ADDIS ABABA UNIVERSITY
SCHOOL OF GRAUATE STUDIES
MASTER'S THESIS

GIS AND REMOTE SENSING IN LAND USE AND LAND COVER CHANGE DETECTION AND LAND DEGERADATION: IN AREA BETWEEN HARAR AND DIRE DAWA, EASTERN ETHIOPIA.

By DEREGE TSEGAYE

July 2006,

Addis Ababa University

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In Partial Fulfillment of the Requirements for the Degree of

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By

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List of Acronyms and Abbreviations

AU	Alemaya University
CSA	Central Statistics Authority
DEM	Digital Elevation Model
ETo	Evapo-transpiration
FAO	Food and Agricultural Organization
GCPS	Ground control points.
GIS	Geographical Information system.
GPS	Global positioning system.
Ha	hectare
K.M	kilo meter
LUCC	Land use and Land cover change.
m	meter
M.a.s.l	meter above see level
PCA	principal component Analyses
RGB	Red, Green, Blue
TM	Thematic Mapper
TRPA	Tahoe Regional planning Agency
UN	United Nation
USDA	United State Development Agency
RH	Relative Humidity

ABSTRACTS

The study evaluated changes in landuse and landcover that occurred from 1985-2003 in the area between Harer and Dire Dawa, eastern Ethiopia high land. The majority of the study area falls in Alamaya woreda. The total study area covers about 650km^2, so it can be representative of a large part of Eastern Ethiopia highland, in terms of topography, climate, vegetation and socioeconomic conditions.

The objectives of the study were to access the pattern and driving forces of landuse and land cover changes and to analyze implication of the change on land and lake degradation. To this end, remotely sensed data i.e. Landsat satellite images of 1985 and 2003 were used to produce ten classes of landuse using Geographical Information System (GIS) with field verification.

The results show that during the last 20 years, grassland and shrubs decreased by 716.7 ha (42.4%) and 391.2 ha (20.7%) respectively, mainly due to their conversion to agriculture lands. Marsh area is the most converted class, it was expanded by over 705.9% of it's size in 1985, which is resulted from drying up of lakes. Temporal croplands decreased by 7081.6 ha (25.4%) while perennial cropland increased by 3050.8 ha (26.4%) woodlands and residential area also increased in 2003.

Land and lake degradations are observed as major problems in the area. Land degradation is increased by 3089.4 ha (20.5%) where as, lake and other water bodies are decreased by 524.1 ha (59.1%). These land use changes in general have got paramount implications upon the environment and local people. Especially, land degradation which is intensifying itself in the area requires immediate attention in particular.

Slope analyses have been also carried out based on selected and relevant land uses, such as, bareland, temporal crop, shrubs and grasslands. So as the result illustrates, the highest changes for barelands are seen in the slope range between 5.5- 9.6, in temporal croplands 9.7 – 19.5 and in shrubs and grasslands 0- 1.9.

Population growth, topography of the area, unwise use of land and other socio-economic activities are major driving forces for the observed changes. Hence different landuse practices, environmental rehabilitation programs and family planning education are some of the appropriate interventions.

CHAPTER ONE

1 Introduction

1.1 Background of the study

Landuse and landcover change is taken as a serious problem in changing the environment, which in turn, could lead to global climatic change (Dale, 1997; Imbrnaon, 1999; Li, 1996; Meyer and Turner, 1991). This change could be the result of intricate interactions of socio economic and biophysical situation like economic, technological advancement, demography, scenic and etc (Reid *et al.*, 2000).

The term landuse denotes the human employment of the land. It includes settlement, cultivation, pasture, range land, recreation and so on. Whereas, land cover primarily denotes the physical state of the land (William B.Meyer, 1991).

The motor of land use/cover changes are countless. Some act slowly and some others trigger the event quickly and visibly .The major category of driving forces are political, economic, demographic and environmental (Reid *et al.*, 2000).

The extent and rate of changes in landcover and some landuses are known with some certainty (Mayer and Turner et al., 1991). According to Turner et al. (1994), of the total land surface, about 40% has already in the way of conversion into other uses. It is only about 25% where the land use and land cover remains nearly unchanged and these areas are mostly peripheral in location or are fairly inaccessible.

In the case of Ethiopia, studies on landuse and landcover change are a few. More over those limited studies are focused on the northern Ethiopian highlands. According to those studies, in Ethiopia highlands, agriculture is being extended to the traditionally unexploited part of the environment. This expansion holds true in the more difficult terrain such as to the steeper slopes and swampy plains (Gete zeleke and Hurni, 1993).

Generally, landuse and landcover changes can impact the socio-economic status of the rural population (Lambin, 2000). Consequently, agricultural productivity, which determines rural income levels and wealth, can be affected by the landuse and landcover change.

1.2 Statement of the problem

Landuse and landcover are dynamic in nature. However, various processes influence the speed of the change, the distribution and the type of landcover and landuse .Increasing the number of population in an area is one of the factors that rapidly change both the distribution and type of landuse and landcover (Solomon,1994).

As discussed above, there are a few studies that are conducted on landuse and landcover change in different parts of the country. For instance, Solomon (1994) reported cover changes of land in Metu area, south western Ethiopia. Similarly, Giest (2002) and few others have reported a significant study of landuse landcover changes in north highlands of Ethiopia. Lakew et al., 2000, stated that during 1958 and 1986, in Kalu district, southern Wollo, in the north eastern part of the country, shrub land and grazing land expanded at the expense of forest land. Furthermore (Woldeamelake, 2002) has reported the expansion of cultivated land and grazing land at the expense of forest land in the period since 1850 in Chomoga watershed, Blue Nile Basin.

However, most of the studies on land use/land cover change detection have been concentrated in northern highland of Ethiopia, and relatively less attention is paid in eastern highlands of Ethiopia. Therefore this study mainly aims to integrate GIS and Remote sensing to detect land use and land cover change, and it's driving forces and consequences in terms of land degradation, in the area between Harer and Dire Dawa, Eastern Ethiopia highland. An attempt has also been made to analyze the over all impact of the change against the local agricultural productivity and livestock.

Thus, this study attempts to contribute empirical analyses of the pattern, rate of change, quantity and to map of these changes by using GIS and remote sensing techniques. And there by analyzing the impact of the change on the land, agriculture and livestock and to forward suggestion for sustainable use in the future.

1.3 Objective of the study

1.3.1 General objective

- To Asses the rate, pattern, cause and environmental implication (impact) of land-use and landcover change in the area between Harer –Dire dawa, using GIS and remote sensing techniques.

1.3.2 Specific objectives

- To map and quantify land use/ land cover change and its rate over 20 years (1985-2005).
- To identify driving forces of landuse and landcover change in the study area.
- To analyze the impact of landuse and landcover change in terms of land degradation and to study the impact on agriculture and livestock.
- To propose options for a sustainable use of land in the study area.

1.4 Materials and methods of study

1.4.1 Materials

Multi-date satellite images were prerequisite for the present study. Thus, Landsat TM and ETM+ Digital images, having 30m resolution, acquired in 1985 and 2003 were analyzed. Both images were spatially merged with high resolution panchromatic image and hence their resolution could be improved to 15m resolution, so that more detailed information could be obtained from the images.

Topographic maps of scale 1:50,000, Meteorological data, population data, socio economic data and field survey data as well as field photographs were used. GPS instrument, which is called Garmin, has been used during field survey to ensure the positional accuracy of the spatial data and land use/land cover features.

In addition, GIS and remote sensing software which includes Arc GIS 9, Arc view 3.2, ENVI 3.5, ERDAS 8.6, and MICRODEM were used for enhancement and analysis of land-use and landcover data.

1.4.2 Methods

1.4.2.1 Methods of data collection and preparation

A. Field method

- Ground truthing using GPS and base map.
- Event mapping like barelands, degraded areas etc. was done using GPS and satellite images.
- Communication and interviews with the local elders on land use and landcovers conditions at present and past.

B. Laboratory methods

- Delineation of the study area, deriving drainage networks, contours, roads and settlements from topographic map of the area.

- Developing Digital elevation model (DEM) of the study area from a topographic map 1:50,000 scale and contour interval of 30m.The topographic map was scanned and geo-referenced before contour lines have been digitized at 30 meter interval on the screen. Then DEM was derived from the obtained contours and it is used to over impose the classified land use and land cover change and to derive DTM like slope and slope aspect.

- Landcovers removal analysis with respect to slope and its consequences.

- Landuse interpretations of lake area using aerial photographs.

- Image processing and analysis such as radiometric and geometric corrections, enhancements, principal component analyses (PCA), transformations, interpretation, classification, and etc. using remote sensing softwares.

- Processing field data by integrating with images and other layers in the laboratory.

1.4.2.2 Analysis method

Time series landuse and land cover data obtained from image analysis, other data prepared in GIS database and field survey data are integrated in GIS data structure. Moreover, slope analyses in terms of land use and land cover is done.

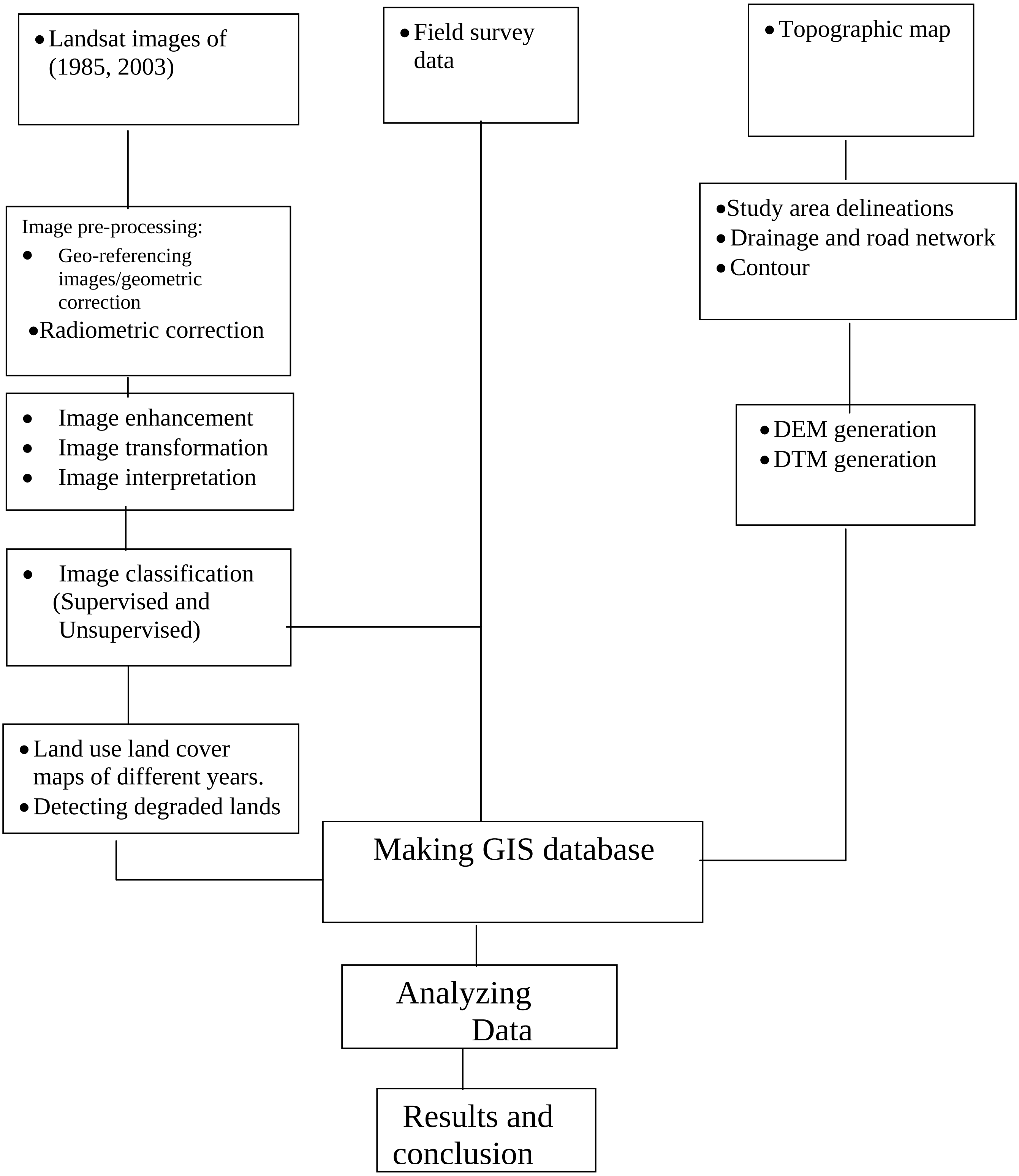

Figure-1.1: proposed study approach

1.5 Significance of the study

The paternal study of landuse and landcover change in the area will be important indicator and guideline for sustainable resource utilization and management, which provides a basis for conservation and planning. Moreover such studies are important to identify the constraints and potentials for sustainable development of land resources like agriculture and livestock .In addition the result will help as an input for others who will make research in the area.

1.6 Limitation of the study

The LUCC in twenty years was intended to be done in three phases, and images of 1985, 1995 and 2003 were required. However, after all attempts, it was possible to get only images of 1985 and 2003. All the efforts that were exerted to get images of 1995 was not successful. So I am forced to make the study in two phases, 1985 and 2003.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1. The Link between LandUse and LandCover Change (LUCC)

One confusing issue that has not been effectively resolved in existing classification schemes is the distinction between "landuse" and "landcover." Most existing schemes group these two geographic variables together since they are closely related. There are, however, key differences that create confusion when they are blended together in a single classification scheme and map. "Landcover" refers to the vegetative or non-vegetative characteristics of a portion of the Earth’s surface. "Landuse" describes some human activity on the surface. The concept of landcover is best understood when applied to natural surfaces where no activity has occurred (Grubler, 1996).

The type of **landcover** present is determined directly by observation. This observation may use satellite imagery or aerial photography for certain levels of classification detail and positional accuracy (Meyer, 1991).
Landuse types may also be determined through observation by deducing human activity or disturbance based on the appearance of the landscape. As in the case of landcover, landuse classes may also be determined, in many cases from satellite imagery or aerial photographs (Grubler, 1996).

It has been noted that as the scale of mapping increases (more detailed mapping), applications using a map become more dependent on landuse information. While the difference between landuse and landcover is not always obvious in specific instances, a fundamental distinction does exist. For this reason, Geographers and environmentalists have decided to create separate (but logically related) classification schemes distinguishing land use and landcover (Dale, 1997).

In some cases, there is also confusion between landuse, landcover, and other types of geographic information. GIS views landuse and landcover as "layers" among a series of other layers that can be displayed or analyzed together. Soils, topography, political and administrative boundaries, and other layers can be accessed and used together with landuse and landcover to answer questions and address specific problems (Grubler, 1996).

2.2 History of Lucc study over the last century

Beginning with the eighteenth and nineteenth centuries, a different approach for determining changes in landuse is possible. Data can be obtained directly from land statistics compiled at administrative districts of varying scales. Croplands are relatively well documented in census records world wide (Richards, 1990).

Areas of pasture or grazing land are more problematic, but they can be estimated from records of livestock and stocking densities. Based on Historical data and assumptions, approximately 28% of the forest area in Latin America was lost between 1850 and1985 (Houghton et al.1991; Figure 2.1). The area in crop lands, pastures, and fallows had grown from 357 X106 ha to 918 x 106 ha over the 135 year period.

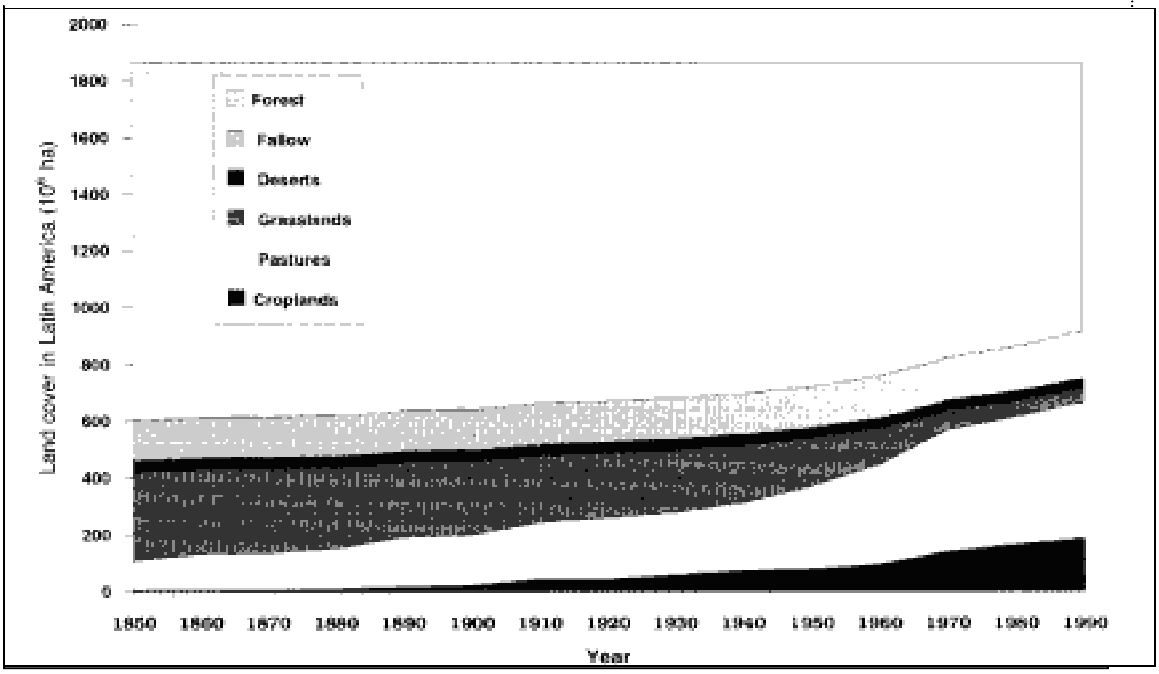

Figure 2.1 Change in land use /land cover in Latin America between 1850 and 1990 (from Houghton et al., 1991).

A similar study in south and south East Asia showed a 34-38% reduction in forest area over the last 140 years (Houghton and Hackler 1994, Richards and Flint 1994). Lands altered for human use in that area expanded by approximately 176x106 ha. The lose of forests and the expansion of agriculture area occurred in a similar pattern in tropical Africa over the last century.

