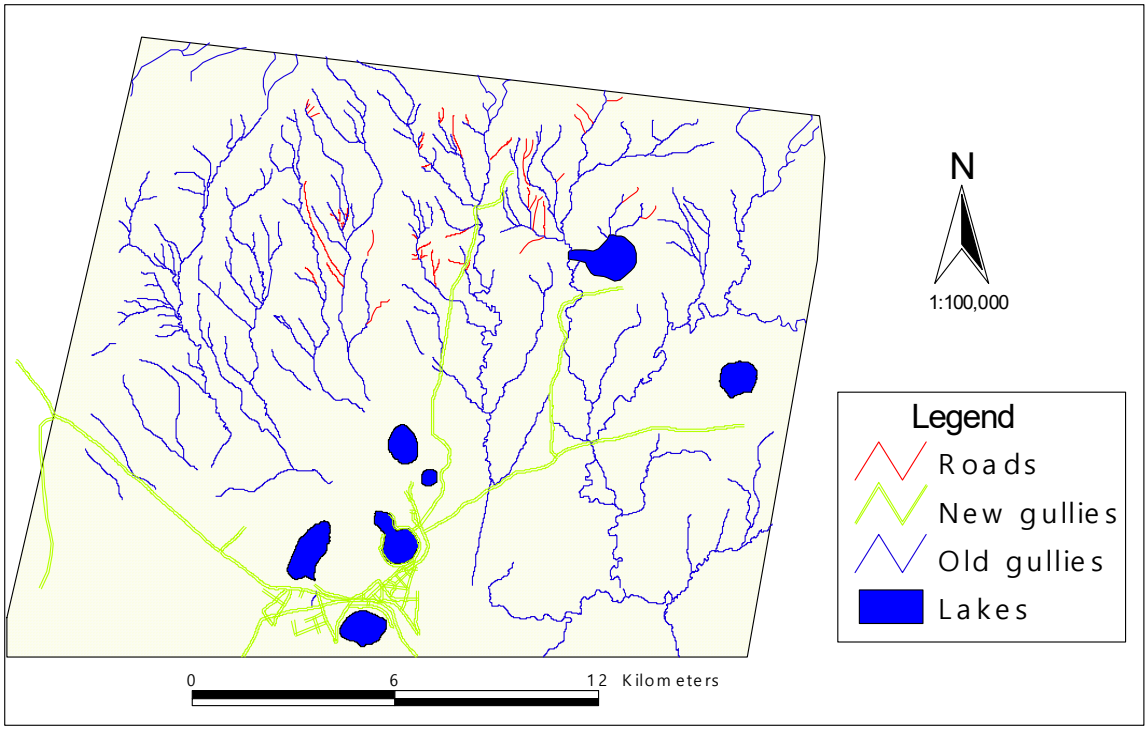


Figure 5.3 map showing new gullies developed on the northern part of the study area

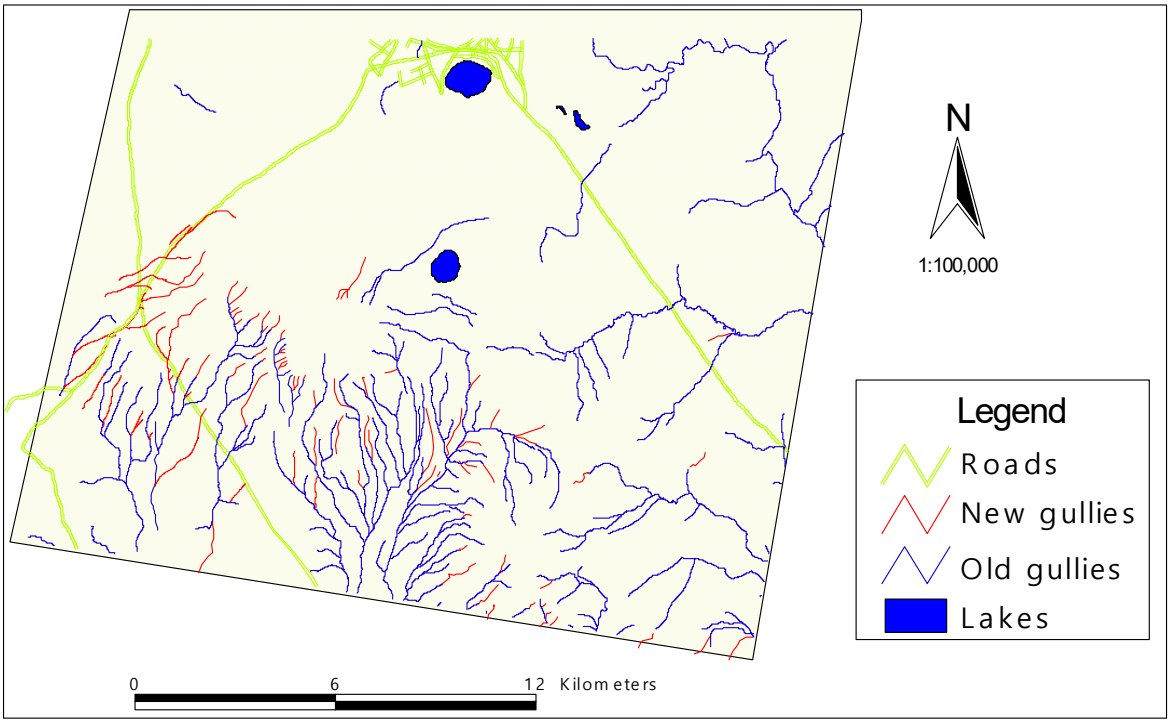


Figure 5.4- map showing new gullies developed on the southern part of the study area

Results

The final out put of this procedure has shown that gully initiation and development rate has been increasing with in the time frame of 31 years. New gullies have developed intensively and the old gullies show head ward erosion of significant and considerable length. The data base produced after digitization of these gullies shows that a total length of 101.9 km gullies have developed with in this time gap.

Out of this 101.9 km, on the northern side of the study area the total length of new gullies developed with in the 60.1 km^2 of aerial coverage is found to be 27.3 km and on the southern part of the study area it is about 74.6 km with in the area of 169.1 km^2. So the rate of gully initiation and development is about 0.88 km/year and 2.41 km/year in the northern and southern part respectively.

5.3 Soil Loss Quantification by Gully Erosion

Gullies do not only grow in length, but also in depth and width. While head cut retreat is the main mechanism of gully development, it is not necessarily the main source of sediment eroding from gullies. Blong et al., 1982 showed that near gully head walls, sidewall processes are much more important contributors of sediment than are the processes of vertical incision. Estimates of linear incision/ sidewall erosion ratios of gullies in Australia suggest that side wall erosion is responsible for more than half the gully volume. Nevertheless gully erosion is usually quantified by measuring head cut erosion, while deepening and widening of the down stream channel are often neglected (Thompson, 1964). In contrast, Leopold et al., 1966 did measure the total sediment production from gullies by represented surveys of channel flows, cross-sections along the gully axis, and head cuts. However, such measurements are labour intensive and time consuming. Some studies quantify gully erosion by measuring the aerial extent of entire gullies on high altitude aerial photographs (Beer and Johanson, 1963; Seginer, 1966), thus taking in to account side wall erosions. Digital Terrain Models (DTMs) allow to quantify

volumetric gully retreat, including widening and deepening, but require very high resolution photographs taken at low altitudes (Sneddon et al., 1988). Such photographs require highly specialized equipment and there will always be a tradeoff between scale and coverage of the photo's.

Seginer, (1966) proposed a mathematical method to estimate the total sediment yield from a gully system. In this method the shape of an idealized gully is modeled as wedge, the tip being at the gully head and the wide end at the junction with a higher order gully. The wedge model implies a non decreasing cross-section down stream and assumes that no sedimentation occurs in the gully system and that a good correlation exists between the cross- section area of a gully at a given point and the distance from this point to the gully head.