For most of the tropics, rates have been increasing, with the last few decades showing the most dramatic increase (Figure 2.2). Before 1960 crop lands were expanding more rapidly in regions out side the tropics. In North America, Europe, the former Soviet Union, and China, the largest changes in landuse occurred earlier (Houghton and Skole 1990, Williams 1990).

The annual rate of increases in these regions seems never to have been as high as currents in the tropics (Figure 2.2).The area of crop land world wide more than doubled in this 140 years period. Half of the world's crop lands were added in the last 90 years. This rate resembles the History of population growth. In addition to the increased areas covered by cropland, pastures, and grazing land, there are changes in landuse that do not involve reallocation of area (Skole, 1995).

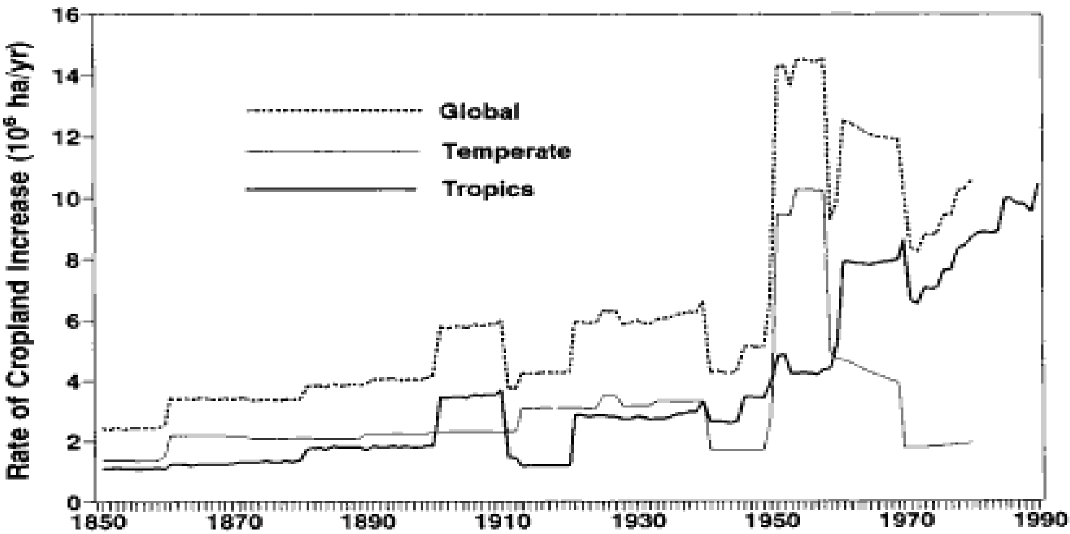

Figure 2.2 Annual rates of crop land expansion over the last 130-140 years .For the globe (dotted line),temperate regions (lighter solid line) and tropical region heavier line (from Brown,1991).

In the last two decades, a new approach for determining changes in landuse has appeared. With the launch of landsat in 1972, direct measurement of areas of different types of land cover and changes of these covers has become possible (Richards, 1999).
In Africa and Latin America most of the land used in Agriculture was derived from grasslands or shrub lands, where as in tropical Asia most was derived from forests and woodlands (Anderson, 1998).

2.3. The relationship between LUCC and population

The Earth's population doubled between 1960 and 1999, increasing from three billion to six billion people. During that period, human induced changes in the global environment accelerated in unprecedented fashion. Given continued population growth and environmental degradation, it has become paramount that we deepen our understanding of the role played by human population dynamics in environmental change (Bilsborrow, 1992).

Population Size:
Population size is inherently linked to the environment as a result of individual resource needs as well as individual contributions to pollution. However, no simple relationship exists between population size and environmental change (Ehrlich, 1990). Large human numbers in some instances have a direct impact on the environment. More often, however, the environmental implications of population size are ultimately determined by complex interactions among many forces, including technology, political and institutional contexts, and cultural factors (Blaikie, 1997).

However, as global population continues to grow, limits on such global resources as land and water have come into sharper focus. For example, only in the latter half of the twentieth century has the unavailability of land become a potentially limiting factor in global food production. Assuming constant rates of production, per capital and requirements for food production now fall within the range of Estimate available cultivable land. Likewise, continued population Growth occurs in the context of an accelerating human thirst for Water: Global water consumption raised six fold between 1900 and1995, more than double the rate of population growth (Blaikie, 1997).

Population Distribution:

"Population distribution" refers to the dispersal and density of population. During the past 40 years, two trends have powerfully influenced the distribution of humans around the globe. First, continued high fertility rates in many developing regions, coupled with low fertility in more-developed regions, have resulted in ever-increasing shares of the global population residing in less-developed countries (Ehrlich, 1990).

According to UN estimates, 80 percent of the world population in1999 lived in developing nations. Second, the Earth's population is increasingly concentrated in urban areas. As recently as 1960, only one-third of the world's population lived in cities. By 1999, the percentage had increased to nearly half (47 percent). This trend is expected to continue well into the twenty-first century. The distribution of people around the globe has its own implications in landuse and landcover change (FAO, 1997).

Population Composition:

"Population composition" refers to the characteristics of a particular group of people. Age and socioeconomic composition, for instance, have environmental implications.

As for age group, Young people are more likely than their older counterparts to migrate, primarily as they leave the parental home in search of new opportunities. Given the relatively large younger generation, we might anticipate increasing levels of migration and urbanization and, therefore, intensified urban environmental concerns (Allen, 1985).

Income is an especially important demographic characteristic relevant to environmental conditions. Across nations, the relationship between economic development and environmental pressure resembles an inverted U-shaped curve; nations with economies in the middle-development range are most likely to exert powerful Pressures on the natural environment, mostly in the form of industrial emissions. By contrast, the least-developed nations—because of low levels of industrial activity—are likely to exert relatively lower levels of environmental pressure. In addition, at highly advanced development stages, environmental pressures should subside due to improved efficiencies (Blaikie, 1997).

Environmental pressures can be greatest at the lowest and highest income levels. Population growth and poverty often interact to produce unsustainable levels of resource use. Furthermore, higher levels of income tend to correlate with increased levels of production and consumption (Bilshorrow, 1992).

Technology:

Technological factors have always influenced the relationship between population dynamics and environmental change. The agricultural revolution of the seventeenth and eighteenth centuries, for instance, enabled demographic shifts that otherwise could not have occurred because it permitted food production sufficient to feed the world's growing population (Boserup, 2001).

The technological changes that have most affected environmental conditions relate to energy use. In particular, the consumption of oil, natural gas, and coal increased dramatically during the twentieth Century. Until about 1960, developed nations were responsible for most of this consumption. Since then, however, the newly developing nations have experienced increasing levels of industrialization, resulting in greater reliance upon resource-intensive and highly polluting production processes. Obviously, improved energy efficiencies could greatly diminish the environmental impacts from energy consumption in both developed and developing nations (Grubler, 1996).

Land Use and population:

Fulfilling the resource requirements of a growing population ultimately requires some form of land-use change, whether to expand food production through forest clearing, to intensify production on already cultivated land, or to develop the infrastructure needed to support increased population (Haile yesus, 1996).

Indeed, it is humans' ability to manipulate the landscape that has allowed for the rapid pace of contemporary population growth, agriculture and deforestation are three prominent forms of human induced Land-use change (Bilshorrow, 1992).

During the past three centuries, the amount of Earth's cultivated land has grown by more than 450 percent, increasing from 2.65 million square kilometers to 15 million square kilometers. At the same time, the world's forests have been shrinking. Deforestation is closely linked to agricultural land-use Change, because it often represents a consequence of agricultural expansion. A net decline in forest cover of 180 million acres occurred during the 15-year interval 1980–1995, although changes in forest Cover varies greatly across regions (Boserup, 2001).

Changing land use and deforestation in particular have several ecological impacts. Agriculture can lead to soil erosion, while overuse of chemical inputs can also degrade soil. Deforestation also increases soil erosion, in addition to reducing rainfall due to localized climate changes, lessening the ability of soils to hold water, and increasing the frequency and severity of floods (Allen, 1985).

Landuse change in general results in habitat loss and fragmentation, which is the primary cause of contemporary species decline. It has been suggested that if current rates of forest clearing continue, a quarter of all species on Earth could be Lost within the next 50 years (Bilshorrow, 1992).

2.4. The Linkage between LUCC and land degradation

Land degradation means a reduction or loss, in arid and dry sub humid areas of biological or economic productivity, complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and wood lands resulting from landuses or combination of processes.

These processes includes those which arising from human activities and habitation patterns, such as soil erosion caused by wind or water, deterioration of the physical, chemical and biological properties of soils as well as lost of natural vegetation and biodiversity (Turner, et.al. 1994).

Over the last ten years, a lot of attention has been drawn on the issue of landuse and land cover (LUCC) changes and the direct or indirect relation ship that the changes might have with the observed land degradation (Brandt and Thrones, 1996).Such changes are the result of practices such as the relocation of people to the coastal border, farm and grazing abandonment, and the intensification of agriculture, among other landuses. Fore example, overgrazing, leads to compacting of the soil which reduces the infiltration and thus Increases the amount that leaves as runoff and later land degradation.

Deforestation also leads to increase over land flow since it removes the vegetation which probably affects rates of run off more than any other single factor. The rate of runoff is therefore a useful indicator of land degradation and desertification process which results from landuse practices (Brandt, 1985). World wide, soil loss and degradation and sediment transport have undoubtedly been increased greatly as a consequence of landcover change (Anderson, 1990)

2.5. Environmental consequences of LUCC

Each category of landcover change is associated with a number of secondary environmental consequences: wet land drainage, for instance, can affect biodiversity, trace gas emissions, soil, and hydrological balance (Crosson, 1990).
In economic terms, these effects often represent the externalities of land cover changes the costs and benefits passed on to others by the land user (Arnold, 1998).

2.5.1. Impact of LUCC on Hydrology

Hydrological (surface and ground water) impacts of landcover and landuse changes include changes in water quality and in water flows. Water pollution due directly to land cover changes stems from cultivation (Principally application of fertilizers and pesticides) and settlement or urban sewage (McCarthy, 1997). Changes in water quality and flow associated with land alteration result both from deliberate withdrawals and from land cover changes such as deforestation (Anderson, 1990).

Irrigation largely a consumptive use is by far the largest element of global withdrawal from hydrologic cycle; it accounts for about 75% of demand, though the share varies greatly across the globe, which is highest in Asia and minimal in many countries (Douglas, 1996).Secondary hydrologic effect of irrigation include depletion of Down Stream Rivers and water bodies.

Many ground water aquifers have been severely depleted, but the world wide human impact is unknown; “there is no readily available set of data to indicate their magnitude and depletion rates on a continental scale” (Boughton and others, 1997).Claims have long been made that deforestation, especially in highlands, increases the frequency and severity of flooding down stream. Grass land change has similar effects (TRPA, 1996).

2.5.2. Impact of LUCC on forest /Tree cover

Changes in the world’s forest /Tree cover are of two kinds: clearance and conversion to another land cover like cultivation, grassland or settlement. The world’s current area of closed forest, based on FAO data, is estimated to be around 29x106 sq.km, or 21% of the world’s land area (Bailey, 1998). Adebyo (1999) estimates that an original 62x106 sq.km of forest and wood land has been reduced by 9x106 sq.km, of which 7x106 represent loss of closed forest.

Goals and proximate sources of forest change differ considerably across the world (Anderson, 1998) clearance for cultivation, is probably the most common and widespread cause of deforestation.

Ranching and pasture development have been significant causes of clearance in central and Latin America. Timber extraction is the main case of deforestation in south East Asia and to some extent in tropical forest of western Africa; fuel wood extraction is most common in Africa & some part of India (Grubler, 1996).

Changes of condition of forests are perhaps of greater significance. Desertification has been widely identified as a major human induced global change associated with excessive pressure on forests (Hennden, 1998).

2.5.3. Impact of LUCC on Atmosphere and climate

Much of human contribution to atmospheric trace species occurs through the process of industrial metabolism, but landcover changes significantly contribute to increase in a number of important components (Harvey, 1988). Several of the green house gases implicated in global climatic changes are mainly increased by land-cover change: CO2 from forest clearance and soil carbon oxidation as well as from fossil fuel burning, methane from rice paddies, biomass burning, and N_2O from soils, fertilizers and biomass burning (Houghton, 1991).

With regard to climate, various microclimatic changes as a result of land cover changes are clear; deforestation may affect global temperature through alb Edo change (Henderson-sellers, 1998).

The urban heat effect is the best climatic consequence of settlement expansion. Global warming is the regional impact of landcover charge on climate though the emission of industrial gases plays their own parts. (Houghton,1991). Deforestation would significantly lesson rain fall and increase temperature. Possible regional effect on temperature and precipitation of vegetation loss through over grazing is also the other impact of LUCC on climate (Graetz, 1999).

CHAPTER THREE

3. General Description of the Study Area

3.1 Location

The study area is located in the Eastern highlands of Ethiopia, which is administratively situated in Eastern Harerghe Zone, Oromia Regional National state. It is situated at $9^{0}23'$– $9^{0}26'$North latitude and $41^{0}59'$– $42^{0}02'$East longitude.

The study area mainly concern Alemaya woreda and part of it's surrounding, which lies in the towns between Harer and Dire dawa .The main road that joins Addis Ababa to Harer passes through the area, so it can be accessed easily from the main road sides.

The central part of the study area, which is Alemaya town is found at the distance of 504k.m from Addis Ababa, 18 km from Harer and 40 km from dire dawa.

The total surface area and perimeter of the study covers about 650sq.km and 103km respectively.

3.2 Topography

The Harerghe highlands lying in the eastern part of the country are generally known for their rugged topography, mountainous landscapes which govern the variations in regional geomorphology, soil tops sequences, ecological zones, quantity and quality of plant and animal life (Tamire, 1981).

About 71% of Alemaya area is characterized by undulating and rolling topography. The hilly and steep land in the east and northeast of the area covers only 8%. The remaining part is a flat land in the middle and close to the Alemaya Lake. The altitude of the area ranges between 1980 and 2343 M.a.s.l. It is characterized by undulating relief and rolling topography. As cultivation is practiced on sloppy lands, soil erosion is a serious problem in the area.

According to the terrain relief map of the area the undulating and rolling features are dominant land forms. The hilly and steep land accounts for large percentages and the flat lands are relatively small.

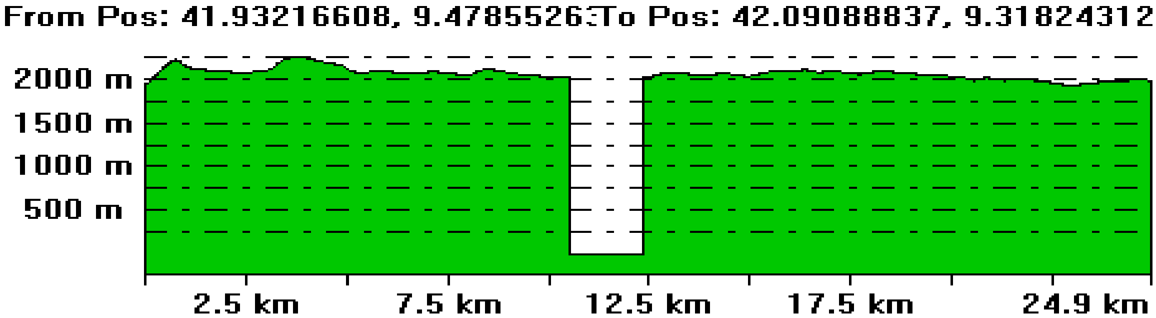

Figure 3.1 Elevation profile of the study area (from dire dawa border to Harer).