The wedge model also assumes that (Figure 5.5(a)) the cross-section of a gully decreases from the gully outlet to the gully head but maintain a constant depth. The gully head is modeled as vertical line, i.e. the cross-sectional area is zero. The total volume of a wedge (V) is given by:

$$V=A_0*L/2$$

Where V=total wedge volume,

A_0 = base plane area,

L= total length

Alternatively the truncated pyramid model (Figure 5.5(b)) assumes that the cross- section of a gully decreases both in width and depth from the gully outlet to the gully head. The gully head is modeled as a cross-section parallel to the cross-section at the outlet. The total truncated pyramid volume:

$$(V)=L/3*(A_0+A_1\sqrt{}(A_0*A_1))$$

Where V= total truncated pyramid volume,

A_0= base plane area,

A_1= upper plane area,

L= total length

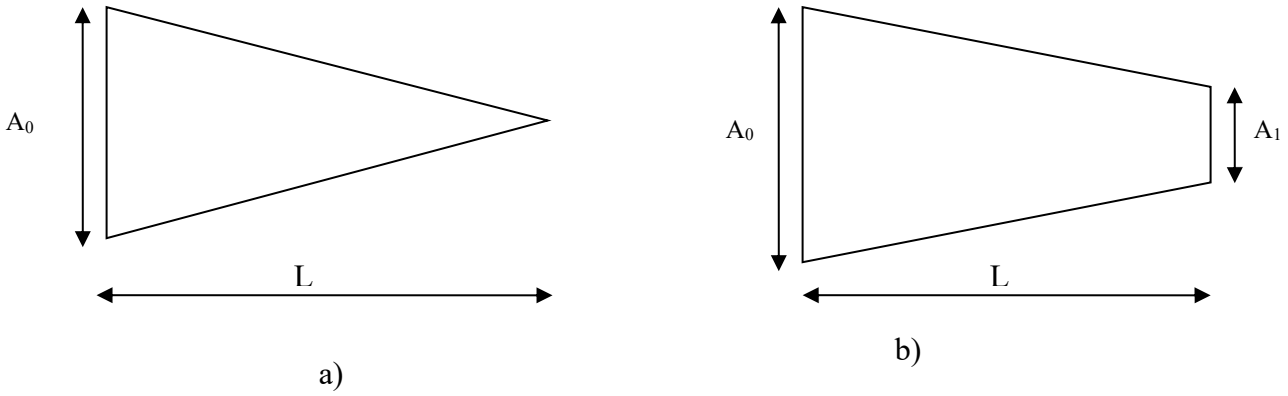


Figure 5.5 Modeling the total volume of a gully (a) as a wedge and (b) as a truncated Pyramid – plan view

The geomorphology of the gullies in the test area both in the northern and southern part of the study area are close to the truncated pyramid model. In order to use either of the Wedge or Truncated model to calculate the total volume loss by bank and head ward erosion test gullies were taken from the northern and southern test areas.

In the northern test area of the study area, a 1.5 km length gully was measured at different locations where there is a variation in depth and/or width (Table 5.3), the total gully volume is calculated as 103,595m^3. The Wedge and truncated Pyramid models approximate the volume of this gully as 150,365m^3 and 100,243m^3 respectively. As we compare these values, although the truncated pyramid model underestimates the value it has approximated the soil loss better than the wedge model.

Location	Latitude	Longitude	Depth,m	Width,m	Length,m	Volume,

						m^3
p1	500527	976166	0.2	0.3		
p2	500593	976129	3	7	80	1680
p15	500772	976098	3.8	15	170	9690
p3	500770	976095	4.2	20	5	420
p4	500821	976071	5	17	60	5100
p5	500930	976033	2.6	12	130	4056
p6	501010	975997	5	18	130	11700
p7	500977	975905	6.45	20	100	12900
p8	501049	975828	4	9	90	3240
p9	501101	975756	4.5	4.6	90	1863
p10	501126	975672	6	6.3	90	3402
p11	501163	975506	6.5	12	180	14040
p12	501161	975333	6.1	12	180	13176
p13	501208	975233	3.6	13	140	6552
p14	501268	975222	5.8	34	80	15776
				Total	1525	103595

Table 5.2 Depth-width measurement of gully G12

In the same way, a 1.49 km length gully was measured from the Dire test area at different locations where variation in depth and width is observed (Table 5.4). The total gully volume is calculated as 9,713.6m^3. The Wedge and Truncated Pyramid models approximate the volume of this gully as 13,386.07 m^3 and 8,922.86 m^3 respectively. The calculated volume of the gully using the Wedge and Truncated pyramid models were compared with the test gully volume and the Truncated pyramid model approximates the volume better than the Wedge model.

Point	Latitude	Longitude	Depth	Width	Length	Volume (m^3)
P1	487583	957968	0.2	0.5		
P2	487474	957788	0.8	0.9	210	151.2
P3	487340	957622	1.7	2.1	220	785.4
P4	487305	957389	1.5	2.2	240	792
P5	487286	957233	1.8	2.5	150	675
P6	487211	957038	2.2	3.2	210	1478.4
P7	487101	956810	2.4	3.5	269	2259.6
P8	487061	956617	3.8	4.7	200	3572
				Total	1499	9713.6

Table 5.3 Depth-width measurement of gully DN 33

As the Truncated pyramid model approximates the amount of soil loss by the test gullies better than the wedge model, this model is used for calculating the amount of soil loss by gulling in the two test areas with certain modification. From the measurements taken the upper plane of most of the gullies has a negligible area as compared to the basal plane area as a result the formula is modified as:

$$V=A_0*L/3$$

Where V=total truncated pyramid volume,

A_0 = base plane area,

L= total length

From the two test areas 83 gullies were mapped and their depth, width and length were measured (Annex 5). A total of 45 gullies are mapped from the northern test area of which 19 are long old gullies and 26 short new gullies. The rest 38 gullies are from the southern test area; here 14 old gullies and 24 new gullies are mapped.

The amount soil lost from these gullies is calculated based on the above discussed models. Since Truncated pyramid model shows the best estimate of the soil loss from the gullies, this model is used in order to calculate the volume of the soil lost from both new and old gullies.

Test area	Old gully volume(m^3)	New gully volume(m^3)	Area (ha)	Rate of soil loss ($m^3ha^{-1}yr^{-1}$)
Godino	1,962,087.89	788,612.7	5404.5	4.71
Dire	7,048,317.04	275,071.7	6603.3	1.34

Table 5.5 The amount of soil lost from Godino and Dire test areas

The rate of the soil loss is calculated only for the new gullies because from the above discussion on part 5.2 i.e. rate of development; they are developed with in the 31 years interval. So we took the areas of the two test sites in the northern and southern part of the study area to calculate the amount of soil lost by the new gullies. As indicated on the summery of the volume of soil lost from the two test areas 4.71 m^3 of soil is lost from one hectare of land with in one year time from the Godino test area. In the same way 1.34 m^3 of soil is lost from the Dire test area every year.

CHAPTER SIX

DISCUSSION AND INTERPRETATION

6.1 Influence of landcover dynamics on gully formation.

Vegetation cover, because of its thinness, is often undervalued in terms of its control over landscape incision and evolution. Its resistance to erosion may be of the same order of magnitude as the underlying bedrock (Howard, 1977).

Over the last 31 years the landuse landcover of the study area is constantly changing. The change of dense shrub land to different landuse classes especially to open wood lands and shrub lands is the major change. The increasing number of population size and tree clearance for seeking additional cultivation land due to the increasing demand for food is one cause.

As indicated in tables 4.4 & 4.7 (slope analysis) 1025.41ha of land was cultivated by 1973 and it increased to 1034.37 ha of land by 2002 on a slope greater than 15 degrees. This agricultural practice aggravated soil erosion and the development of gullies.

Human population in many hilly and mountainous regions of developing countries is growing rapidly. The growth is associated with agricultural expansion and intensification. The apparent ecological vulnerability of hillside and mountain environments has led to a widespread concern that agricultural use will inevitably lead to land degradation. The resulting policy action often seeks to restrict population or agricultural growth. As human pressure, rural settlement and the expansion of urban and agricultural areas on to marginal sites as well as an intensified exploitation of the currently used areas will increase the risk of land degradation.

The challenge to African agriculture is not only to meet the increased food demands of the expanding population, but also the judicious use of soils so that their productivity is sustained in the foreseeable future. Different types of soil erosion and land degradation occur in the southern Ethiopian Rift Valley. Distinct population growth causes an increase of land use intensity. Due to inappropriate cultivation techniques soil erosion and land degradation becomes a worsening problem in agricultural areas.

The use of remote sensing data for mapping of landuse and landcover has become an important tool in landuse and landcover studies. Landuse and landcover mapping procedures often rely heavily on the difference of spectral characteristic of the landscape for separation into meaningful landuse and landcover classes (Brandon R. Bottomley 1998). This tool is providing the means to producing more accurate landuse and landcover maps. The accuracy of the maps was evaluated using error (confusion) matrix.

On this study an overall accuracy of 90.83% were achieved with a Kappa coefficient of 0.88.The overall accuracy is a similar average with the accuracy of each class weighted by the proportion of test samples for that class in the total training or testing sets.

The results of the overall accuracy showed good results and Kappa coefficient showed the Kappa values lies between 0.4 and 0.8 which represents moderate agreement (Congalton, 1996) cited in (Brandon R. Bottomley 1998).