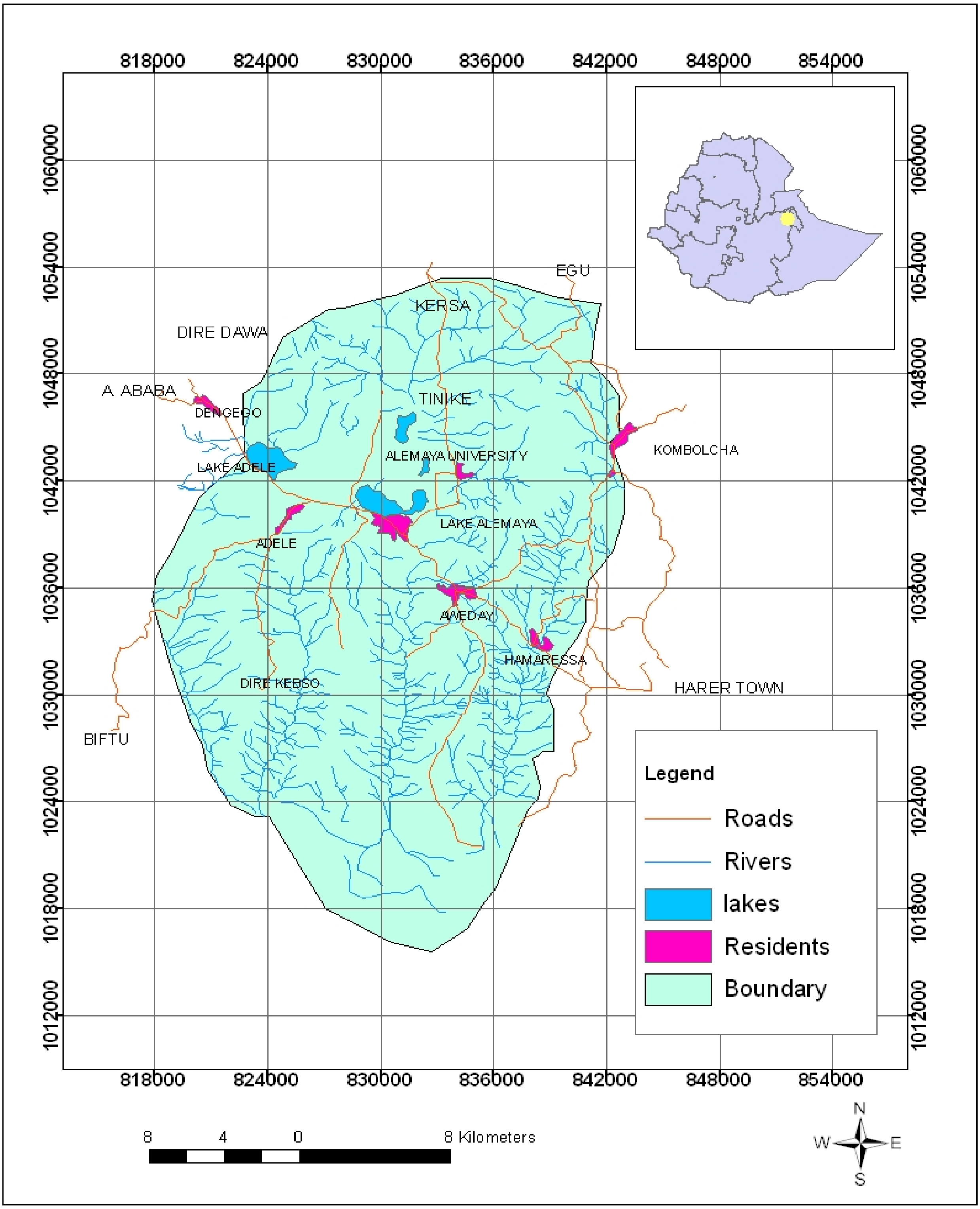

Figure 3.2 Location map of the study area

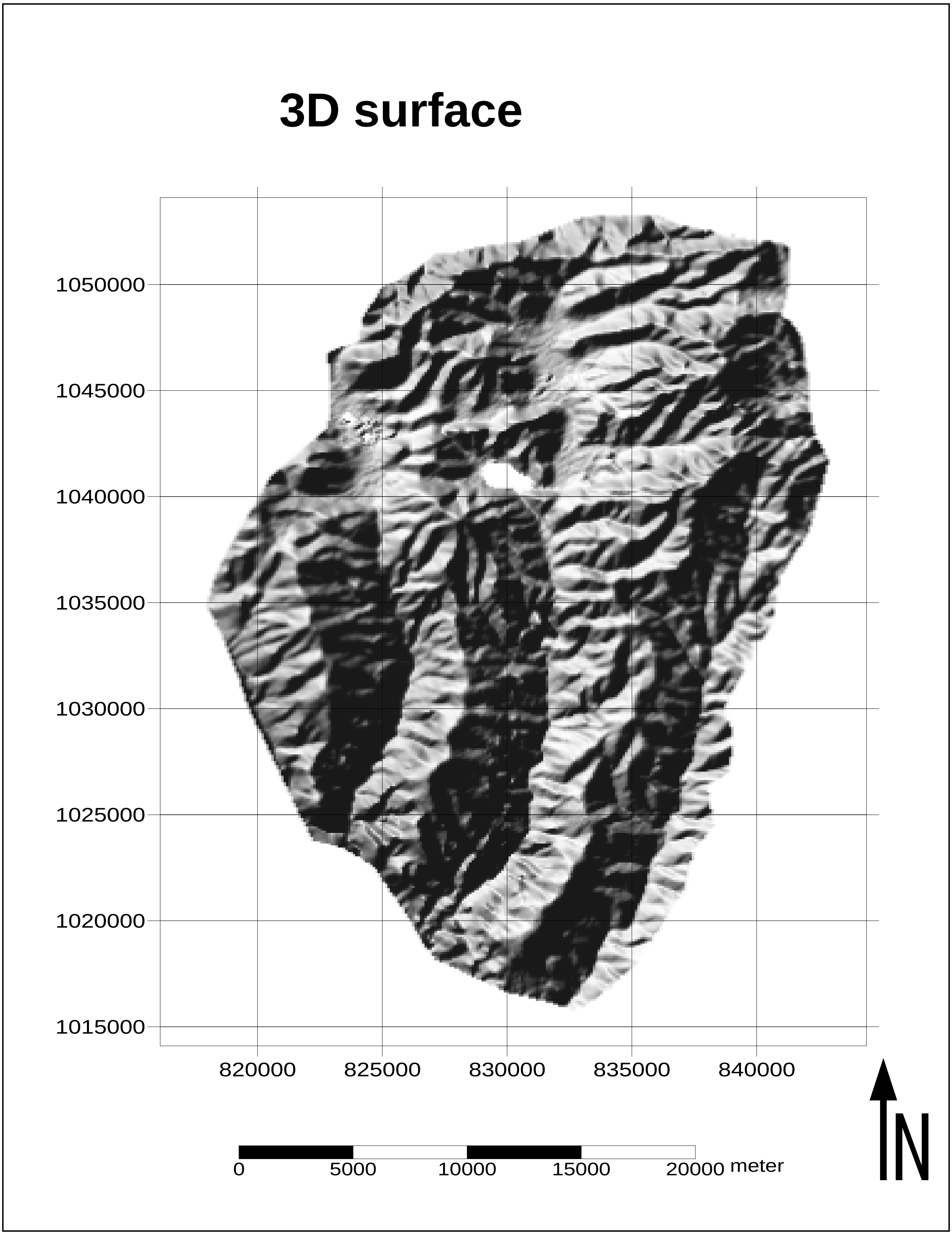

Figure 3.3 shaded relief map of the study area

3.3 Climatic Characteristics

Generally, the climate of Ethiopia varies mainly according to elevation. The tropical zone below approximately 1830 m has an average annual temperature of about 27° C and receives less than 510 mm of annual rainfall The subtropical zone, which includes most of the highland plateau and is between 1500 and 2440 m in elevation, has an average temperature of 22° C with an annual rainfall ranging from 510 to 1530 mm. Above 2440 m, is a temperate zone with an average temperature of about 16° C and an annual rainfall between 1270 and 1780 mm (Keller E.J. Encarta, 2005).

3.3.1 Rainfall

The watershed of Alemaya area experiences a bimodal rainfall distribution, which is characterized by "Woina Dega" agro climatic ecology. March and April have the "small" rains, and the principal rainy season occurs between mid-June and September. The average annual rainfall within Alemaya area for 25 years of observation at Alemaya University meteorological station is about 798 mm and the distribution is erratic (Table 3.1), while the annual potential Evapo-transpiration amounts is 1,574 mm (Figure 3.6).

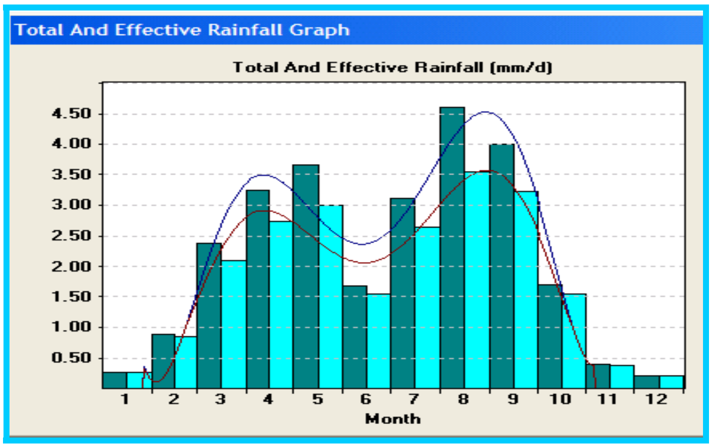

Figure 3.4 Distribution of total and effective rainfall (1983-2004).

The minimum and maximum precipitation values of the study area are 6.4 and 142.7 mm of rainfall in the month of December and August respectively. Distribution of average monthly rainfall is shown in Figure 3.5.

The effective rainfall of the area, that is the net amount of rain water stored in the root zone and available for the plant, was calculated based on the USDA Soil Conservation Service method. The computed annual average effective rainfall of Alemaya area is 673 mm.

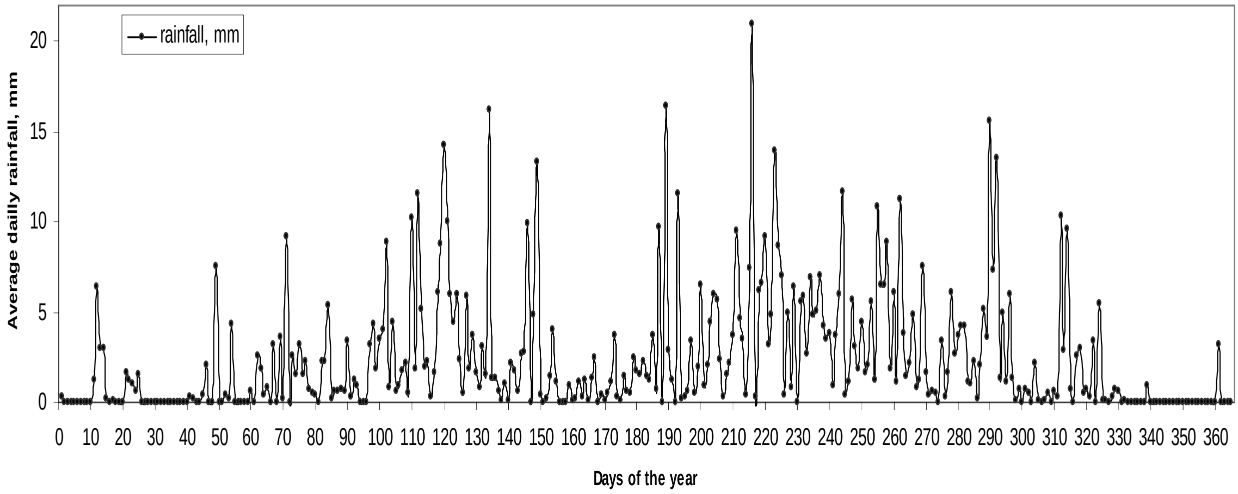

Figure 3.5 Five years average daily rainfall distribution (2000 – 2004) of Alemaya area.

3.3.2 Temperature:

The daily temperature ranges from 10^{0}C to 25^{0}C. The elevation of the area had resulted in moderate temperature, the annual mean being 18^{0}C with little annual variation. The highest value of the minimum temperature was found to be 13^0 C and the lowest value of the minimum temperature was 2.7^{0}C, whereas the highest and lowest values of maximum mean temperatures were 24.9 and 22.3 ^{0}C respectively. The minimum mean and maximum mean temperatures are 9^{o}c and 23^{o}c respectively.

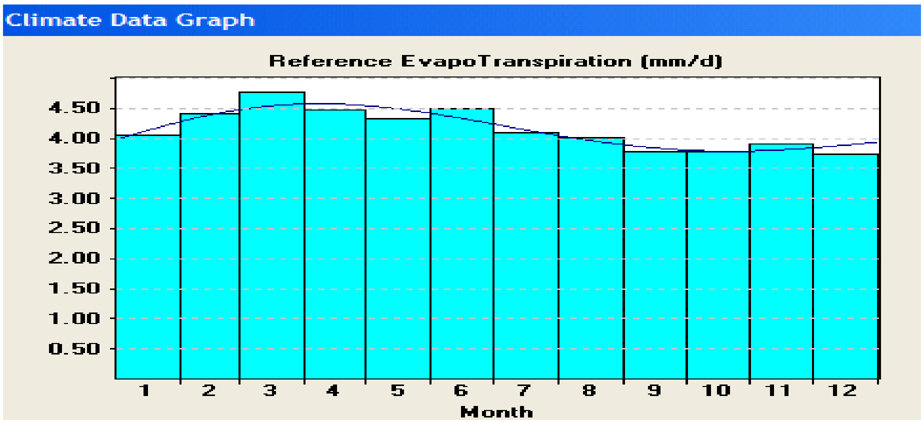

Figure 3.6 Distribution of Evapo-Transpiration (1983-2004)

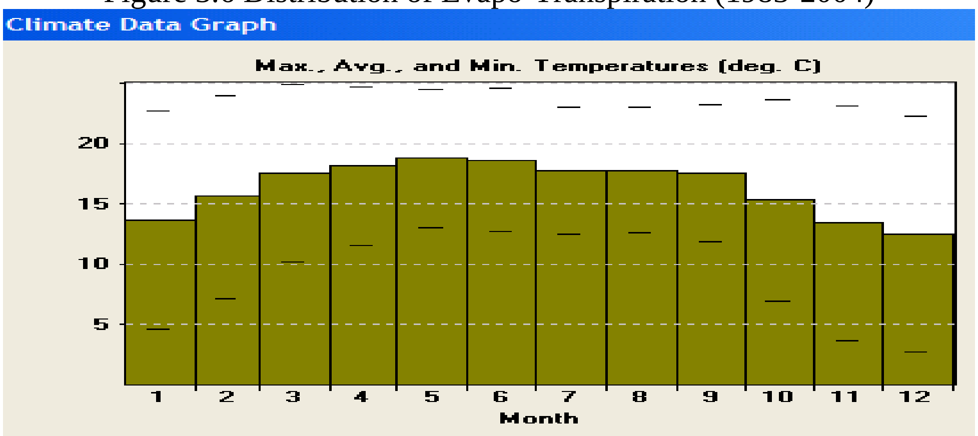

Figure 3.7 Maximum, average and minimum temperature, ^{o}C (1983-2004).

Month	Max. Temp. (°C)	Min. Temp. (°C)	Humidity (%)	Wind speed (km/d)	Sunshine (MJ/m2/d)	Solar radiation (MJ/m2/d)	Rainfall (mm)	ETo (mm/d)
January	22.7	4.6	49.9	155.5	9.4	21.2	8.2	4.1
February	24	7.1	55.1	173.7	8.6	21.4	24.9	4.4
March	24.9	10.2	54.6	184	8.3	22.1	73.9	4.8
April	24.7	11.6	58.1	167.6	7.1	20.5	97.3	4.5
May	24.5	13.0	65.6	174.5	7.5	20.6	113.7	4.3
June	24.6	12.7	65.8	244.5	7.3	19.9	50.4	4.5
July	23	12.5	70.4	240.2	6.9	19.4	96.8	4.1
August	23	12.6	70.3	193.5	6.8	19.7	142.7	4.0
September	23.2	11.9	70.8	121.0	6.8	19.7	120.1	3.8
October	23.6	6.9	56.3	98.5	7.7	20.3	52.5	3.8
November	23.1	3.7	49.7	120.1	9.6	21.7	11.8	3.9
December	22.3	2.7	52.4	133.9	9.4	20.7	6.4	3.7
Average	**23.6**	**9.1**	**59.9**	**167.3**	**7.9**	**20.6**	66.6	**4.2**

Table 3.1 Average meteorological data of Alemaya area (1983 -2004)

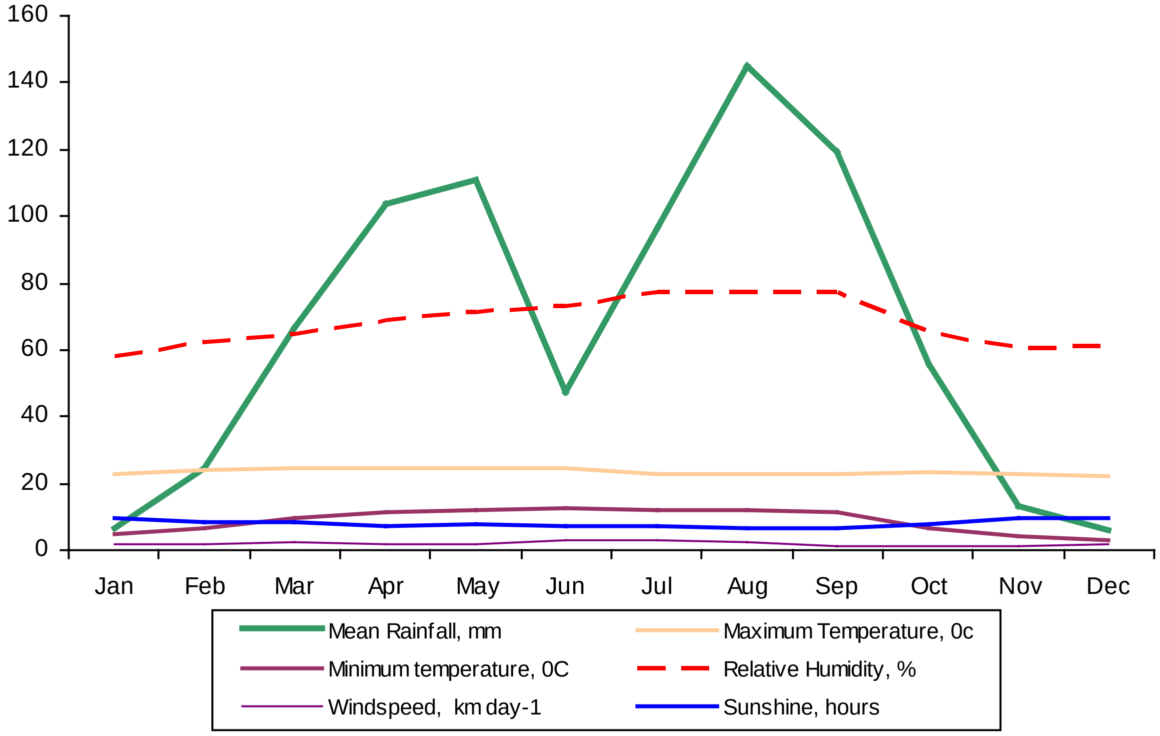

Figure 3.8 Mean monthly values of meteorological observations for the Alemaya area (1983-2004)

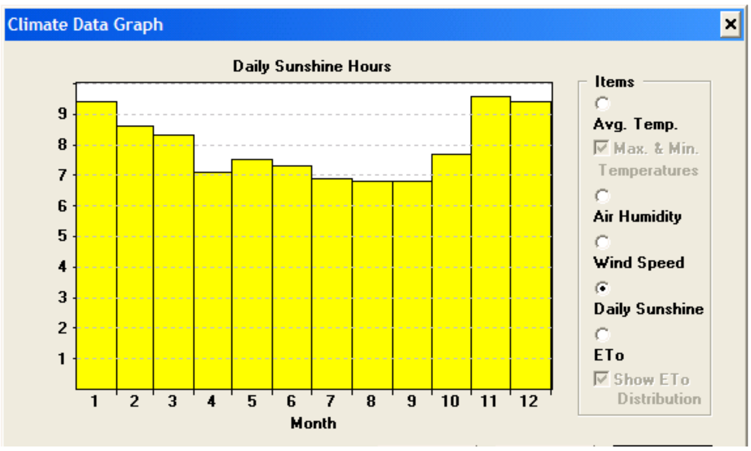

Figure 3.9 Average Daily sunshine hours with in the year (1983-2004)

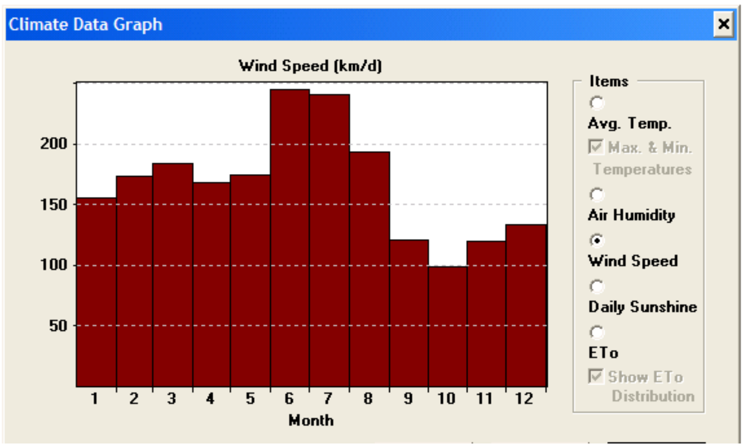

Figure 3.10 Average monthly wind speeds with in the year (1983-2004).