For the detection of changes which have occurred within the various land cover classes, post classification comparison is employed on the 4 different thematic maps of the 1973, 1986, 1995 and 2002 images. The result is evaluated based on the time gaps between the respective analyzed images of the three periods, which are period one: 1973-1986, period two: 1986-1995 and period three: 1995-2002.

First period change (1973-1986)

Here a gap of 13 years is taken due to the availability of the satellite images and by considering the change in relation to the size of population. It is believed that the amount of change with in these years is less significant compared to the change after the high population increase on recent decades.

On this period significant change is observed on the size of the cultivated land and on the grass land. The amount of cultivated land has increased from 50 % to 55% while the grass land decreases from 35 to 28%. No significant change has been observed in the other classes on the basis of percentage evaluation except for the open woodland which has increased by 1%.

Evaluation in hectares shows that there is a small amount of increase in the size of urban and lakes. The change in the size of the lakes occurred due to the construction of the Belbela dam with in this period. Significant changes have been observed in the southern half of the study area.

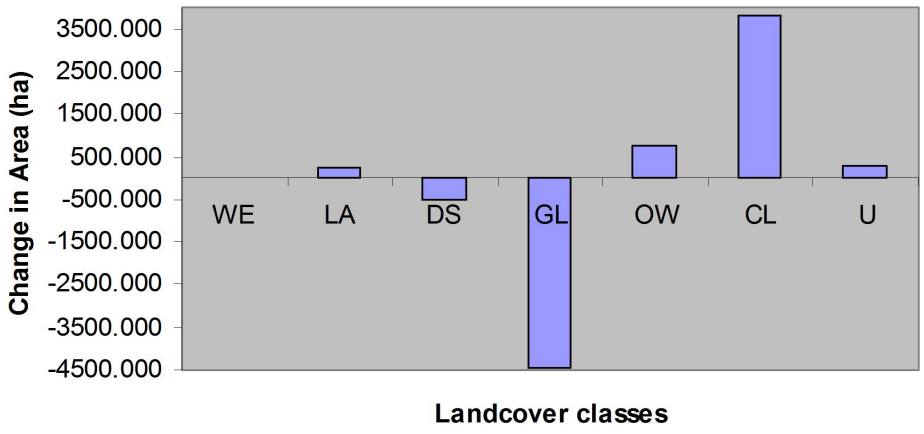


Figure 6.1 Change in area for the landuse classes between the year 1973 and 1986

Second period change (1986-1995)

This period covers 9 years. The evaluated change is almost similar with the previous period except that the change in the size of the cultivated area is accounted for the decrease in the size of both the grassland and shrub. Cultivated area has changed from 62% to 69% and grass land and shrub land have shown a decrease of 12% and 1% respectively.

Although it is not expressed on the percentage there is an increase in the size of the lakes between the two periods.

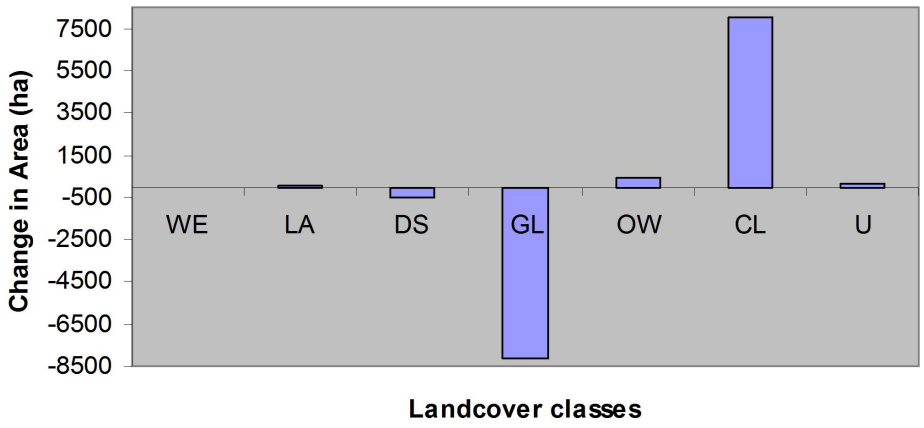


Figure 6.2 Change in area for the landuse classes between the year 1986 and 1995

Third period change (1995-2002)

During this period a time gap of 7 years is evaluated. As it can be observed from the thematic maps and from the table, it is evident that the size of the land which was coverd by grass and shrubs has decreased and cultivated land show a slow but persistant increase. Althogh it is a general trend, the rate of increase is quite small compared to the rate during the other periods.

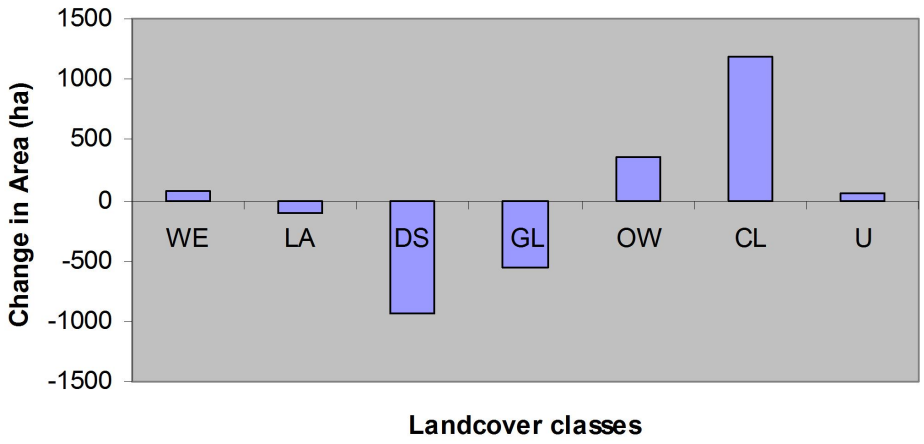


Figure 6.3 Change in area for the landuse classes between the year 1995 and 2002

To identify which landcover class is changed to which, the Post-classification comparison change detection approach was employed. This method involves comparing two independently produced classified land use and land cover maps from images of two different dates (Table 4.8).

Most gullies are observed on cultivated land and some are seen on the grassland and open woodland classes. This can be due to the change from the original natural land cover causing a disruption from its normal state. Since cultivation is seasonal and the land may not be covered with crops during stormy rainfall season, initiation of the gullies might take place. In the recent past and currently, the trees which are planted on the open wood land areas are mostly eucalyptus and their capacity to protect the soil from erosion is minimal as compared to its original land cover.

It is clear that under natural forests and to a lesser extent other natural vegetation, land degradation is relatively less. Landuse change to extensive agriculture using chemical

weed killers and fire “improved” grazing produces lands which are devoid of natural protection. Without the provision of appropriate conservation measures, these contribute almost as much as ill-planned construction to the instability hazards.

Changes in forest cover, though not as dramatic as often stated, are, however, real (Melaku, 1992), as it was found in several analyses using aerial photo interpretation. One study shows an increase in forest cover in an eucalyptus growing area, around the Ankober Pass, in 1986 as compared to 1957 (Wøien, 1995). Though no studies exist for Ethiopia, eucalyptus trees are generally expected to lead to increased soil loss rates due to reduced understorey cover.

Human activity expanded from margin between Vertisol areas and narrow alluvial valley bottoms which could be irrigated (Michels, 1988) to the present-day occupation of steep slopes for agriculture through a number of stages, including forest clearing and removal of remnant trees and shrubs.

Pankhurst (1995) notes that, in 1913, a decree was issued compelling the uprooting of eucalyptus trees; for economic reasons (Jagger and Pender, 2003), it was never enforced. One can expect at least a localized impact on soil erosion rates by the increased area planted with eucalyptus (Conway, 1997). Kebrom and Hedlund (2000), comparing the 1986 situation to that of 1958 for a 110-km^2 area in southern Wollo, find a decrease of forest cover from 8% to 5% and shrub land from 28% to 14%. Near Ambo, ‘‘bush and woodland’’ decreased from 42% to 33% of the area between 1957 and 1994 (Van Muysen et al., 1998). Gete and Hurni (2001) found that the 27% natural forest cover in parts of Gojam had nearly totally disappeared after 1957. For centuries, within deforested areas, both on arable and shrub land, many trees and shrubs were present. Due to grazing, woodcutting and ploughing of vegetated areas in between fields, the vegetation cover by trees and shrubs gradually decreased.