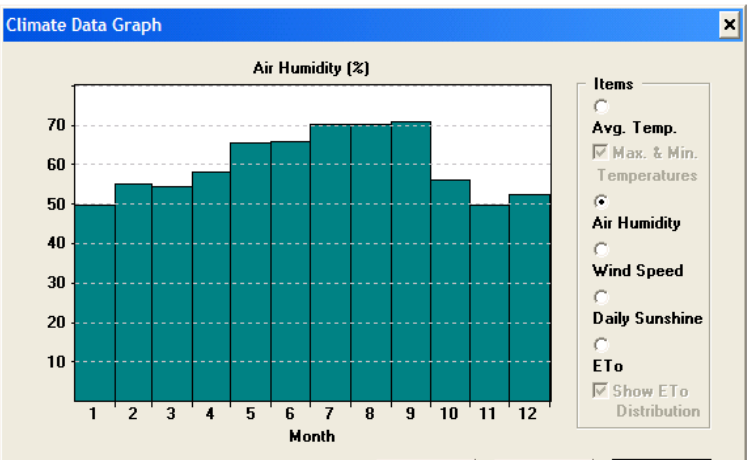

Figure 3.11 Average monthly Daily air humidity (1983-2004)

3.4 Drainage

The slope, landform and the configuration of the hills and peaks surrounding the study area have created a drainage network, which takes the surface flow towards Lake Alemaya.

The major streamlines in this sub-catchments are Lega-Hidha, Lega-Ambo, Lega-Burqa and Lega-Bati. Characteristically, all of them are intermittent streams. These streams are supplied by rill lines, gully lines, ephemeral streams, and road channels and sometimes directly from overland flows of adjacent farmlands (Solomon, 2002).

Most of the sub catchments are characterized by parallel drainage network, which converge at their outlets. Some of the smaller sub-catchments surrounding the lake drain a small land area totaling 11% of the total drainage area.

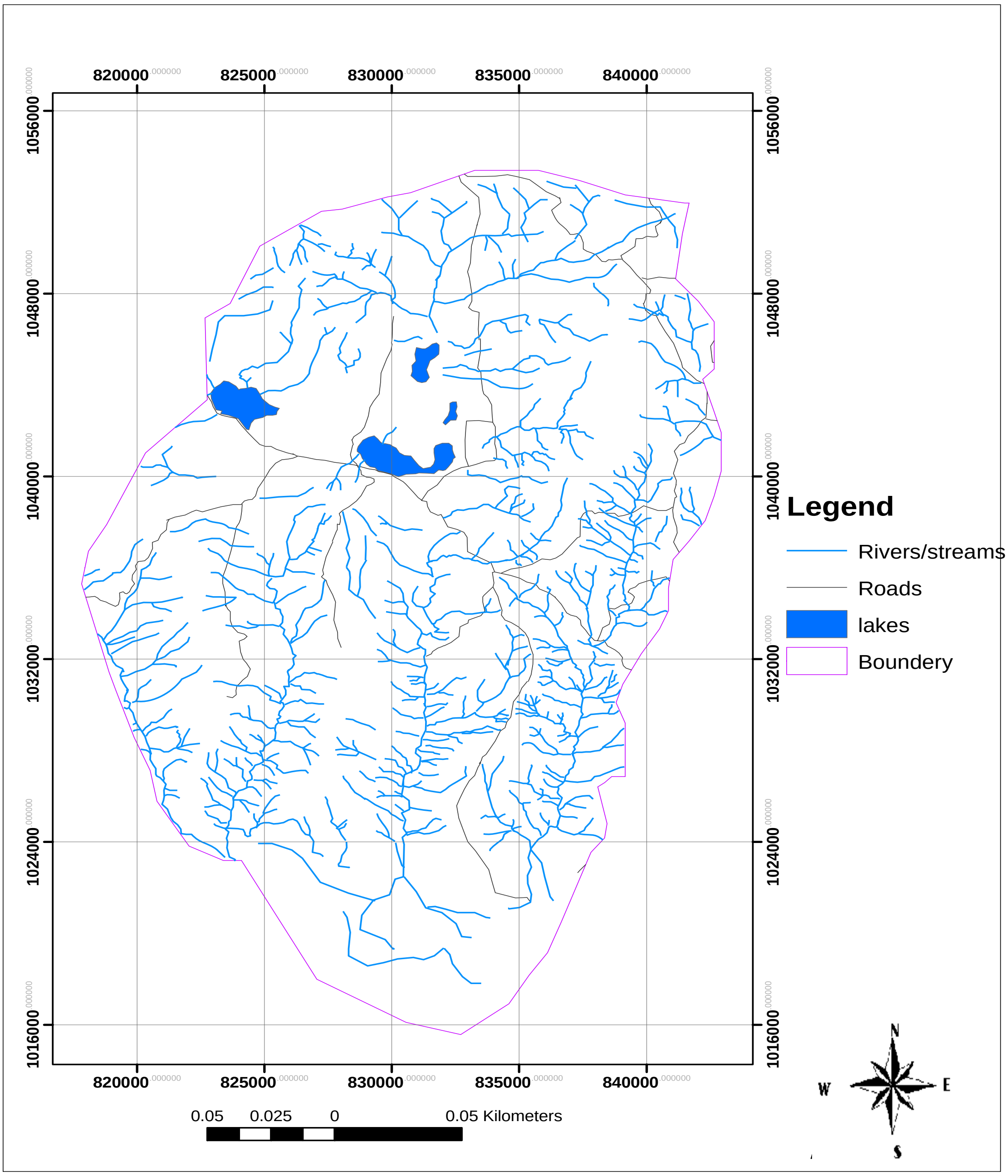

Figure 3.12 Drainage map of the study area.

3.5 Vegetation and LandUse

In the Eastern highlands of Ethiopia, including Alemaya area, the indiscriminate forest clearing, complete crop residue removal, overgrazing, low fertilizer inputs, absence of soil conservation and poor soil management and landuse practices and the erosive storms have caused accelerated soil erosion and nutrient depletion from the soil. Therefore, the low crop yields can be attributed mainly to the low fertility status of the soil caused by erosion, owing to the low permeability and high runoff rates (Tamire, 1981).

3.6 Geology and Soils

The region as a whole is overlain by limestone and sand stone deposits which started during Triassic period of Mesozoic era, and the Jurassic and cretaceous periods of the same era. The formation of sandstones and limestone's has been described as deposits left over the crystalline basement of the pre-Cambrian which are about 600 million years old. The crystalline basement is found exposed to the surface in most parts of the region and includes, among others, granites, mica-schist, quartz, syanites, gabbros and diorites (Eylachew Zewdie, 1998).

Likewise in Alemaya area, as shown in Figure 2, Precambrian quartz and sandstones or Mesozoic calcareous sediments form the parent rock in these eastern parts. The pre-Cambrian metamorphic rock, granite, and to a lesser extent genesis and mica schist, are particularly exposed on the surface. The steeper slopes have a large rounded boulders of granite rocks exposed on the surface. This is a clear indication of severe erosion that has washed away the surface soil and exposed weathering granite boulders on the land surface (Tamire, 1986).

3.6.1. Soil Erodibility and Soil Erosion Problem

Eastern Ethiopia in general is severely affected by soil erosion as it is revealed by the common occurrences of deep and wide gullies which are dynamically expanding into agricultural lands at an alarming rate. Gullies also represent the chief source of sediments causing siltation and drying of lakes which are valuable sources of both drinking and irrigation water in the Alemaya and Harer areas (Shiberu, 2002).

Erosion is a very serious problem over most of the Harerghe highlands. Wright (1984) estimated that soil losses under arable crops are of the order of 50 – 150 t/ha/year on slopes up to 40% and 150-250 t/ha/y on steeper lands with slopes more than 40%.

Hurni (1985) stated that as a consequence of accelerating soil degradation, the productive capacity of the Ethiopian highlands is being greatly undermined. It is estimated that the productivity is declining at a rate of 2-3% annually.

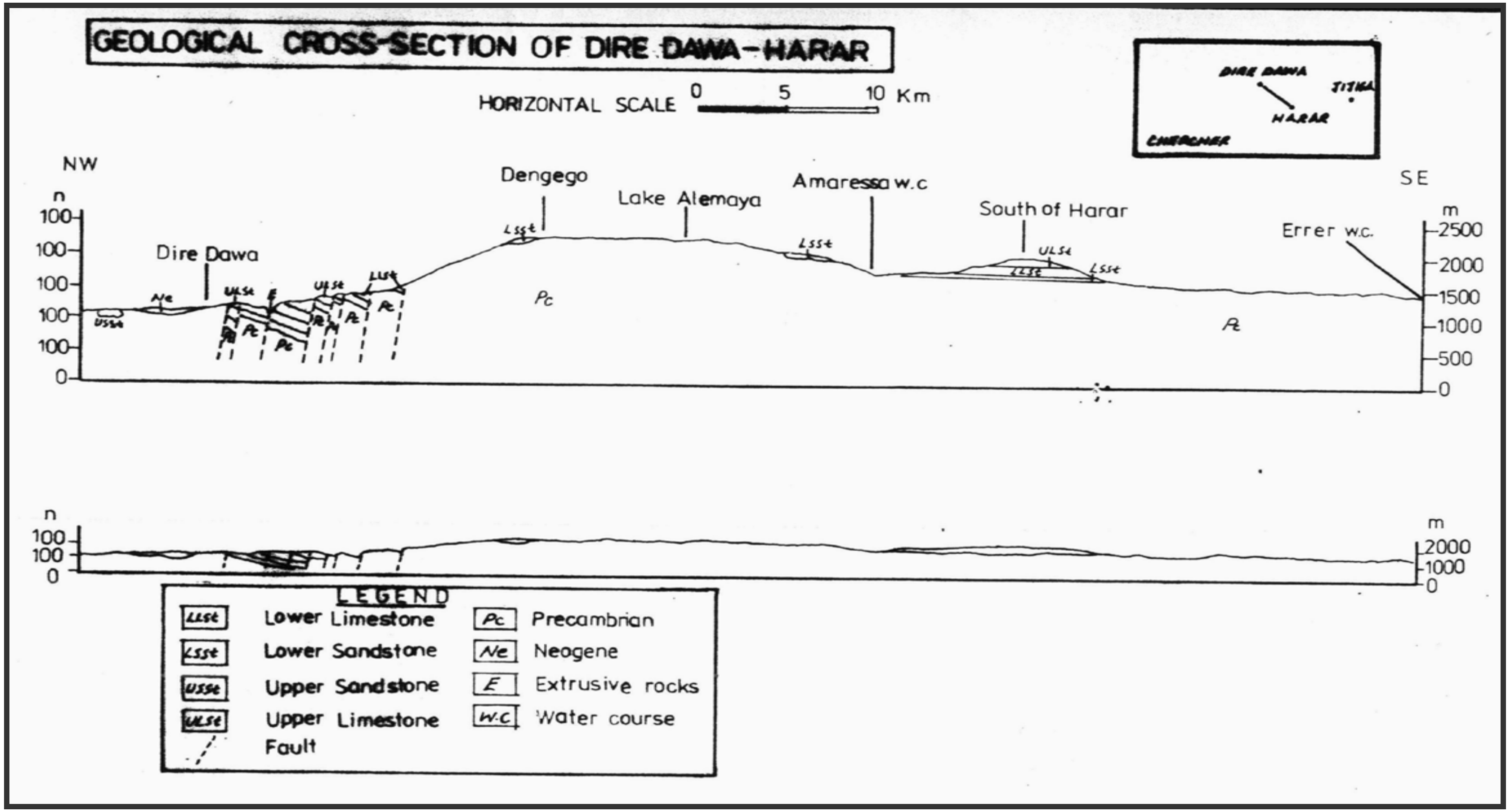

Figure 3.13 Geological cross-section at Dire Dawa – Harer, adapted from Yeshayehu G. 1970 by Tamire 1984

In the eastern highlands of the country, around Alemaya, the removal of 3.5 and 3.0 cm deep fertile surface soil was observed from freshly plowed agricultural lands having 5 to 6% and 3 to 4% slope respectively, from a 39.4 mm of 10 hrs continuous rainfall (Tamire, 1982).

The large rounded boulders of granite rocks exposed on the surface of most of the steeper slopes of Lake Alemaya catchments are good indicators for the prevailing severe erosion in Harerghe highlands. The Legambo area, which is located about two kilometers east of Lake Alemaya represents typical landscape in the Harerghe highlands affected by serious soil erosion.

The area is denuded of natural vegetation, farmlands give the lowest yields and limestone is exposed throughout the steep slopes (Heluf and Johannes, 1997).

Soil erosion from sloping lands also leads to sediment problems down slope in streams and lakes. Sedimentation of lakes reduces their storage capacity and life expectancy. In extreme cases, sedimentation changes an aquatic habitat into a terrestrial one. Chemical fertilizer (nitrogen and phosphorus) carried in sediment and runoff also causes eutrophication in lakes. Lake Alemaya located in Eastern Harerghe zone at an altitude of 2000 m.a.s.l. had once a maximum depth of 7-8 m (Brook, 1995).

According to the study made by Solomon (2002) on the potentials of rain to induce erosion shows 38% of erosive storms occur in the month of August. Nevertheless, the crops attain maximum coverage and are supposed to protect the land. The months of April and May contribute 18% to the erosion intensity. However, in these months the land is freshly cultivated and the crops are at early growth stage. Thus, the land is highly exposed to soil erosion.

Erosion is the primary cause of soil degradation in the area. It decreases arable surfaces, reduces the soil fertility and causes harmful effects like soil and water pollution, the silting of reservoirs and irrigated fields. The estimated annual average soil loss from Lake Alemaya catchments was 31.3 tons/ha.

Soil erosion in the area is affected by different factors such as the rainfall, soil moisture, vegetation cover and land use showed seasonal and monthly variations. The months of August and September showed the maximum erosion risk.

It was estimated that 56% of the annual soil loss occurred in these two months. The months of March, April and May contributed about 31% of the annual soil loss. The total annual gross erosion from the catchments was about 148, 848 tons.

According to recent research findings (Larney, 1995), the reduction in crop yield per cm depth of surface soil removal is estimated to be 6%. Hence, in the case of Alemaya Lake catchments, the maximum loss in grain yield of crops with a simple conservative estimate could be more than 18%.

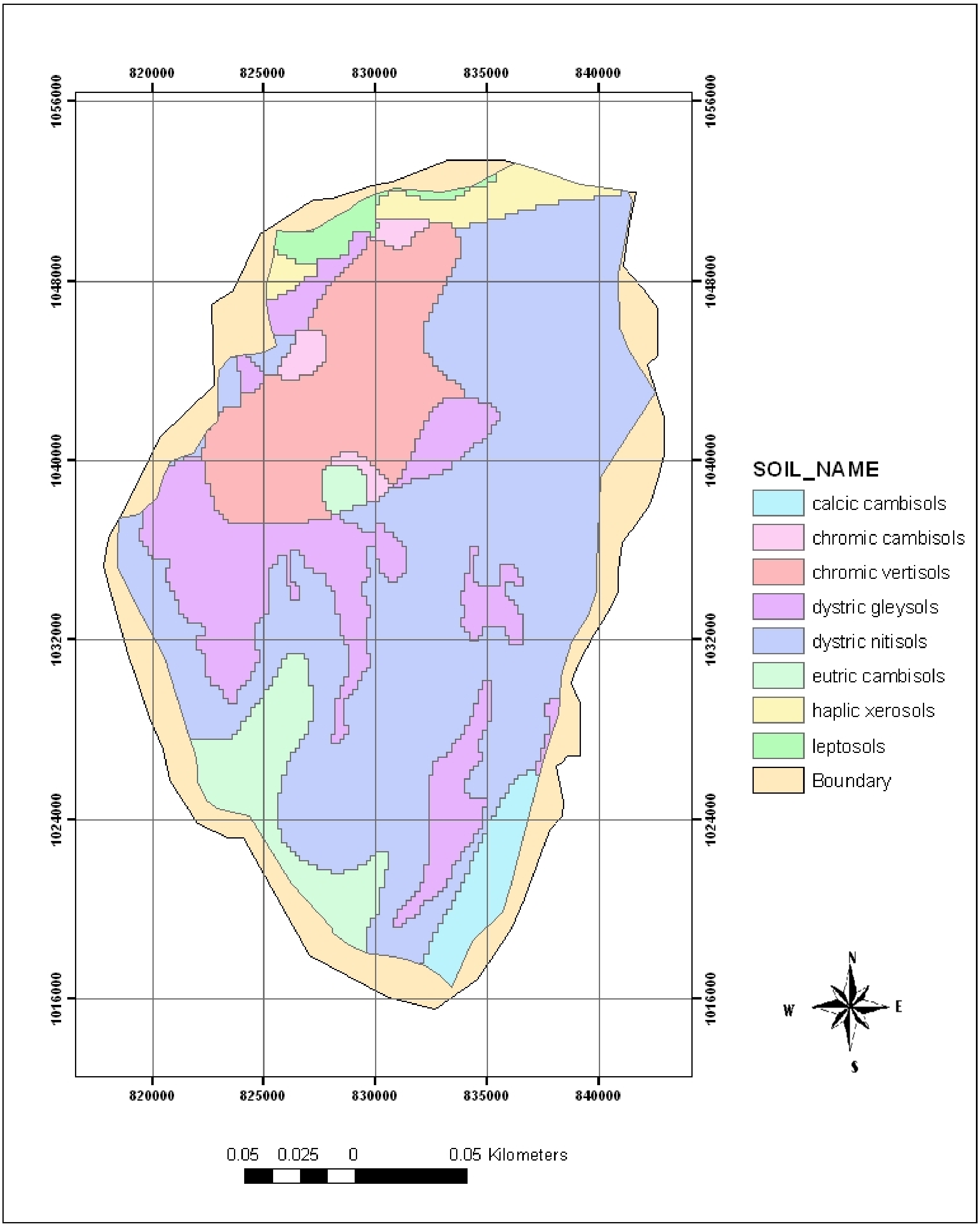

Figure 3.14 soil map of the study area.