Wøien (1995) finds a decrease of scattered trees around Debre Sina. This deterioration of the woody vegetation cover is illustrated some 200 km more to the north by Kebrom and Hedlund (2000), who found that most of the 'lost' forest had become shrub land, and most of the 'lost' shrub land turned into 'open areas.' It appears thus that deforestation is a very old phenomenon, as old as the basis of already discussed soil accumulations overlying burnt horizons (around 2450 ^{14}C years BP in parts of Wollo, e.g., Hurni, 1985), or as the signal of ruderal species in pollen diagrams in Bale and Arsi from 2000 ^{14}C years BP on (Bonnefille and Hamilton, 1986). What has triggered recent degradation is generally not rapid deforestation, but a progressive initiation and further development of gully change in land cover, including removal of trees and shrubs in between fields, along rivers and in areas with secondary re-growth ('shrub land').

6.2 Influence of Slope on Gully Formation

Slope is the main factor for the initiation and further development of gullies in addition to other factors like geology, landuse and soil type.

It is always believed that gullies develop on hilly areas but in this study most of the gullies are observed to occur on gently undulating slope class which is 2-10 percent. The landcover class which co-occurs with this slope class helping the further development and initiation of gullies is cultivated land. The two test sites on the north and southern part of the study area are dominated by gently undulating slope class as well as some hilly and mountainous classes. And from this area, most of the newly developing gullies are found on gently undulating slope class. From the development rate mapping gullies are also observed to develop on flat slope classes (Figure 6.4).

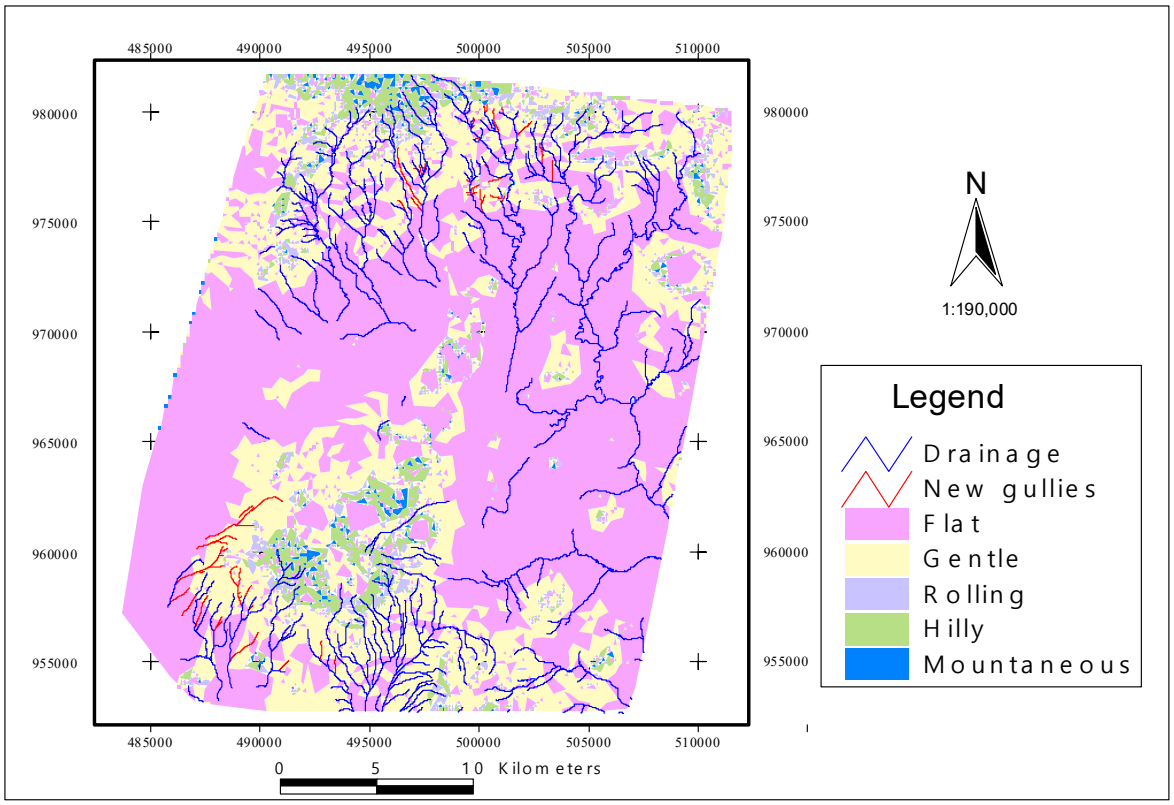


Figure 6.4 Gullies at different slope classes

6.3 Influence of Lithology and soil on Gully Development

The lithological variation with in the study area is summarized as; Trachytic lava flows of the northern part of the study area with some surges, pumice deposits of the southern part and lacustrine deposits of the central flat lands. These three different lithologies show different degree of susceptibility for the formation and development of gullies.

Gulling requires a concentration of flow and deep erodible material. This condition is well satisfied on the trachytic lava flow of the Yerer volcano. This place has very thick soil cover on and near the mountain. The gullies observed on this place have a very significant depth, cutting different profiles of soil horizons that are developed from the trachyte and recent volcanic products. The under lying pyroclastic surge deposit is exposed at places on the pediment found at the foot of the mountain and near Debre Zeyit town. This

exposure is incised and even the underlaying paleosoil and older episode of the pyroclastic surge flow deposits are exposed. In addition to the favorable geology, forming deep soil profiles, the concentration of runoff, made the down cutting likely, although the surge deposit is well intact and difficult to erode.

Pumice deposit is found on the southern part of the study area overlaying the trachytic and rhyolitic deposits. Soils developed out of this kind of rock are easily friable and detachable by runoff, and the gullies found in this area are less penetrative but closely spaced. The underlaying rhyolite and trachitic deposits are found near the surface at a lower depth except on the hilly part of the Bede Gebabe which is made of pumice. Gullies are concentrated on the gently sloping part of this area and are encountered by the under lying bed rocks at shallow depth. The damaging effect of these gullies regarding sediment loss is due to their tightly spaced nature rather than their depth, unlike the gullies found on the northern side of the study area.

In addition to these natural factors there are human induced factors such as infrastructure development that have contributed to the density of the gullies developed in the southern part of the study area.

6.4 Influence of infrastructure development on gully formation

Human settlement with concomitant agricultural exploitation induces changes in land cover, which inturn alter infiltration and runoff conditions (Mengistu, 1999), as well as erosion processes (Olson, 1981; Bunney, 1990). Detailed studies show that settlement decisions were made on a clear ecological basis, especially from the beginning of the pre-Axumite era (700 BC) on. Preferred locations were at the margin between Vertisol areas and narrow alluvial valley bottoms which could be irrigated (Michels, 1988).

In the study area and else where, the increase in population and the expansion of infrastructure caused landcover and landuse changes. Those trails which were used to connect two or more small towns have been developed to all weather roads that are constructed recently. Since these roads didn't take in to consideration the amount of runoff that comes from the upper lying gently sloping areas their culverts are small and inefficient in protecting even the road itself (Plates 5.2&5.3). The runoff that comes from the upper sloppy areas becomes more powerful and energetic on the outlet of the culverts and this made the downstream part to erode rapidly. This is confirmed by the observed pothole structures on the down stream part of gullies (plate 5.4(3&4)). As it is discussed on the previous chapter the density of gullies, initiated and developed after the construction of the road has also increased.

This case is also observed regionally, on the northern part of the country in particular case of the construction of the new all weather road from Mekelle to Abi-Adi, the number of culverts is too low which leads to runoff concentrations and gully incision. In addition to this on the road from Mekelle to Adwa Nyssen et al., (2001) also proved the same results about the culverts causing gully erosion.

From the meteorological data of the study area, the yearly average rainfall recorded at the Debre Zeyit air force station shows a declining five years moving average starting from the early seventies. Since this study concentrates on the years from the 1971 to the recent, we can not say that the development of gullies has been initiated mainly by natural factors like stormy rainfall during certain periods. Rather it can tell us that the major factors in the initiation and development of the gullies are mostly anthropogenic with a positive feed back from internal factors such as soil, slope and lithology.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The principal environmental problem in Ethiopia is land degradation, in the form of soil erosion, gully formation, soil fertility loss and severe soil moisture stress, which is partly the result of loss in soil depth and organic matter. Ethiopia is very much affected by soil erosion processes, among them gullies play a very important role and the amount of soil loss due to gulling has become a very serious problem in recent decayed as it was associated to remarkable depletion of cultivated land. The development of gullies has many negative impacts as it normally involves the loss and (in some cases) the deposition of a great amount of soil. For many countries, the loss of large soil masses by gully erosion often stands for the depletion of a basic natural resource.

To evaluate the causes, extent and rate of land degradation in the Debre Zeyit area integrated remote sensing and GIS technique is employed. Using the 1973, 1986, 1995 and 2002 satellite images and 1971 aerial photographs land use-land cover maps and change detection for three periods (i.e. 1973-1986, 1986-1995 and 1995-2002) have been done. The distribution of old and new gullies were mapped and rate of degradation for the last 31 years have been computed.

The landuse and landcover situation for the period between 1973 and 2002 indicates that the area has experienced changes on different mapped classes. The major Landuse-landcover classes are dense shrub land and remnant trees, open wood land and shrubs, wet land, grassland, cultivated land, lakes and urban.

The change detection analysis showed that dense shrub land and remnant trees declined from 4337.51 ha to 2359.45 ha due to forest clearance while the open woodland and cultivated land increased from 4833.51 to 6345.22 and 34611.18 to 47694.86 ha

respectively. The water body increased from 507.86 ha to 705.46 ha due to the construction of Belbela dam. The grassland declined from 24257.8 ha to 10902.08 ha and wetland increased from 171.92 ha to 256.89 ha.

Due to disruption of the normal state i.e. change from the original landcover, most of the gullies in the study area are observed on the cultivated landcover class and some gullies are seen on the grassland and open woodland classes.

The spatial and temporal environmental deterioration caused by natural and/or anthropogenic impacts are assessed. Physical factors like slope, geology, and soil type with anthropogenic factors such as intensification of agriculture, cultivation on sloppy areas, forest clearance and infrastructure development (i.e. road construction) result in the change of infiltration capacity of soil and increases run-off. The concentration of water by culverts and the increase of run-off cause gully development and hence soil erosion.

New gullies have developed intensively and the old gullies show head ward erosion of significant and considerable length. Over the last 31 years, a total of 101.9km new gullies have developed. 27.3 km length new gullies developed with in the 60.1 km^2 in the northern part of study area and the remaining 74.6 km length gully is from the area of 169.1 km^2. Rate of gully initiation and development is about 0.88 km/year and 2.41 km/year in the northern and southern part respectively.

From the two test areas 83 gullies were mapped and their depth, width and length were measured. A total of 45 gullies are mapped from the northern test area of which 19 are long old gullies and 26 short new gullies. The rest of the 38 gullies are from the southern test area; here 14 old gullies and 24 new gullies have been mapped.

To calculate the total volume of the soil lost from the new and old gullies a truncated pyramid model is used. From the Godino and Dire test areas a total of 2750700 m^3 and 7323389 m^3 of soil is lost respectively. From the newly developed gullies at Godino test

area it is calculated that 4.71 m^3 of soil is lost from one hectare of land with in one year time. In the same way 1.34 m^3 of soil is lost from the Dire test area every year.

6.2 Recommendations

- Gullies thrive only where there is surface runoff that can collect and concentrate in their channels. If there is less or no runoff, then these features cannot grow and may heal. so to minimize the amount of runoff entering the channels either construction of diversion structures to totally avoid the runoff from active areas or controlling the velocity of the run off by increasing the roughness (the frictional resistance of the surface over which it flows) through lining the channel with riprap (cobbles), or with vegetation, or by providing other barriers such as check dams should be done.

- Once sheet erosion starts on previously sustainable land, it develops to advance inter rill and rill erosions. These erosions then develop to gully erosion. Hence once gullies start they are almost impossible to eradicate or manage, leading to the abandonment of the land as badlands. Therefore in order to control the intensity of natural erosion or soil loss by water to certain limit erosion controlling trends has to be followed. To do so, communities in the study area should be aware of the need to diminish erosion processes and an integral soil conservation development program should be implemented.

- Increase in population pressure caused the people to seek for more land to be cultivated and feed their family. These resulted in the migration of the people to the slopes and clear the original landcover and cultivate the land which again caused the degradation of the land through the less resistance for erosion. To minimize these phenomena there should be release off population pressure through family planning, creating off farm employment, implementing other income

generating activities, and also through voluntary and well planned re-settlement programs.

- During infrastructure development such as access road construction or expansion, there should be involvement of other professionals like environmental expert and/or Geologists for proper environmental considerations and in helping visualize the damage it will cause on the land by taking in to consideration the type of soil, lithology and structure of the area.

- For those places where cultivation on slopes >10% is taking place, if it is not possible to convert the landuse, it is better to use strip cropping, physical constructions, planting of deep rooted trees and trees with broad canopy that intercept rainfall have to be planted, in addition to the other conservation practices such as complete stripping or terracing of the soil to a bedrock slope has to be practiced. Because terraces reduce the slope length and sometimes the slope steepness.

- Conservation practices increase sustainable farm productivity levels and the incentives for rural households to construct and maintain effective conservation structures should be well established with clear right of ownership structures.

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Annex1-Mean monthly rainfall (mm) from Debre Zeyit Air Force station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	mm/yr
1958	65.5	52.3	23.8	49.4	7	175.9	273.8	243.2	172.2	16.3	0.8	0	1080.2
1959	18	34	38.4	48.9	42.1	108.3	244.3	215.4	125.4	14.5	0	16	905.3
1960	0.8	5	43.3	16.6	99.5	56.5	167.9	301.9	161.6	0	5.2	0	858.3
1961	0	3.2	111	41.9	28.2	107.2	153.8	227.2	89.9	39.3	16.7	0	818.6
1962	0	1	62	24.7	3.7	0	101.1	237.3	181.8	46.5	0.9	21.6	680.6
1963	0	1.6	0	61.9	103.5	76	181.2	448	103.2	0	2.7	27.5	1005.6
1964	0	0	0	184	42.3	56	434.5	365.3	187.1	22.6	0	11	1302.8
1965	37.8	0	58.5	29.5	0	38.2	408.5	246.5	125.6	76.9	6.7	0	1028.2
1966	0	256.2	27.5	135	25.1	122.5	251.4	409.6	168.5	40	0	0	1436
1967	0	0	100	73.9	164.8	62.1	314.2	259.6	136	16	79.1	0	1205.7
1968	0	190.1	12.6	102	5	60.1	272.3	140.2	203	0	17.8	0	1003.1
1969	11	0	56.7	104	24.9	137.1	125.1	278.6	64.6	7.5	3.2	0	812.7
1970	44.1	31.1	7.5	71.4	45.3	46	250.7	290.1	112	5.9	0	0	904.1
1971	0.7	0	16.5	63	107.6	121.3	215.8	281	123.1	2.9	0.3	14.4	946.6
1972	0	95.2	53.7	136	47.7	102.1	214.4	124.6	66	2.6	0	0	842.3
1973	0	0	0	2.7	28		138.5	251.9	133.7	42.1	0	2	598.9
1974	0	12.5	104	7.6	98.1	114.4	307.3	199		3	0	0	846.1
1975	0		19.5	21.1	54.5	149.7	382.1	223.4	154.4	7	0	0	1011.7
1976	0	0	70.1	106	80.7	102.9	236.9	232.2	42.2	3.8	35.2	0.8	910.8
1977	43.1	1	87.7	90	57.6	101.6	272.8	202.7	82.2	112.7	3.4	0	1054.8
1978	1.4	69	34.5	47.4	28.5	133.7	132.3	191.1	122.3	24.6		0.1	784.9
1979	77.7	0	54.7	13.5	76	110.9	224.9	187.6	83.8	12.6	0	0	841.7
1980	20	10.1	32.3	24.2	69.4	76.1	242.4	215.5	58.1	40.7	0	0	788.8
1981	0	20.5	164	6.1	7.1	35.8	294.6	151.8	162.8	4.2	0	1.2	848.3
1982	20.8	75.4	34.5	47.3	57.7	91	123.9	233.6	46.1	25.5	9.4	0	765.2
1983	0	10.2	62.8	105	209.5	149.4	128.8	344.8	88.6	23.4	0	0	1122.7
1984	0	0	19.3	0	108.7	80.7	220.5	217.3	85	0	0	3.6	735.1
1985	3.5	0	14.5	63.6	111.4	74	307.3	292.7	130	1.1	0	0	998.1
1986							81.8	116.9	130.6	11.3	0	0	340.6
1987	0	61.4	138	90.1	164	65.5	83.3	155.9	80.9	4.6	0	0	843.9
1988	8	15.9	6	44.6	36.8	100.6	145.9	236.8	121.4	16.6	0	0	732.6
1989	1.5	12.2	35.1	47	0.4	59	183.7	171.5	135.2	21.2	0	3.3	670.1
1990	0	123.2	58.2	86.4	36.5	76	224	173.2	102.4	0	0	0	879.9
1994		0	29.2	19.5	19.6	74.5	232.8	187.3	86.6	0	10.2	0	659.7
1995	0	2.4	7.8	33.9	5.5	92.5	188.4	169.6	175.1	0	0	11.9	687.1
1996	16.4	0	103	55.3	105.4	261.5	164.1	275.6	90	0.1	5.9	0	1077.4
1997	27.8	0	26.7	74.8	13.6	121.7	235.8	171.8	71.4	99.9	10.9	0	854.4
1998	32	51.4	13.9	77.2	41.8	77.7	206.3	293.5	97.6	93.3	0	0	984.7
1999	0.5	0	36.6	0	10	176.8	298.7	258.6	48.7	90.9	0	0	920.8
2000	0	0	8.6	50.4	65.4	77.4	244.3	181.4	139.4	40	23.4	3.4	833.7
2001	0	4.6	166	21.8	104	79.5	252.3	142.8	64.3	37.2	0	0	872.1
2002	8.6	0	48.2	34.6	11	102.3	194.3	181	58.4	0	0	21.3	659.7
2003	38.3	55.4	61.6	100	21.1	81.4	277.9	285.1	119.4	6	3.6	35.4	1085.5
2004			68.1	120	2	133.5	172.5	209.1	79.6	22.6			807.3
average	11.6	29.14	49.2	58.9	55.14	96.89	222.9	232.3	111.9	23.53	5.605	4.035	887.425