3.7 Socio-Economic Conditions

Based on the population report of Planning and Economic Development Department of Eastern Harerghe Zone, the total population within Alemaya District is 18,800 with the population density of 360 person/km^2 and with male / female ratio of 104:100.

The average household size is 4.74, while the estimated total rural population of the sub-watershed around Lake Alemaya is 1500 households. The 1994 population and housing census show that the active age group (15-64 years) accounts some 51%, which means that about half of the population is not economically active.

The livelihood of the community in Alemaya area is mainly based on mixed farming, that is, cropping and livestock production. Despite the high population pressure, the lands are intensively cultivated. All marginal and grazing lands are brought under cultivation. The high population pressure of Alemaya watershed has forced to put every piece of land under cultivation. The Harerghe region in general is considered to be the main area for cultivation and trade. Production of Chat has increased considerably over the last ten years, as shown in Table 6, by increasing values of exports to neighboring countries (Dechasa, 2001).

Year	**Birr**	**Year**	**Birr**
1975	5,424	1980	24,732
1976	6.468	1981	17,892
1977	5,331	1982	32,858
1978	5,803	1983	28,862
1979	10,508		

Table 3.2 Chat export through Dire Dawa (in thousands of birr)

CHAPTER FOUR

4 LandUse-LandCover Pattern and Change Detection (1985-2003)

4.1 Description of landuse /landcovers categories in the study area

4.1.1 Perennial crop lands

It is Agricultural land which used primarily for production of chat crop which is known by its scientific name as **"Catha edulis".** It also includes land that is used for coffee and grain. Also Land used for the production of tree crops, and other agricultural activities is included in this category. They are found almost green in all seasons of the year so that they are easily identifiable in the image from the temporal crops, which are not available in all seasons

4.1.2 Temporal crop land

It is another Agriculture land mainly consisted with seasonal crops. This subcategory includes land used for the cultivation of food crops like sorghum and maize. These crops do not found all the year unlike the perennial crop so that are mostly harvested at November and December that is why also they are called seasonal or temporal crops. They are found covering large part of the study area. Unless careful field observation is done they might confuse with bare land since have similar spectral response in some parts especially in the image which is taken in the winter season.

4.1.3 BareLands

This category includes non-forested, non-vegetated, and non-agricultural land that has less than 50 percent herbaceous cover. Lands which were formerly agricultural but now due to erosion and over use became worth less are also classified under this category. This types of lands are widely found in the southern part of the area .To some extent barelands are also found in the former lake area, especially in Adele lake area i.e. when the lake completely dry up part of the lake area will become a kind of bareland. In the image they are easily identified because due to their high reflectance value they appear whiter than the surround features.

4.1.4 Plantation

Plantations are lands that are covered by man made forests/trees of eucalypts and conifers species, which are about 3 meter or more in height .Other wise there is no natural forest in the study area.

This category includes managed areas of tree growth such as eucalyptus and conifers tree farms that meet the basic criteria for forest areas. The conifers do not seasonally lose their leaves.

4.1.5 Residential

Residential land uses range from high density, represented by the multiple-unit structures of urban cores, to low density, where houses are on lots of coverage and which could be identifiable from image, at the periphery of urban expansion. Linear residential developments along transportation routes extending outward from urban areas are included.
Areas of sparse residential land use surrounded by other uses (e.g., Agricultural) are not included in this subcategory

4.1.6 Grasslands

This category includes areas dominated by native or introduced grasses and forbs, including grass like plants such as sedges and rushes, and small flowering and non-flowering plants occurring on upland and lowland areas. To be placed in this subcategory, the area should have roughly a 50-50 mix of plant cover versus bare land. This subcategory includes agricultural pasture land.

4.1.7 Shrubland

This category includes land predominantly covered by communities of grasses, grass like plants, including medium flowering and non-flowering plants, and mixtures of them includes unmanaged land as well as significant managed areas of herbaceous cover such as pasture.

4.1.8 Woodlands

Woodlands are dominated by low woody plants generally below 3 meters in height. Included are areas of immature trees that may be in transition to forest. They are also mainly from eucalyptus and conifers species. More over this wood lands are not natural rather human made vegetations like plantation.

4.1.9 Marshy area

It is obvious that most marsh areas are resulted from the drying of water body. They also resulted from temporal logging of water, especially in rainy season, so that land will remain as marsh area. Hence, areas which are like wet land and a mixture of grass and water are classified under this category. Large part of this kind of land is delineated from the lake areas.

4.1.10 Water Bodies

This category includes all areas of surface water with no, or minimal, emergent vegetation. All lakes, ponds, rivers, and streams, that cover an area large enough to be delineated as area features, are included in this category.

4.2. Image interpretation and image classification system

In this study, interpretation and classification was carried out in such away that first false color composite (741 RGB) and unsupervised classification of landsat ETM + of 2003 had been prepared and taken to the field, then in the field it was cross checked using Garmin GPS.

Using ENVI software, 32 points (GCPS) were selected from each classified groups to be checked in the field. Later some more points were added in the field which was important for feature identification of the image. So, based on the ground checked points supervised classification is done in the image.

For the year 2003, false color composite was prepared using the order of 7,4,1 band sequence and for the year 1985, true color composite also done using the band sequence of 3,2,1 (See figures 4.1 and 4.2). Then different enhancements were made to increase the visual interpretation of the image.

The false color composite and unsupervised classifications were done using ENVI softwares where as supervised classification was done in ERDAS with accuracy assessment of 88% and landuse maps of the area was prepared in Are view.

At last, the supervised classified images were exported to Arc view GIS for manual digitization on screen in to different landuse /landcover classes (see figures 4.5 and 4.6).

4.2.1. Image interpretation elements

Different image interpretation elements were used to distinguish variations among features.
To begin with pattern, it refers to the spatial arrangement of objects. The repetition of certain general forms or relationships can characterize many objects, both natural and man made so it gives aid in recognizing them. For example, landcover types like grass land, crop land, and wood land could be interpreted using this interpretation element.

Tone is directly related to reflectance of light from features. It is a measure of the relative amount of light reflection by an object and actually recorded on image. It was a fundamental element to distinguish features especially like water, plantation, crop types, wood lands, shrubs, grasslands and barelands. For example in the false color composite of (741 RGB), plantations appear dark green, wood lands appear semi dark green, grasslands and temporal crops provide light green tones etc.

Shape is the other interpretation element. It refers to general form, structure, and configuration or out line of an individual object. It is one of the most important factors for recognizing objects from images. So using it, it was possible to distinguish land uses like plantation, crop lands, water bodies and wood lands.

Size is a function of scale. It is important to relate size of features to other features in the scene. So that using this interpretation key it was possible to identify temporal crops from perennial crops, plantations and water bodies.

Association is the other helpful clue in identification of features. For instance, features like marsh are could be identified by associating with water bodies. Residents and towns could be also separated from bare lands by associating with roads and taking into account their shapes.

Texture is the arrangement and frequency of tonal variation in particular areas of the image. Smooth textures like grass could be possibly separated from crop lands though they have similar reflectance. More over, water bodies can be easily separated from the surrounding features due to their smooth features. Urban areas can also be separated from bare land due to their rough texture.

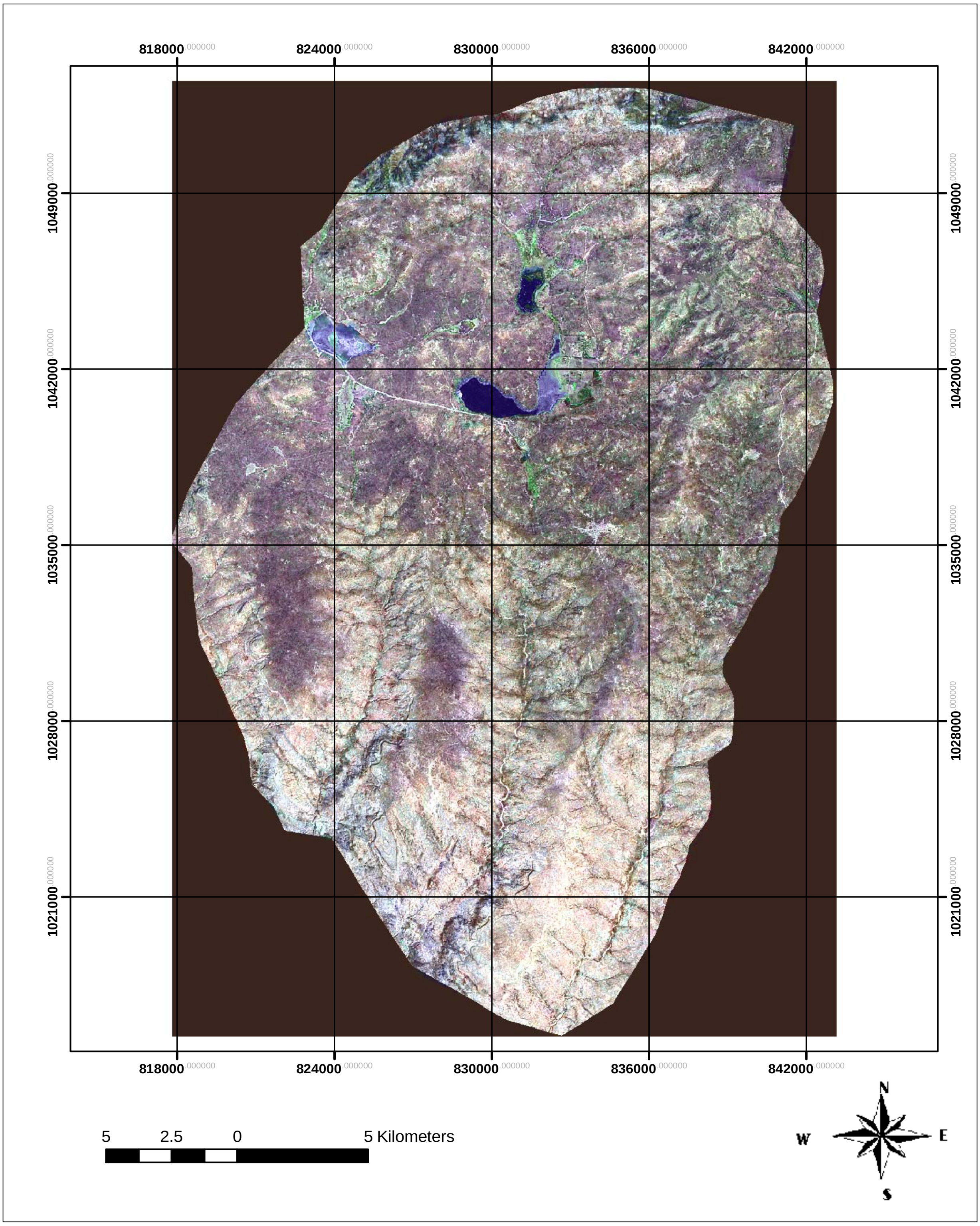

Figure 4.1 True color composite (321 RGB order) map of Landsat Tm image, 1985.

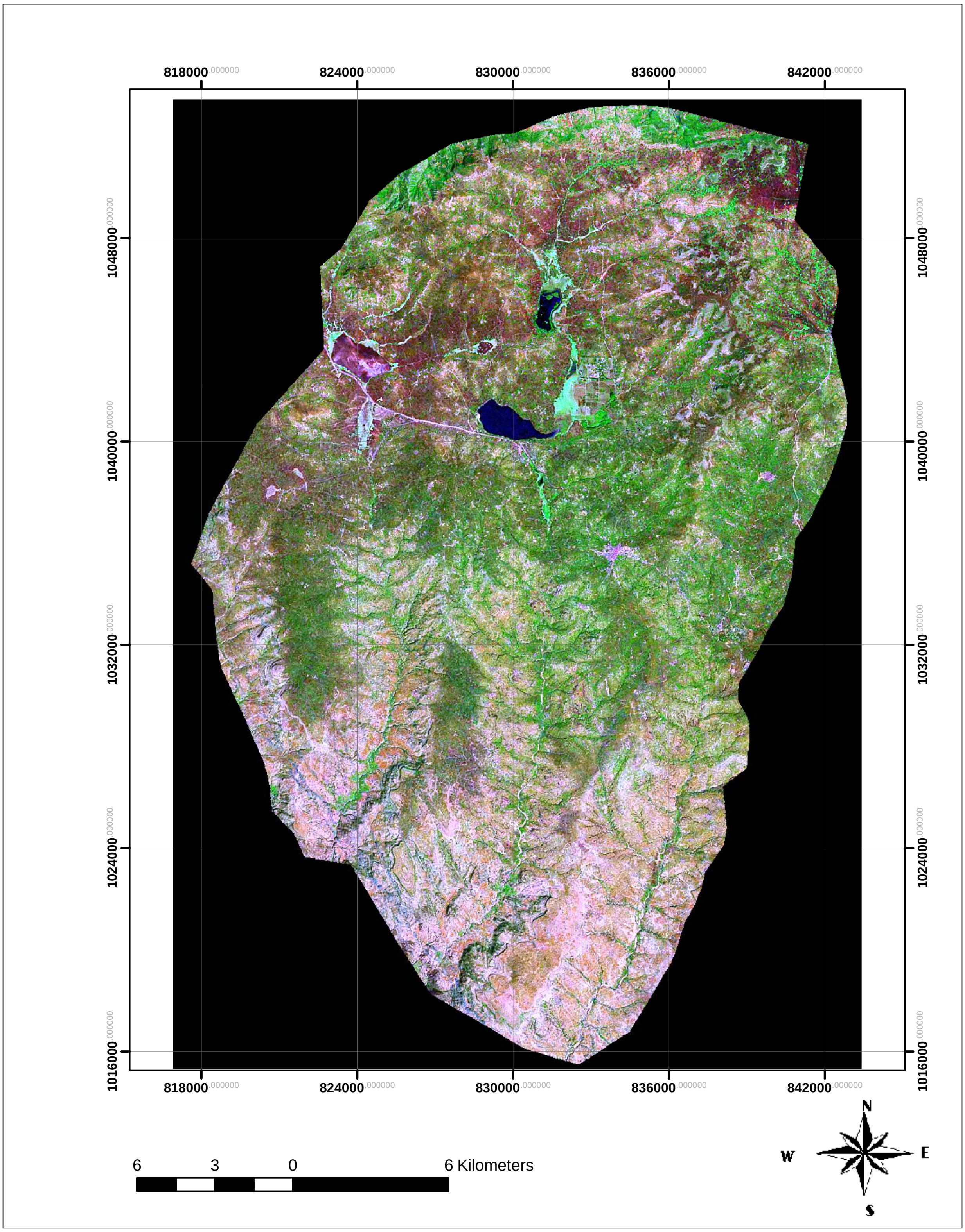

Figure 4.2 False color composite (741 RGB order) map of Landsat ETM+ image, 2003.

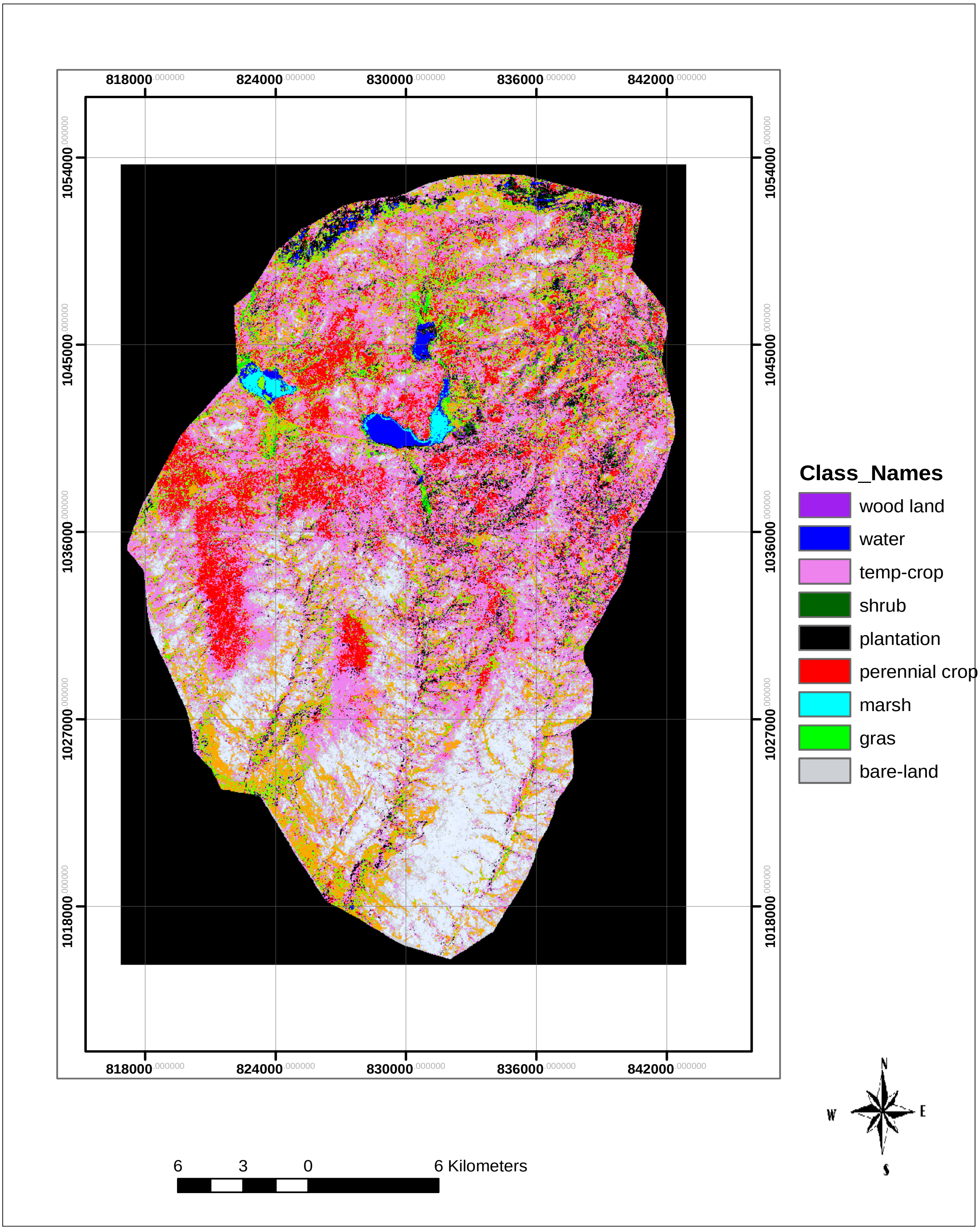

Figure 4.3 Maximum likelihood classification of image 1985.

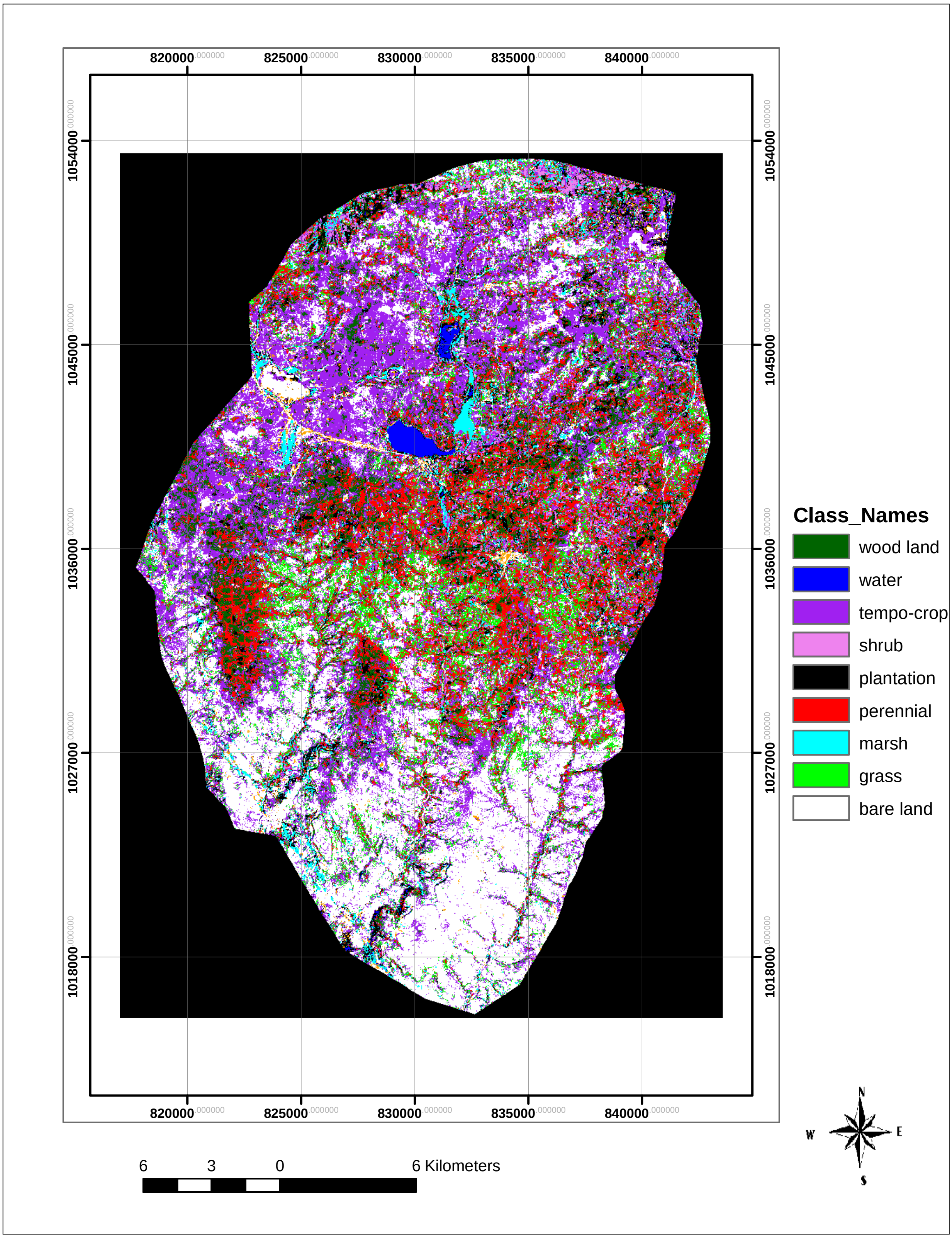

Figure 4.4 maximum likelihood classification of image 2003.

4.3. Change detection for the period 1985-2003

4.3.1. Land use and land cover of the area in 1985

In 1985, majority of the land was occupied by temporal crop (maize and sorghum) which is 51.6%, bare land 22.8%, perennial crops (mainly chat) 17.2% and water body covers 1.3%. (See Table 4.1). The smaller landcovers were residents and marsh areas which covers 33.4 ha and 279.7 ha, respectively.

Land use /cover	Area (ha)	Area (%)
Grass	973.1	1.43
Bare land	18,119.2	26.72
Marsh	2,254.3	3.32
Perennial crop	14,579.7	21.50
Plantation	933.4	1.38
Residents	701.7	1.04
Shrub	391.2	0.58
Water	362.6	0.54
Wood land	1,604.1	2.36
Temporal crops	27,881.2	41.12
Total	**67,750.1**	**100%**

Table 4.1 landuse /landcover class for the year 1985.

4.3.2. Landuse and landcover of the area in 2003

In 2003, land was still mainly caught by temporal cropland which is 41.12% of the total. The other landuses covers, barelands 26.72%, perennial crops (chat) 21.50%, and marsh 3.32%, and wood land 2.36%. The smaller landuses were covered by grass which is 1.43%, residents 1.05, and water which is the smallest 0.54 % (Table 4.2).

Land use /cover	Area in ha.	Area in %
Grass	1689.8	2.49
Bare land	15,029.8	22.18
Marsh	279.7	0.41
Perennial crop	11,528.9	17.41
Plantation	1,054.5	1.56
Residents	334.6	0.49
Shrub	493.3	0.73
Water	886.7	1.30
Wood land	1496	2.21
Temporal crops	34,962.8	51.60
Total	**67,756.1**	**100%**

Table 4.2 landuses and landcover class for the year 2003

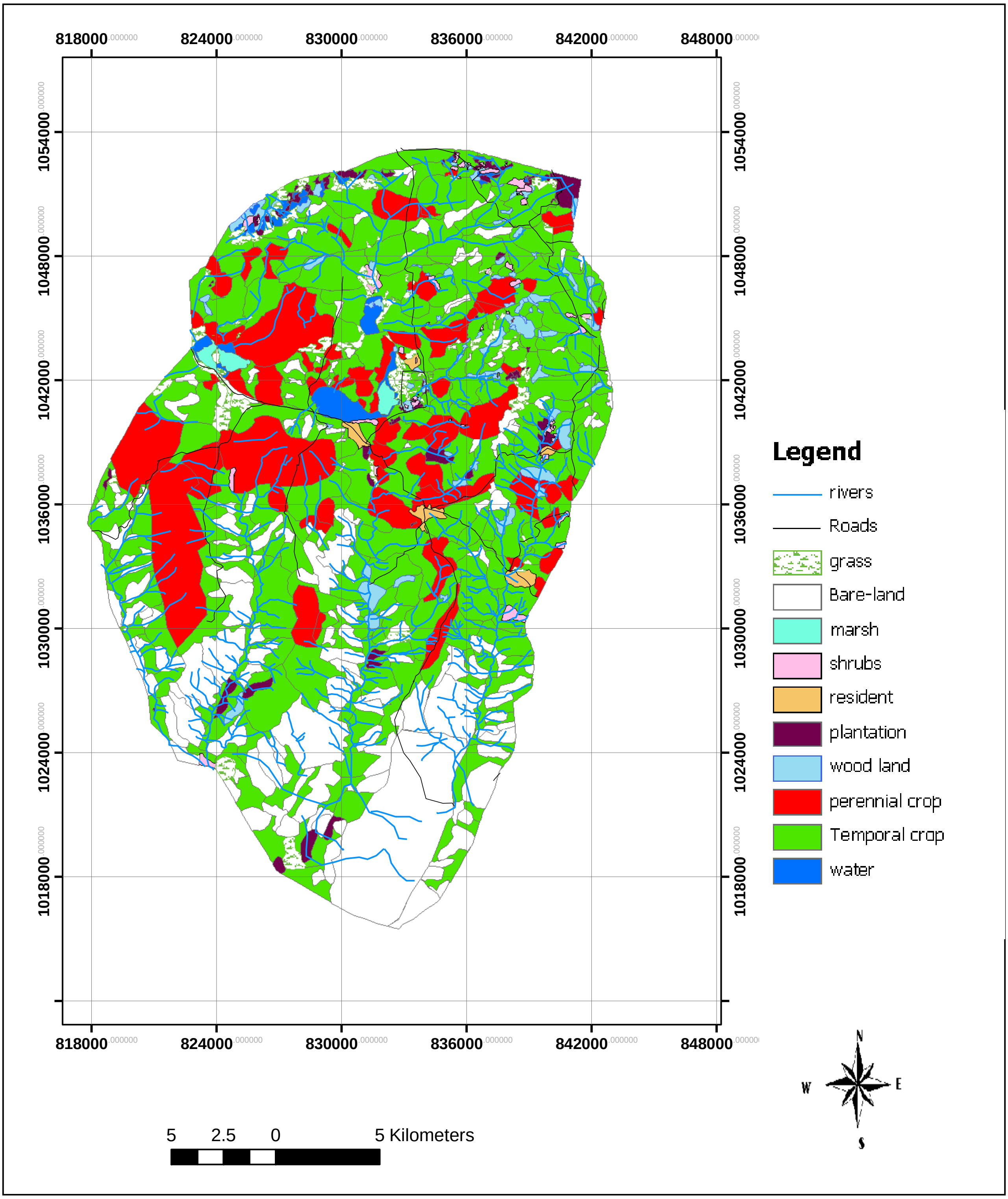

Figure 4.5 landuse and landcover map of 1985.

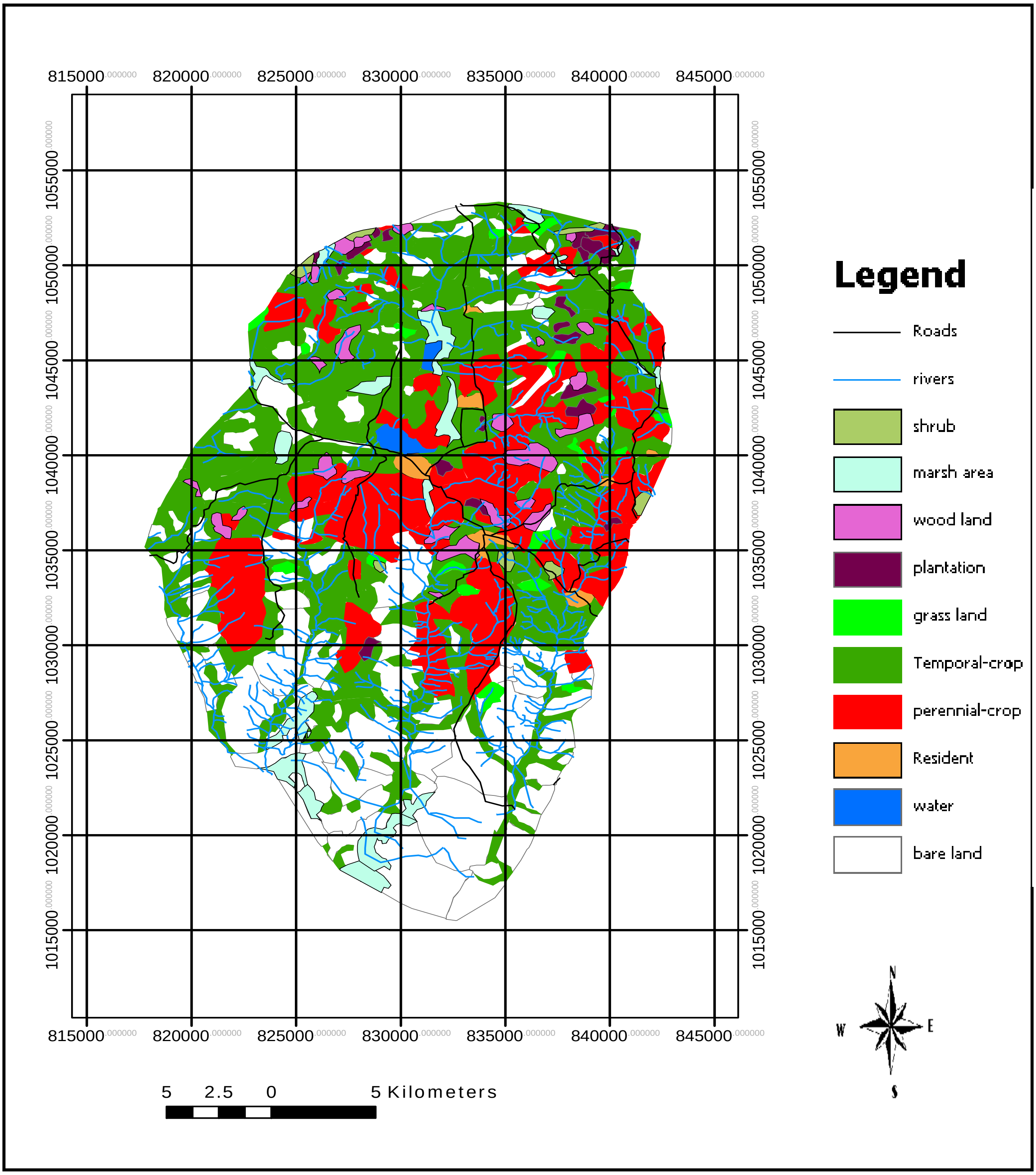

Figure 4.6 Landuse and landcover map of 2003.

4.3.3. Landuse and land cover change analyses for the period 1985-2003

It is true that variety of changes in landuse and landcover especially in agriculture (temporal and perennial crops), water body, grassland and bareland are seen in the area with in the period between 1985-2003 .Hence the over all change is analyzed here under (Table 4.3).
The detail about the changes in landuse and landcover and the causes that result the changes are explained well in discussion part.

Class	**Year**		**Changes**	
	1985 (ha)	**2003 (ha)**	**Change (ha)**	**Change (%)**
Grass	1689.8ha	973.1ha	-716.7	-42.41%
Bare land	15,029.8	18,119.2	3089.4	20.56
Marsh	279.7	2,254.3	1974.6	705.97
Perennial crop	11,528.9	14,579.7	3050.8	26.47
Plantation	1,054.5	933.4	-121.1	-11.48
Residents	334.6	701.7	367.1	109.71
Shrub	493.5	391.2	-102.3	-20.73
Water	886.7	362.6	-524.1	-59.11
Wood land	1496	1,604.1	108.1	7.23
Temporal crops	34,962.8	27,881.2	-7081.6	-25

Table 4.3 landuse /land coverclass and change in the period (1985-2003).

Rate of land use land cover changes

The rate of landuse/ landcover change for each class was calculated as follow:
Rate of change (ha/year) = (A-B)/C
Where, A= recent land use / cover area in ha.
B= Previous area of land use /cover in ha.
C= interval between A and B in years.
The result of the change rate is summarized in a table below (Table 4.4)

Class	**Year (ha)**		**Rate of change (ha/year)**
	1985 (ha)	**2003 (ha)**	
Grass land	1689.8	973.1	-39.82
Bare land	15029.8	18,119.2	171.63
Marsh	279.7	2,254.3	109.7
Perennial	11528.9	14,579.7	169.49
Plantation	1054.5	933.4	-6.73
Residents	334.6	701.7	20.39
Shrubs	493.5	391.2	-5.68
Water	886.7	362.6	-29.12
Wood lands	1496	1,604.4	6.01
Temporal crops	34,962.8	27,881.2	-393.42

Table 4.4 land use/land cover class change rate (1985-2003)

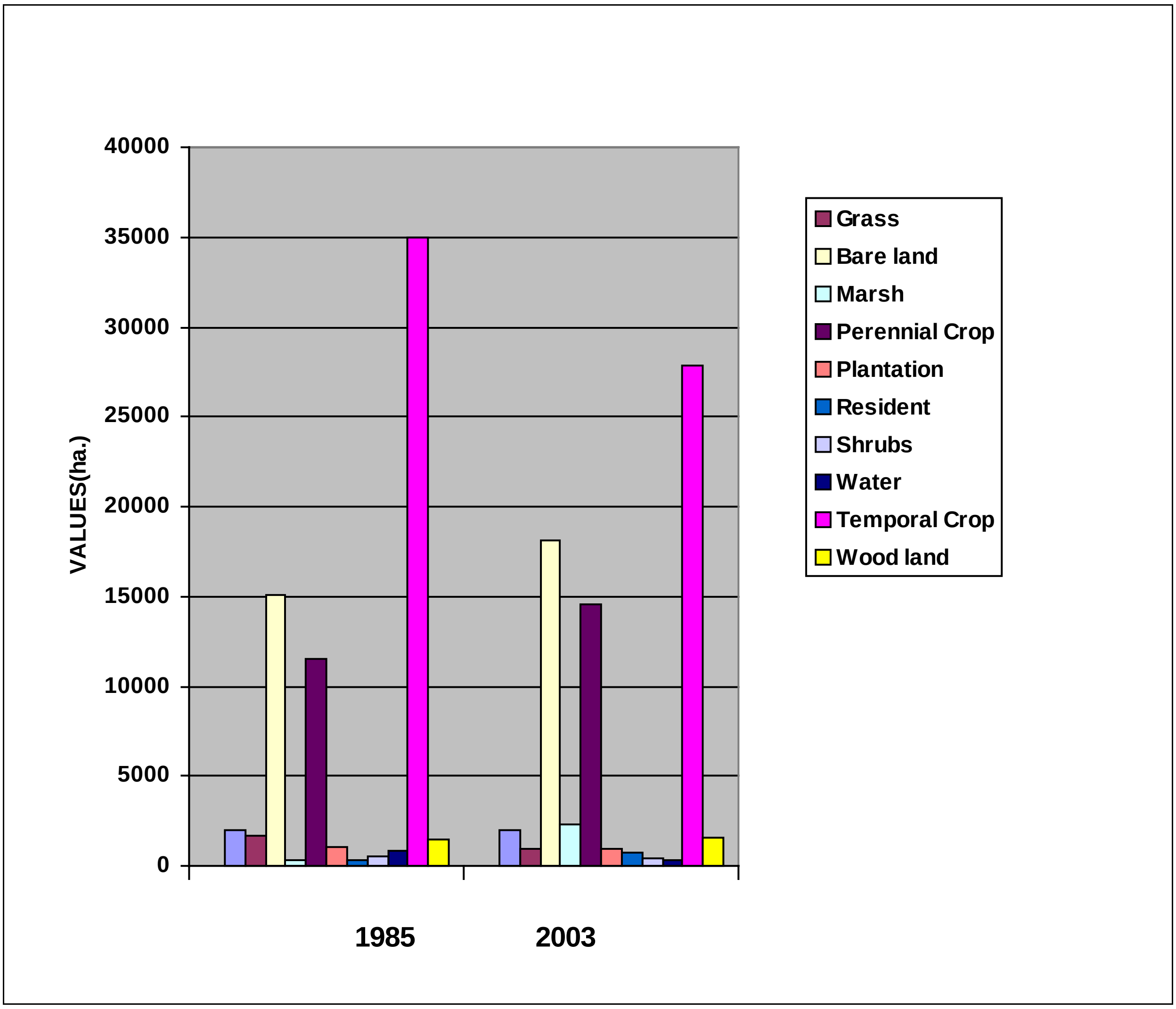

Figure 4.7 Land Use/land cover graph of 1985, 2003.