Annex 2- Mean monthly maximum temperature (°C) from Debre Zeyit Air Force station

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Y.avg.
1958	25.7	24.9	28.5	28.7	30.4	26.5	22.9	23.3	24.8	25.8	25.7	26.2	26.12
1959	27.4	27.8	28.4	29.5	29.4	28.4	23.5	23.2	24.5	26	25.5	25.4	26.58
1960	25.2	27.5	27.4	28.5	27.7	27.6	24	24	24.9	26.3	25.7	25.5	26.19
1961	26.4	26.9	27.2	27	29.3	26.4	22.7	23	24.7	24.9	24.1	25.2	25.65
1962	26	27	27.3	29.4	29.2	27.6	25.1	24.1	24.5	24.8	25.2	26	26.35
1963	25.2	27.5	28	26.5	27.2	27.7	25.2	23.6	25.3	26.6	25.5	25	26.11
1964	25.8	28.1	29.7	27.2	28	26.3	23.3	23.6	23.9	24.7	25.2	24.1	25.83
1965	26	27.1	28	27.7	29.6	29.1	24.8	23.8	25.7	25.4	25	25.8	26.50
1966	27.1	26	27.4	27.1	29.3	27.5	25	24.2	25.1	26.3	25.5	26.7	26.43
1967	25.7	27.3	27.5	27.1	27.5	27.3	22.9	24	24.4	24.8	24.1	24.1	25.56
1968	26	23.8	26.5	26.4	28.2	27	24.7	24.3	25.7	25.9	25.6	25.8	25.83
1969	26.1	25.4	26.4	28.5	28.2	26.4	24.2	23.9	25.8	27.1	26.2	26.1	26.19
1970	25.3	27.7	26.8	28.5	29.4	28.4	24.8	23.1	25	26.4	25.3	25.2	26.33
1971	25.5	27.7	27.9	28.4	27.1	25.8	23.7	23.8	24.8	26.2	24.6	23.7	25.77
1972	26.1	25.5	27	26.1	27.9	27.1	24.2	24.2	25.4	27.3	26.8	27.5	26.26
1973	27.7	29.3	30.3	30.7	28.6		24.7	23.6	24.6	25.5	25.6	24.5	26.83
1974	26.6	26.9	26.5	28.1	27.4	26.1	23.4	23.6		27.1	24.9	25.5	26.01
1975	26.2		28.9	27.7	28.4	25.7	22.9	22.2	23.7	25.1	24.6	25	25.49
1976	25.7	27.3	28		26.8	26.9		23.3	25.2	26.7	24.7	25.5	26.01
1977	24.6	25.9	27.4	27.5	27.2	26.3	23.6	23.8	24.7		24.5	25.1	25.51
1978	25.8	26.3	27.1	28.2	28.4	26.9	22.9	24.2	24.7	25.6		25.2	25.94
1979	24.5	26.8	27.2	28.3	27.9	27	24	24.1	25	26.2	26.2	26.1	26.11
1980	26.2	28.2	29.1	28.6	29.2	27.2	24	23.9	25	25.7	25.9	26	26.58
1981	27.1	27.3	25.9	25.7	28.8	29.1	24.4	23.9	23.2	25.4	25.5	25.6	25.99
1982	25.9	26.1	27.9	26.8	27.6	27.5	24.6	23	25	24.6	25.3	25.3	25.80
1983	25.9	27.1	28.2	26.9	27.6	26.8	25.5	23.5	24.8	25.6	26.4	26	26.19
1984	26.3	27.4	29.1	30.1	28	26	24.1		25	26.6	26.5	25.4	26.77
1985	26.5	26.8	28.5	26.7	27	27.3	23.2	22.9	24.4	25.9	26.2	25.7	25.93
1986							24.2	24.6	25	26.5	26.6	25.9	25.47
1987	25.7	27.1	26.7	26.9	27	26.3	26.3	25.3	26.8	27.5	26.8	26.4	26.57
1988	26.5	28	29.8	28.9	29.4	27.3	23.1	23.7	24.3	25.2	25.6	25.8	26.47
1989	24.5	26.5	28	26.5	28.9	27.7	23.3	22.4	24.6	25.2	26.1	25.2	25.74
1990	26.5	26.3	26.7	26.5	29	27.6	24.6	23.9	24.8	26.2	26.8	26.2	26.26
1994		27.8	28.4	28.9	29.6	26.9	23.8	23.1	24.4	26	25	25.5	26.31
1995	26.4	28.7	28.5	27.8	29.9	29.2	24.4	23.7	25	26.2	26.1	26.4	26.86
1996	26	28.7	28	27.8	27.2	24.2	24	24.2	25.5	26.5	25.7	25.7	26.13
1997	26.1	27.4	29	27.2	29.7	27.7	24.9	25.2	26.9	25.9	25.3	25.9	26.77
1998	26.6	27.8	28.6	30.1	29.6	28.9	24.6	23.6	25.3	25.8	25.7	25.4	26.83
1999	26.9	28.8	27.8	29.7	30	28	23.7	24.3			25.1	25.4	26.97
2000	26.7	28.2	29.7	29.4	29.1	27.5	24.8	23.7	24.9	25.1	25.5	25.8	26.70
2001	26.5	29.2	27.9	29.1	28.4	26.7	24.6	24.1	26.9	27.6	26.9	27.6	27.13
2002	27	29.9	29.3	30.4	31.4	29.1	26.8	25.3	26.4	27.9	27.3	26.2	28.08
2003	26.9	28.9	28.6	27.8	29.3	27.6	23.6	23.9	25	26.6	26.3	24.7	26.60
2004			27.5	26.5	28.6	26.7	24	24.1	25.3	25.5	25.5	25.4	25.91
Monthly avg.	26.12	27.29	27.97	27.99	28.57	27.22	24.2	23.8	25.02	26	25.64	25.61	26.26