4.4 Change analysis with respect to slope

Based on ARC GIS soft ware, change analysis was done with respect to slope for different landuse/ cover types. This change analysis with respect to slope has certain significance to inter the implication of land use and land cover change.

In this study landuse types of grass, shrubs, temporal crops and barelands were considered under this analysis. The implication of the slope analysis in given landuse will be discussed in discussion part.

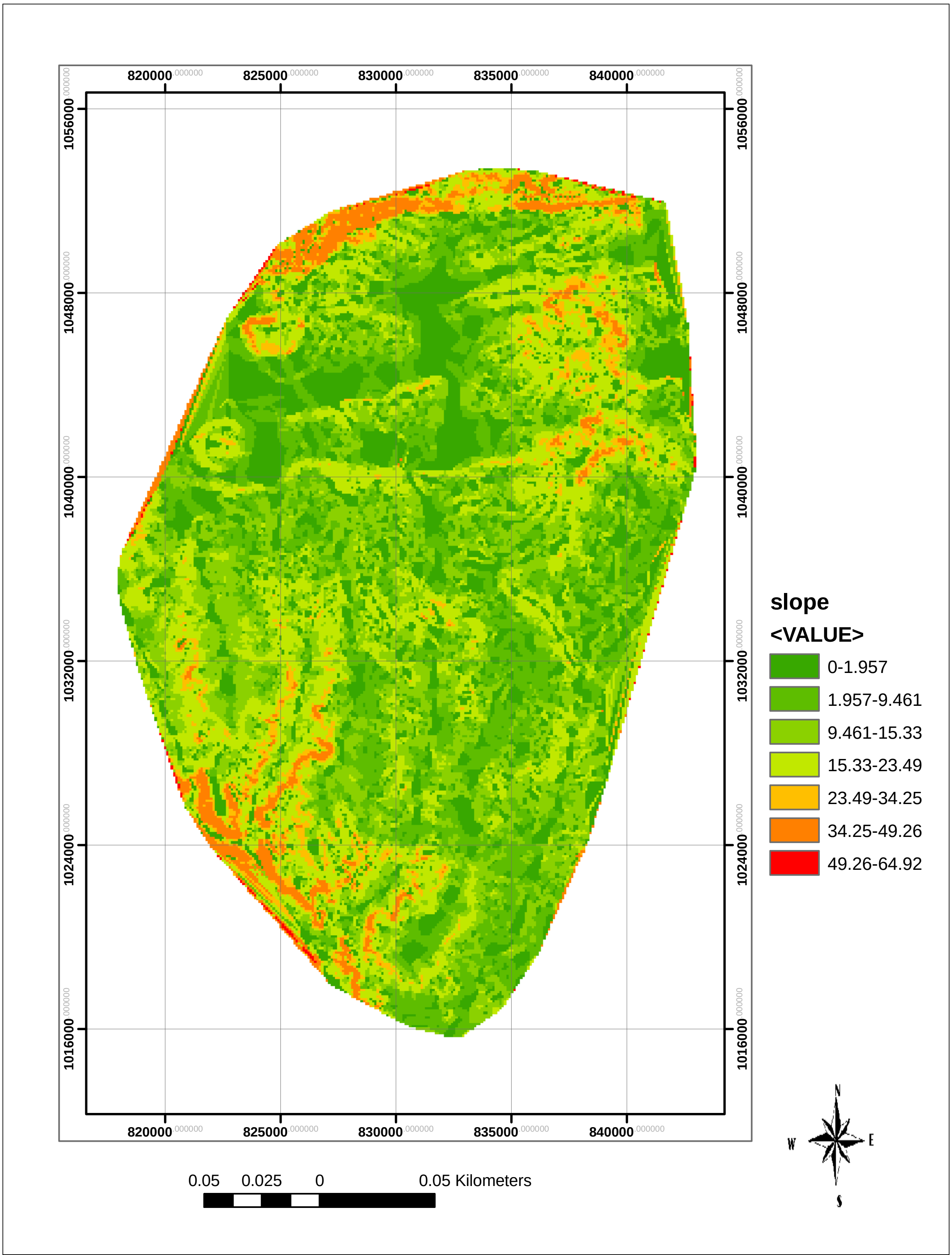

Figure 4.8 slope map (in degree).

Slope class	Years		Change (ha)
	1985	2003	
0-1.957	216.82	75.32	-141.5
1.957 - 5.546	103.20	71.77	-31.43
5.546 - 9.461	44.28	81.22	36.94
9.461 – 15.33	59.06	39.69	-19.37
15.33 – 23.49	47.64	79.02	31.38
23.49 – 34.25	22.28	42.09	19.81
34.25 – 49.26	0	1.86	1.86
49.26 – 64.92	0	0	0
Total	493.30	391.00	

Table 4.5 Shrubland change with respect to slope class (1985-2003).

Slope class	Years		Change (ha)
	1985	2003	
0-1.957	2402.35	3243.47	841.12
1.957 - 5.546	5984.56	7023.93	1039.37
5.546 - 9.461	4413.49	5587.08	1173.59
9.461 – 15.33	1591.80	2300.84	709.04
15.33 – 23.49	440.98	745.57	304.59
23.49 – 34.25	100.30	133.41	33.11
34.25 – 49.26	2.17	2.7	0.53
49.26 – 64.92	0.78	0.78	0
Total	14,936.46	29394.84	

Table 4.6 Bareland expansion with respect to slope class (1985-2003).

Slope class	Years		Change (ha)
	1985	2003	
0-1.957	689.74	166.56	-523.18
1.957 - 5.546	207.61	266.83	59.22
5.546 - 9.461	182.47	326.28	143.81
9.461 – 15.33	278.02	164.86	-113.16
15.33 – 23.49	265.43	40.14	-225.29
23.49 – 34.25	58.98	8.24	-50.74
34.25 – 49.26	1.00	0.02	-0.98
49.26 – 64.92	0	0	0
Total	1683.27	972.97	

Table 4.7 Amount of grassland change with respect to slope class.

Slope class	Years		Change (ha)
	1985	2003	
0-1.957	10094.76	7300.76	-2794
1.957 - 5.546	18349.48	11134.63	-7214.85
5.546 - 9.461	5202.46	7338.63	2136.17
9.461 - 15.33	1136.99	2675.92	1538.93
15.33 - 23.49	149.29	829.23	679.94
23.49 - 34.25	22.73	112.66	88.99
34.25 - 49.26	3.15	1.58	-1.57
49.26 - 64.92	2.09	1.40	-0.69
Total	34,962.35	19,037.81	

Table 4.8 Temporal crop land change with respect to slope class

4.5. DISCUSSIONS

In this study different soft wares were used to identify, classify and digitize landuse and land cover classes and different results were obtained. Both supervised and unsupervised classifications were attempted and supervised classification was preferred due it gave a better result while the unsupervised generalized some landuses on others.

So that since the supervised classification matched with each land classes, digitization also done based on it (Figure 4.3 and 4.4).In both images (1985 and 2003) ten landuse classes were identified but most of the landuses either increased or decreased in size at different change rate in 2003, as compared to 1985.

Marsh area increased from 279.7ha to 2,254.3 ha with change rate of 109.7ha /year. The cause is obvious that when the lakes or other water body dries, at 1st stage they become marsh area.

Barelands also increased from 15,029.8 ha to 18,119.2 ha with change rate of 171.63 ha/year mainly at the expense of temporal cropland, grasslands, shrubs and to some extent water bodies. This is the most dynamic landcover type which is extending itself every year and major problem in the area.

Perennial crop in their turn increased from 11,528.9 ha to 14,579 ha it is because of more lands from shrubs and grass as well as from temporal croplands were converted to perennial cropland, mainly to cultivate chat.

Woodlands are the other classes that showed some increment in 2003. This is mainly due to different initiatives of environmental rehabilitation programs and soil conservation in some selected places. These initiatives and woodland expansion were largely done and being held by Alemaya University and Harer brewery factory (Table 4.3).

Due to increase of population and expansion of Alemaya University, Residential areas also increased in 2003. Around the University (Bati Keble) and Alemaya town population is increasing every time so it results in urban expansion.

Grass lands and shrubs, since already converted to Agricultural lands and partly to bare land they decreased from 1689.8 ha to 973.1 ha and from 493.5 ha to 391.2 ha respectively. Temporal crop lands also decreased from 34, 62.8 ha in 1985 to 27,881.2 ha in 2003. This cause is due to conversion to bare land and perennial crop land. This kind of landuse changes are observed in many places in the study area.

Water bodies are the other significant body which showed a serous of decline. They progressively decreased in size and finally dried up in 2005. Even though it had been alive in 2003, within two years i.e. in the beginning of 2005 the water totally disappeared and dried up (figure 5.9).

With regard to slope, the amount of change is so significant especially in the case of temporal crop land, grassland, shrub and bareland as compared to other classes. The changes of shrubs and grasslands in gentle and less steep slope areas is due to their importance for agriculture .Hence both shrubs and grass lands decreased in low slop areas especially in the range of (0-1.957) ,due to their conversion for agricultural lands and since these areas are more conducive for agricultural activities .It also seems that the agricultural areas are expanding even in more steep slope areas ,as times went on (table 4.5 and 4.7).

Bare land expansion increased in both gentle and steep slop area. In gentle slope areas the increment came from conversion of Agricultural lands (mainly temporal crop lands) to bare land and to some extent from water bodies and grass lands. Because, these features are mostly found in gentle slop areas. Also, in steep slop areas (15.33-23.49&23.49-34.2) it showed increment .This is mainly because of the terrain and erosion factors i.e. since the steep slop areas are more vulnerable for erosion the cumulated effect increased the land degradation. In this aspect the highest changes are seen in the slop range of 5.546-9.461 due to the dual effect of both slop and human actions..

*Temporal cropland is the other landuse which has significant implication with slop class change .Highest change (decline) in this aspect is seen in the slop range between(*9.7-19.5*),this is due to the conversion of existed crop land to bareland .It showed increment in steeper slop areas because when the given agricultural lands in gentle slop got degradation , it is inevitable to rush for a new agricultural lands even in more steep areas .Hence high increase of this particular crop land is seen in the slop range between (*19.5-29.2 & 29.2-38.9*), while highest decline is see with in the slop range of (* 9.7-19.5*). It is feared that the expansion for new agricultural lands in steeper slop areas will in turn aggravate land degradation expansion in the future.*

CHAPTER FIVE

5 IMPACT OF LAND USE/ LAND COVER CHANGE IN THE STUDY AREA

5.1 Land Degradation and it's Consequences

5.1.1 Cause of Land Degradation in Alemaya Area

Land degradation can be triggered by various processes which lower potential productivity leading to long term and sometimes irreversible deterioration of land. It is one of the major problems in the study area which is engendered both by natural and human factors. In 1985 it consists 22.8% of the total landuse/ landcover and 26.7% in 2003. It also shows increment from 15,029.8 ha to 18,119.2 ha for the periods 1985 and 2003 respectively (Table 4.3).

The natural factors that contribute to the land degradation in the area are rugged topography and slope. (See figure 3.3, 3D map). The steeper slopes are most vulnerable in this regard.

The Eastern high land, including the study area is characterized by gentle to steeper slope. So that most of the erosion that leads for land degradation is caused by rain. Because large parts of the region receives a high amount of rain fall which is concentrated in a limited period during the year. However, the area doesn't have a serious wind erosion problem except in a small part of the North western part of the study area (towards Dire Dawa boarder).

The human activities which are responsible for the land degradation in the area are unwise use of land, removal of vegetation and plants for the expansion of agricultural lands, expansion of urbanization and road and over use of the land.

In the study area the local farmers don't use contour plough and terracing, only few farmers are observed plaguing with oxen farming system. Most of the farmers use human digging system in their farmland so that this system will break the soil structure and fragment hence it will be more suitable for erosion. The soil would be better protected if the farmers used contour plough by oxen and if they do terracing the steeper slope area.

Rapid population growth is the other important issue to be mentioned as a cause for the expansion of land degradation. The estimated total rural population of the overall catchment is about 20,932 ,with male/female ratio of 104:100 .The average house hold size is 4.74.The 1994 population and housing censes show that the active age group (15-64 years) accounts some 51% ,which means that about half of the population is not economically active. The livelihood of the community around Alemaya is mainly based on mixed farming, that is, cropping and livestock production .Despite the high population pressure, the lands are intensively cultivated .All marginal and grazing lands are brought under cultivation .The high population pressure of the area has forced to put every pieces of land under cultivation.


Figure 5.1 Hand digging system of farming in the area (2006).

Therefore, intensive agriculture in a given farm land and expansion for a new agricultural land i.e. change in land use like by clearing plants and converting the swamps and grass lands, they made the environment to be more suitable and ready for erosion and overall land degradation at later ends.

Environmental degradation in the area is such a current and big issue that will possibly destroy the area resource base and thus in the long run it seriously affects biological and economic productivity.

5.1.2 Form and Signs of Land Degradation In The Study Area

In the area there are different signs, which could be a significant witness for land degradation. As interpreted from the image, besides investigated and checked from the field survey 22.18% of the land in the study area is degraded in 1985 and 26.72% in 2003, mainly because of human and natural case.

Gully and sheet erosions are the major degradation signs and types in the area. They happened mainly because of running water due to steep slope of the area and unwise agricultural practices So in this way since the area is severally eroded and the soil minerals are washed, it results in devoid of vegetation & agricultural uses so that it appears as bareland and leached soil (figure 5.2).It is clear that gullies often indicate an extreme form of land degradation which requires especial attention. Occurrences of wide and deep gullies are common observation in Alemaya and its surrounding.

Figure 5.2 Picture of sheet erosion (2006).

Figure 5.3 Picture of severely eroded area (2006).

The other form of land degradation in the area is weed infestation (see picture below).
It is an occurrence of bushes and weeds on farm lands which have devastated potential in the productivity farms. These weeds are usually thorny that create a great deal of problem on grazing animals and even hamper movement through foot path (figure 5.4).

Figure 5.4 Bush (thorny weed) encroachments (2006).

Usefulness of the plants for economy and soil conservation is very low. They also make the environment to have ugly features.

5.1.3 Consequences of Land Degradation on crop Productivity

It is known that land degradation has a clear impact on the productivity of crops. The immediate impact of land degradation is reducing crop yield and productivity. These two terms are strongly correlated because declining of productivity is one of the direct out come of degradation of land. Shortage of food is the other direct consequence of land degradation in the area

As discussed above, population growth in the area is one of the causes for land degradation but the main cause is misuse of the land and over taxation of the land due to lack of knowledge or socio-economic conditions.

Interview was held with local (Alemaya Woreda) peasants to access their landuse system and their agricultural productivity. Almost all peasants and persons who were interviewed testified that their amount of yield, no matter what, has been declining each year. As a better but may not be best they use fertilizer to increase their yield
According to recent research finding (Hurni, 1993), the area yield per cm depth of surface soil removal is estimated to be (6%).

The most common reasons for this productivity decline according to the peasants are compactness of farm size; lose of soil nutrients due to erosion by seasonal rainfall, and cost of fertilizer. First, with regard to the weather they understood that due to heavy rain sometimes, since the majority don't use erosion prevention mechanism and clear the vegetation covers, their farm lands got erosion with the crops that they did sow on it. So the peasant's explanation of the process is very simple excessive rain washes the soil and the seed, and it results declining of productivity year to year. So they are endangered of food shortage (security) in every year.

Second due to lack of soil nutrients and leaching effect, peasants are forced to use fertilization to sustain the land. But since the price of fertilization is becoming higher than their income, the peasants face troubles. It is also interesting to note that some farmers are using local fertilizer like animal wastes, compost and mixed cultivation systems. These group of farmers should be encouraged because they afraid that the fertilizer would "burn" the soil of the land and lose it out, so they are not volunteer to use it even when they could afford it.

An elderly peasant farmer from Alemaya Woreda summarized the land degradation and its impact in declining of productivity as:

"If I had a son who is more than 18 years old, I cannot give him a pieces of land because I don't have enough even for my self, so he will look for a house hold with an unmarried woman and by being or looks like a very nice person he tries to win a marriage. If that fails, he will look for older people with land and makes some kinds of rental arrangement. If that fails again, he goes to urban areas for daily labor though this is not a good idea. If that all doesn't work, he will help me on the land that I have and that will not be my choice since it will not good for either of us."

So here we can clearly see the problem of population growth coupled with degradation and declining of land productivity.

5.1.4 Implication on Livestock

As discussed above, some lands in the study area are covered with weed infestation and bush encroachment (cactus tree) at the expense of farm and grazing lands. So this thing truly affects the existing livestock condition in the area; that means, due to lack of grazing lands the number of household animals like sheep, ox and goat are decreased.

The peasants who were interviewed responded that, we have small grazing lands and even the existing grazing land is being converted to agricultural lands. So that, even though we wish to have more of those cattle, we have no access to feed them.

Majority of the peasants that we interviewed and contacted in person have got only one ox or none. So unlike other highlands of Ethiopia, in eastern highland especially in Alemaya woreda and the surrounding most places, people use human hand digging cultivation and only rare peasants practiced oxen plaguing system.