Annex3- Mean monthly minimum temperature (°C) from Debre Zeyit Air Force station

Year	Jan.	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	yearly avg.
1958	11.1	12.5	12.5	14.1	12.9	12.9	13.6	12.9	12.8	10.2	8.5	10.3	12.03
1959	11.3	12	12.4	13.6	13.6	12.4	13.5	12.8	12.4	11.5	8.7	8.6	11.90
1960	8.7	10.1	13.2	13.1	13.5	12.2	13	12.9	12.4	10.4	9	10.2	11.56
1961	9.6	11.3	12.7	13.5	12.8	12.5	13.4	12.9	13	11.1	12	8.3	11.93
1962	7.6	9	12	12.5	12.6	12.1	12.9	13.1	13.3	9.8	10.6	10.2	11.31
1963	10	12	13	13.9	13.2	12.2	13.2	13.2	12.2	10.6	10.7	10.2	12.03
1964	11.3	12.8	13.8	13.7	12	11.2	12.9	12.4	12.1	11	9.1	8.4	11.73
1965	10.1	10	11.8	13.9	12.8	12.7	12.6	13	12.2	10.9	10.9	9.4	11.69
1966	1.5	13	12.8	13.9	13.2	12.1	12.4	13.3	11.2	11.3	10.5	7.9	11.09
1967	8	11.8	13.6	13.4	12.7	12.1	12.8	12.5	12.6	10.6	11.1	6.3	11.46
1968	7.3	12.4	10.7	13.4	12.7	12.6	11.5	12.4	12.4	10.8	9.7	9.1	11.25
1969	11.9	11.1	12.6	12.7	12.7	11.3	12.9	13	12.2	10.5	10.5	7.8	11.60
1970	12	11.8	13.7	13.7	13.3	12.6	13.6	13.2	12.5	11	7.2	7	11.80
1971	9.8	9.4	12	12.2	12.4	12.1	12.8	11.6	11.2	9.6	8.6	7.2	10.74
1972	8.3	10.1	10	11.7	11	10.6	11.7	11.2	10.2	9.1	8	8.1	10.00
1973	8.6	9.4	12.1	14.2	12.8		12.7	11.6	11.5	8.8	7.9	5.8	10.49
1974	8.9	10.2	12.7	12.3	12.6	12.1	12.4	11.9		9.7	6.8	7.5	10.65
1975	8		12.7	12.8	12.7	12.1	12.3	12.9	12.1	9.6	8.6	7.6	11.04
1976	8	12	12.5		12.5	11.9		12.7	12	11.6	10.5	9	11.27
1977	9.4	10	12.5	127	12.8	12.2	12.9	12.2	11.1		9.2	8.3	21.60
1978	7.9	11.3	12.8	13.8	12.1	11.7	13.7	13.1	12.1	10.6		9.4	11.68
1979	11.5	10.9	12.2	12.9	13	12.7	12.1	12.7	12.3	10.5	8.1	9.2	11.51
1980	9	10.3	12.9	13	12.2	12.3	13.3	12.3	11.9	10.8	9.8	7.6	11.28
1981	9.8	11.2	13.6	13.3	12.5	11.7	12.9	12.6	12.2	9.5	8.4	6	11.14
1982	9.7	11.3	10.8	11.6	13.1	11.8	12.3	13.1	12.3	10.8	10.8	10.6	11.52
1983	9.8	12.7	13.8	13.6	14.3	12.4	13.3	13.9	12.6	10.7	9.1	8.2	12.03
1984	7.8	7.8	12.1	13.9	13.4	13	12.8		12	9.6	9.5	8.1	10.91
1985	8.5	9.8	12.4	12.8	12.3	11.6	11.8	11.9	11.3	9.2	9.2	8.9	10.81
1986							13	13.4	12.3	10.8	10	10	11.58
1987	9.8	11.3	13.7	13.2	14.6	12.9	13.9	13.7	12.8	12.3	9.9	10.3	12.37
1988	11.6	13.9	14.1	15.3	13.6	13.5	14.6	13.6	13	11.1	7.6	8.3	12.52
1989	9.2	11.4	13.1	13.7	11.9	12.7	13.5	12.4	12.7	10.1	9.7	12	11.87
1990	10	13.8	12.9	13.2	14.6	11.2	13.5	13.6	13.2	10.4	9.8	8.6	12.07
1994		10.8	13.5	14.5	13.9	13.2	13.7	13.3	12.4	10.4	9.8	9.1	12.24
1995	9.2	12.2	13.9	14.7	14	12.6	13.6	13.9	12.1	11.6	9.8	11.5	12.43
1996	11.8	11.4	14.3	13.7	13.7	13.9	13.3	13.7	12.6	10.7	9.8	9	12.33
1997	11.9	10.3	13.9	13.9	13.8	14.1	13.8	13.8	13.3	13.3	12.6	9.8	12.88
1998	12.8	14.2	14.7	15.2	14.5	13.8	14.5	14.3	13.5	12.2	8.4	7.6	12.98
1999	9.8	10.2	13.5	14.3	13.7	13.2	13.4	13.5			8.1	8.5	11.82
2000	9	10.3	12.5	14.3	13.3	12.9	13.6	13.2	13.3	11.5	10.5	9.9	12.03
2001	10.2	11.1	13.7	13.8	14.1	13.3	13.9	14.5	12.6	11.8	9.8	11.1	12.49
2002	11.4	11.8	14.3	14.4	13.7	14.2	14.3	14.1	13.3	12.2	10.8	12.6	13.09
2003	11.2	13	14	15.1	14.1	14.1	14.2	14.4	13.7	11.2	11.4	10	13.03
2004			9.5	11.9	9.6	12	13.1	13	11.9	8.4	7.3	8.2	10.49
monthly	9.59	11.3	12.8	16.23	13.04	12.49	13.1	13.02	12.4	10.7	9.5	8.9	

Annex 4- population size of towns by sex

Year	Town	Male	Female	Total
1984	Debre Zeyit	25,764	29,891	55,655
	Dukem	1,449	2,046	3,495
2005	Debre Zeyit	61,664	63,464	125,128
	Dukem	3,907	4,398	8,305

Annex 5-Gully Locations and their diamensions

Gully Name	Gully Location X	Gully Location y	Altitude (m)	Gully width (m)	Gully depth (m)	length (m)	length/3	Area (m^2)	Volume (m^3)
Godino test area									
G11-2	500831	975,027	1,907	22	5.5	2308.5	769.503	121	93109.9
G12-2	501146	975,330	1,917	15.4	6.3	983.22	327.74	97.02	31797.33
G13	500962	976501	1960	5	3	557.38	185.793	15	2786.9
G14-1	500861	977,020	1,963	7	2.5	2027.8	675.933	17.5	11828.83
GN3	502348	979530	2055	2	2.2	238.33	79.4433	4.4	349.5507
GN4	502308	979462	2048	5	4.1	95.06	31.6867	20.5	649.5767
GN5	502133	979302	2039	1.5	2	672.65	224.217	3	672.65
G16	501368	979698	2021	7	3.5	844.21	281.403	24.5	6894.382
GN6	500699	979637	2041	12	6.7	1268.4	422.803	80.4	33993.39
GN16	500303	979985	2048	15	10	463.17	154.39	150	23158.5
GN17	500255	980166	2060	9	8.2	317.44	105.813	73.8	7809.024
GN18	499804	979687	2041	40	20	1033.7	344.58	800	275664
G19-2	499643	979362	2022	40	20	381.9	127.3	800	101840
GN19	499750	978740	2020	20	10	273.33	91.11	200	18222
G20	499700	978681	2019	8	3	493.63	164.543	24	3949.04
GN20	500347	977574	1982	4	2	170.7	56.9	8	455.2
GN21	500241	976181	1951	4.2	1.4	449.15	149.717	5.88	880.334
GN22	500021	976175	1950	5.7	1.7	683.46	227.82	9.69	2207.576
GN1	499672	976267	1948	50	6.3	181.29	60.43	315	19035.45
GN2	499724	976450	1975	12	4.5	258.16	86.0533	54	4646.88
GN23	500819	976892	1971	8	3.5	791.04	263.68	28	7383.04
G25	502217	977435	1959	3	1	1214.3	404.753	3	1214.26
G26	502370	977546	1964	3	1	1273.3	424.42	3	1273.26
GN24	502573	978463	1993	20	25	2048.3	682.77	500	341385
GN25	502881	977618	1963	3	0.9	612.56	204.187	2.7	551.304
GN26	503349	977728	1964	2	0.7	975.98	325.327	1.4	455.4573
G30-3	503135	978167	1972	18	12	2577.4	859.147	216	185575.7
G31	503756	977864	1962	3.5	1.7	2937.8	979.273	5.95	5826.676
G32	499647	976766	1961	25	4	1619.3	539.76	100	53976
G33	499462	976870	1975	5	4.5	144.49	48.1633	22.5	1083.675
G34	498117	977350	1998	35	20	3064.5	1021.49	700	715045.3
G35	497724	977244	1991	12	8	744.05	248.017	96	23809.6

GN7	497510	977221	1973	5	5	241.3	80.4333	25	2010.833
GN8	497530	977487		6	4.5	205.45	68.4833	27	1849.05
GN9	497443	977224	1983	4	2	146.12	48.7067	8	389.6533
GN10	497447	977193	1983	2	3	188.84	62.9467	6	377.68
G38	497356	977125	1983	30	25	962.29	320.763	750	240572.5
GN11	497292	977360	1988	15	20	346.89	115.63	300	34689
GN12	497211	977364	1991	3	1.5	355.32	118.44	4.5	532.98
GN13	497003	976154	1964	4.5	2	3012.6	1004.18	9	9037.65
G39	497137	976753	1988	6	4.5	1676.4	558.79	27	15087.33
GN14	496913	976093	1967	2.5	1	885.97	295.323	2.5	738.3083
G40	496685	975984	1950	25	13	3866.9	1288.96	325	418913.1
GN15	496483	975800	1963	3.5	2	629.42	209.807	7	1468.647
G41	496445	975662	1958	15	7	1357.3	452.42	105	47504.1
Dire test area									
DN11	489627	961960	1991	6	1.8	236.01	78.67	10.8	849.636
DN12	489627	961960	1991	2.5	2	1722.7	574.227	5	2871.133
DN13	489357	961792	1982	10	2	806.57	268.857	20	5377.133
DN14	488915	961251	1967	5	4.3	1607.6	535.877	21.5	11521.35
DN15	488585	960651	1967	3.5	3.5	1262.6	420.87	12.25	5155.658
DN16	488363	960380		5	4.7	1497.9	499.29	23.5	11733.32
DN17	488205	960087	1970	6	4.2	2973.5	991.18	25.2	24977.74
DN18	488227	959339	1992	3	11	710.71	236.903	33	7817.81
DN19	488672	958806	1977	1	0.9	1184.5	394.847	0.9	355.362
DN21-3	488994	957990	1901	10	8.2	1781	593.667	82	48680.67
D22	489285	957913	1907	14.8	6.2	1709.8	569.923	91.76	52296.17
D22-1	489185	957684	1886	6	12	394.19	131.397	72	9460.56
D23	489568	957511	1897	8.2	4.6	841.89	280.63	37.72	10585.36
DN24	489613	957447	1999	5.1	2.6	251.59	83.8633	13.26	1112.028
D25	489716	957301	1897	2.3	6.4	2136.7	712.23	14.72	10484.03
DN26-1	487128	959054	1914	10	11	2922.9	974.307	110	107173.7
DN27-1	487128	959054	1914	10	8.4	289.21	96.4033	84	8097.88
DN28	486310	958686	1894	5.5	2.6	1217.1	405.697	14.3	5801.462
D29	486130	958500	1885	5	4	3085.5	1028.51	20	20570.27
DN30	486502	958013	1880	3	1.5	1174.4	391.45	4.5	1761.525
DN31	486807	957575	1877	3	1	2285.6	761.867	3	2285.6
DN32	487086	957378	1876	5	2	2963.8	987.94	10	9879.4
DN33	487061	956617		4.7	3.8	1546	515.327	17.86	9203.734
D34	487433	957126	1875	5	2	1657.4	552.463	10	5524.633
D35	487736	956907	1871	10	6	2242.5	747.497	60	44849.8
DN36	488118	956736	1859	2	1	773.41	257.803	2	515.6067
DN37	488178	956673	1856	3	1.5	340.51	113.503	4.5	510.765
D38	488346	956513	1851	11.3	7.3	2993.3	997.763	82.49	82305.5
DN39	488499	956385	1848	2	1.5	236.34	78.78	3	236.34
D40	488610	956355	1850	7	4.7	817.61	272.537	32.9	8966.456
D41	488835	956257	1849	15	12	109029	36343	180	6541740
DN42	489758	956008	1860	3	1.7	1933.4	644.463	5.1	3286.763
D43	490393	955980	1869	17	19.2	2018.3	672.757	326.4	219587.8
D44	490787	955781	1859	9	6.3	702.94	234.313	56.7	13285.57
D45	492560	955294	1878	8	4	2159.4	719.797	32	23033.49

D46	492862	955259	1879	5	1	911.27	303.757	5	1518.783
D47	493131	955167	1868	5.2	4.1	578.14	192.713	21.32	4108.648
DN48	493395	954950	1866	4.5	2.3	862.44	287.48	10.35	2975.418
DN49	491282	955035	1663	4	2	670.83	223.61	8	1788.88
Total Volume									10072987

Annex 6-Volume from newly developed gullies at Godino test area

Gully Name	Gully Location X	Gully Location y	Altitude (m)	Gully width (m)	Gully depth (m)	length (m)	length/3	Area (m^2)	Volume (m^3)
G15-1	502348	979530	2055	2	2.2	238.33	79.44	4.4	349.5507
G15-2	502308	979462	2048	5	4.1	95.06	31.69	20.5	649.5767
G15-3	502133	979302	2039	1.5	2	672.65	224.22	3	672.65
G17	500699	979637	2041	12	6.7	1268.41	422.80	80.4	33993.39
G18	500303	979985	2048	15	10	463.17	154.39	150	23158.5
G18-4	500255	980166	2060	9	8.2	317.44	105.81	73.8	7809.024
G19-1	499804	979687	2041	40	20	1033.74	344.58	800	275664
G19-3	499750	978740	2020	20	10	273.33	91.11	200	18222
G21	500347	977574	1982	4	2	170.7	56.90	8	455.2
G22	500241	976181	1951	4.2	1.4	449.15	149.72	5.88	880.334
G23	500021	976175	1950	5.7	1.7	683.46	227.82	9.69	2207.576
GN1	499672	976267	1948	50	6.3	181.29	60.43	315	19035.45
GN2	499724	976450	1975	12	4.5	258.16	86.05	54	4646.88
G24-1	500819	976892	1971	8	3.5	791.04	263.68	28	7383.04
G27-2	502573	978463	1993	20	25	2048.31	682.77	500	341385
G28	502881	977618	1963	3	0.9	612.56	204.19	2.7	551.304
G29	503349	977728	1964	2	0.7	975.98	325.33	1.4	455.4573
GN7	497510	977221	1973	5	5	241.3	80.43	25	2010.833
GN8	497530	977487		6	4.5	205.45	68.48	27	1849.05
GN9	497443	977224	1983	4	2	146.12	48.71	8	389.6533
GN10	497447	977193	1983	2	3	188.84	62.95	6	377.68
GN11	497292	977360	1988	15	20	346.89	115.63	300	34689
GN12	497211	977364	1991	3	1.5	355.32	118.44	4.5	532.98
GN13	497003	976154	1964	4.5	2	3012.55	1004.18	9	9037.65
GN14	496913	976093	1967	2.5	1	885.97	295.32	2.5	738.3083
GN15	496483	975800	1963	3.5	2	629.42	209.81	7	1468.647
Total volume									788612.7

Annex 7-Volume from newly developed gullies at Dire test area

Gully Name	Gully Location X	Gully Location y	Altitude (m)	Gully width (m)	Gully depth (m)	Length (m)	length/3	Area (m^2)	Volume (m^3)
DN11	489627	961960	1991	6	1.8	236.01	78.67	10.8	849.636
DN12	489627	961960	1991	2.5	2	1722.68	574.2267	5	2871.133
DN13	489357	961792	1982	10	2	806.57	268.8567	20	5377.133
DN14	488915	961251	1967	5	4.3	1607.63	535.8767	21.5	11521.35
DN15	488585	960651	1967	3.5	3.5	1262.61	420.87	12.25	5155.658
DN16	488363	960380		5	4.7	1497.87	499.29	23.5	11733.32
DN17	488205	960087	1970	6	4.2	2973.54	991.18	25.2	24977.74
DN18	488227	959339	1992	3	11	710.71	236.9033	33	7817.81
DN19	488672	958806	1977	1	0.9	1184.54	394.8467	0.9	355.362
DN21-3	488994	957990	1901	10	8.2	1781	593.6667	82	48680.67
DN24	489613	957447	1999	5.1	2.6	251.59	83.86333	13.26	1112.028
DN26-1	487128	959054	1914	10	11	2922.92	974.3067	110	107173.7
DN27-1	487128	959054	1914	10	8.4	289.21	96.40333	84	8097.88
DN28	486310	958686	1894	5.5	2.6	1217.09	405.6967	14.3	5801.462
DN30	486502	958013	1880	3	1.5	1174.35	391.45	4.5	1761.525
DN31	486807	957575	1877	3	1	2285.6	761.8667	3	2285.6
DN32	487086	957378	1876	5	2	2963.82	987.94	10	9879.4
DN33	487275	957245		5	4	1545.98	515.3267	20	10306.53
DN36	488118	956736	1859	2	1	773.41	257.8033	2	515.6067
DN37	488178	956673	1856	3	1.5	340.51	113.5033	4.5	510.765
DN39	488499	956385	1848	2	1.5	236.34	78.78	3	236.34
DN42	489758	956008	1860	3	1.7	1933.39	644.4633	5.1	3286.763
DN48	493395	954950	1866	4.5	2.3	862.44	287.48	10.35	2975.418
DN49	491282	955035	1663	4	2	670.83	223.61	8	1788.88
								Total volume	275071.7

DECLARATION

I the undersigned declare that this Thesis is my original work and has not been presented for any degree in any University and all the sources of materials used for the Thesis have been duly acknowledged.

Name Hanna Endale

Signature_____