The main case for the shortage of grazing land is expansion of new agricultural lands at the expense of grass lands and the conversions of former agricultural land to bare land.
As illustrated in (Table 4.3), Grass lands decreased from 1689.8 ha in 1986 to 1973.1 ha in 2003. So that the percentage coverage decreased from 2.49% in 1986 to 1.43% in 2003.

5.2 Lake Degradation

5.2.1 Cause of Lake Degradation

One of the major implications of change in landuse and landcover in the study area is lake degradation. Around the year 1980's and 1990's there were 3 important lakes in the area which had a lot of contributions for the livelihood of the society. These lakes were known by the name Lake Alemaya, Finkile and Adele. Out of these lakes Alemaya was the largest in size and being highly consumed by local people.

Now all of these lakes become history and dried for good due to different reasons. All of these losses ultimately affect the warfare of the local people. There are certain factors that have real contributions for the dry up of the lake. These include:

Sedimentation or siltation: Land degradation in the area also adversely affects water resources through increasing sedimentation and dries up of lakes (figure 5.5). Sedimentation is most often the result of soil erosion due to inappropriate land management. Water pollution and sedimentation are both predominant in the area due to intensive farming.

Figure 5.5 Picture showing erosion impact to the lake (2006).

As a testimony to take sedimentation or siltation as one of the main factor for the lake degradation is there was a water that farmers were using just 2 meter below the surface but now due to increase of depletion of the ground water, the depth reaches to 3.5m below the surface.

Increase of urban population and urban agriculture: Alemaya Lake lies at the center of one of the highly populated area of the country. During the Derge Regime, the population in the water shed has dramatically increased because of the formation of farmers' cooperatives and the villegization program of Ethiopian government. All of the people who live in area from Alemaya up to Harer town and industrial activities make use the lake water for domestic and industrial purposes. So due to this population and urbanization growth in the area, consumption from the lake for a variety of purposes increases and ultimately brought impact in decreasing the size of the lake (see water balance table).

Irrigation by local people: the method of irrigation in the area has also an effect on the lake in that a large quantity of water is being withdrawn for the fields by a number of irrigation pumps with out taking the crop water demand into consideration.

Figure 5.6 Cultivation around Alemaya based on irrigation (2006).

Over the year large area of natural environment around the lakes have been modified and converted to relatively stable agricultural land which are capable of producing vegetables like potato, tomato, onion and other vegetation types as well as the typical perennial crop called "chat". So that, the change of landuse from grass land and shrub to cultivation land made the lake to be exploited more than before for irrigation (picture of vegetables around the lake).

According to Shlimelis (2003), the irrigation water application efficiency of the whole farmers around the lake was estimated as 41%. This is due to poor management of water for irrigation and hence this to some extent leads to depletion of Alemaya Lake.

5.2.2 Water balance of Lake Alemaya

According to Solomon (2002), the water balance of Alemaya Lake is estimated in the following table.

Annual Surface inflow (m^3)	**Abstractions from the Lake, m^3/year**							**Change in storage** (m^3)
	Losses due to evaporation (m^3)	For domestic water supply (m^3)	For Alemaya University (m^3)	For rural household and livestock (m^3)	For irrigation practices around LA (m^3)	[1]Water for miscellaneous uses (m^3)	Total abstraction (m^3)	
6,731,614	**2,630,515**	**1,752,000.**	**150,829**	**550,128**	**1,874,880**	**54,750**	**6,862,273**	**130,659**

Table 5.1 water balance of Alemaya Lake, (water for miscellaneous uses includes water used for construction, carwash, etc).

In the water balance table (Table 5.1), it looks that the climatic factor (evaporation) takes the highest share for water out put from the lake. However, this natural factor is not the immediate case for the lake to dry up because the temperature of the area is almost constant for the last 30 years (see table 3.1).

Generally, due to the above main causes, landuse changes and other human and environmental factors the lake could be dried since February 2005 and a new ecosystem is started in the area .Typically now the lake area is being used for grazing, agriculture and some part left as marsh land (See figure 5.9).

5.2.3. Time series lake size change of Alemaya (1965-2006)

For better comparison of the lake size change, three consecutive aerial photographs of the years 1965, 1996 and 2004 were taken, interpreted and digitized with inclusion of the watershed landuse and landcover classes .And the result put in figure 5.6, 5.7 and 5.8 consecutively, so that as it illustrates, the lake size decreased to 265.9 ha in 1996 and to 226 ha in 2004 which was 393 ha in 1965. The current year (2006) landuse and landcover situation of the lake area also included using field photographs (figure 5.9).

In the interpretation of aerial photograph of 1965 for the categorization of land use and land cover of the study area, crop lands were identified by the regular edges of farm plots, tone and smooth texture. The land use and land cover pattern of the year 1996 was also determined on the basis of interpretation of the aerial photo flown in 1996(in the month of December) along with the land use and cover history of the areas, as expressed by the community .The interpretation of year 1996 aerial photograph and the land use history of the study area around lake Alemaya indicated that majority of the area was cultivated for maize and sorghum crops (figure 5.8).

The analyses for land use and land cover of 2003 showed that the coverage of chat crop has been increasing with time while the lake water decreased in size and nearer to dry up. The elements and distribution of the current land use and land cover in the particular lake place were examined by visual observation and walking inside different parts of the area.

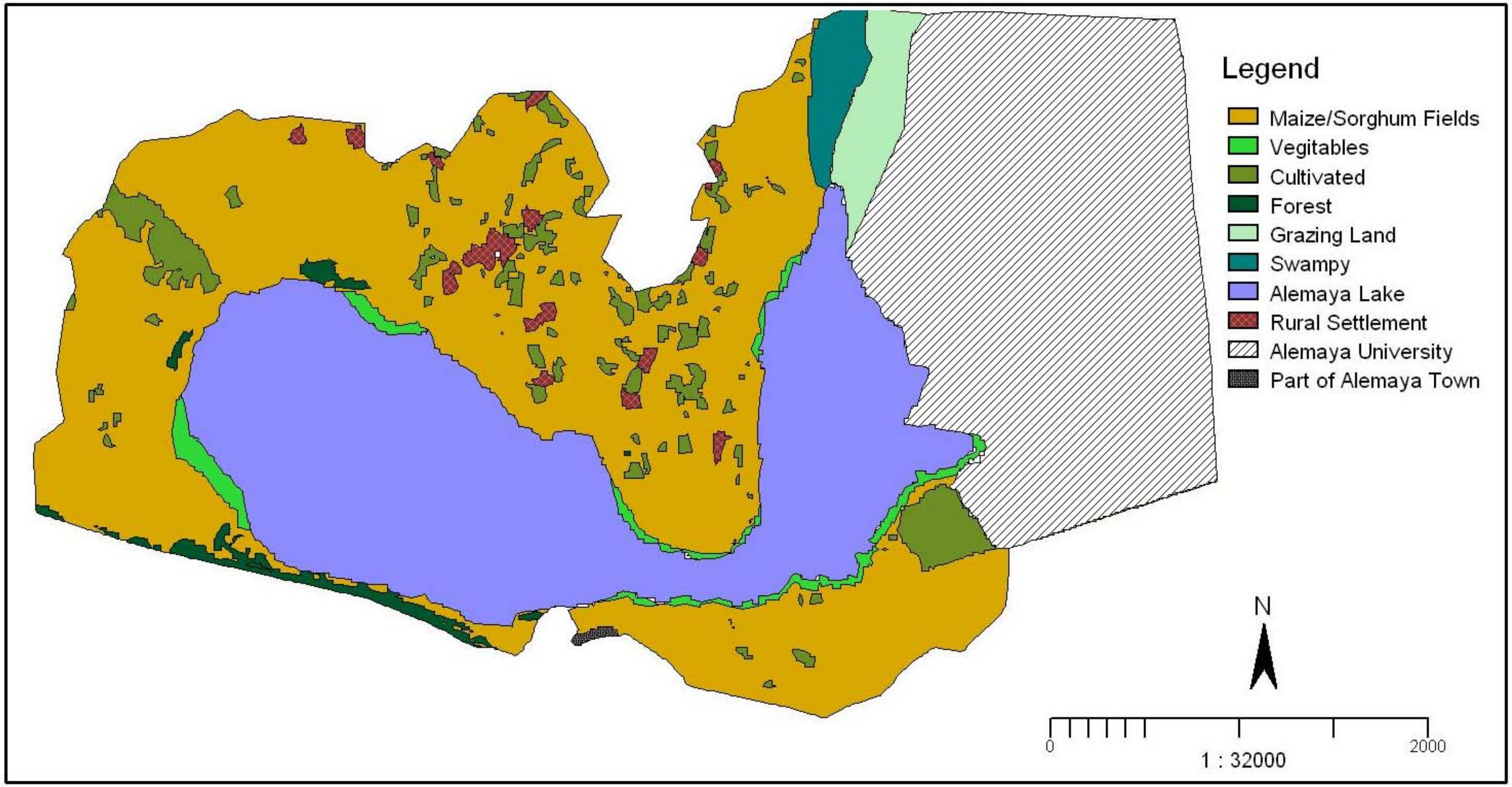

Figure 5.7 The size of Lake Alemaya and it's watershed landuse and landcover map, 1965.

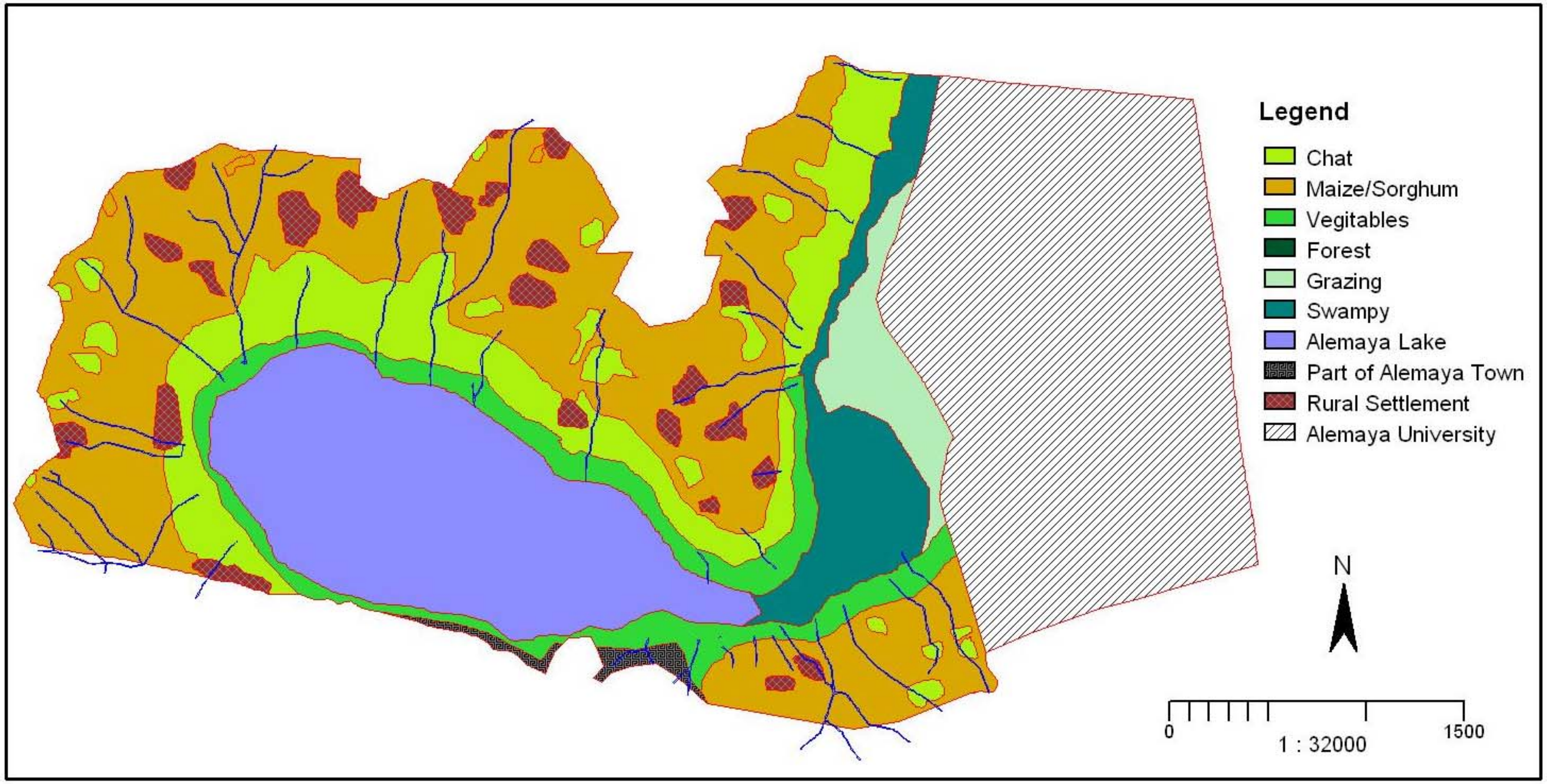

Figure 5.8 The size of Lake Alemaya and it's watershed landuse and landcover map, 1996.

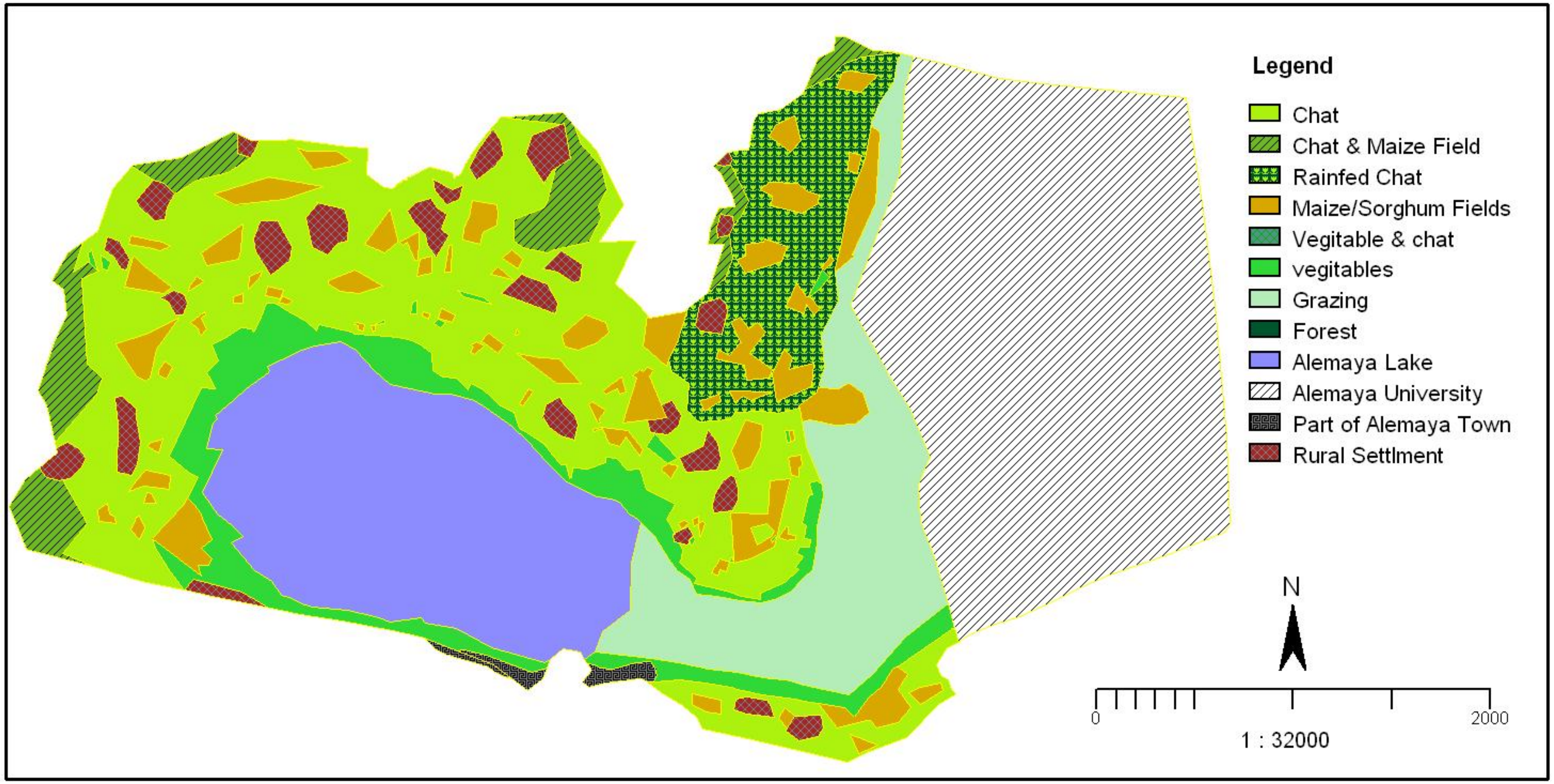

Figure 5.9 The size of Lake Alemaya and it’s watershed landuse and landcover map, 2004.


Marsh area

Grazing

Figure 5.10 current land use/ cover of Alemaya Lake (marsh, grazing and cultivation), 2006.

5.2.4 Consequence of the Lake Degradation

The loss of the lakes brought over all impact in the environmental ecosystem. The local people both farmers and urban dwellers are those who primarily suffered from the lose of the lakes. It is mentioned that Alemaya and Harer people were using the lakes for variety of purposes like: fishing, drinking, recreation and sanitation, transport and irrigation. Now these all become history and none of them are possible at this time.

So it is easy to understand how much the lake was meant to these people and how deep their sorrow is to lose these lakes.

At this time, the hope of the local people and what they practically do is, using the ground water, which is indeed a little bit expensive end requires more money and energy than the surface water which was accessed by all people equally.

Groundwater is being heavily exploited mainly for agriculture and drink purposes. So that tube wells are observed here and there in the lake area.

Figure 5.11 Groundwater well in the lake bed (2006).

In major vegetable producing areas the number of tube wheals has risen which allows many farmers to intensify and stabilize agriculture on their land. However, this ground water potential is not being accessed by all farmers since it needs significant amount of money to buy the pumping machine and the distributor tube.

In this regard interview was held with local farmers to collect data about the depth of their problem following the dry up of the lake. Ato Abdi Ahmed is a farmer living around Alemaya lake since 1975 E.C, he said “Before 2004(1996 E.C), we didn’t consider water shortage as a serious problem. However, after 2004, the farmers in the village including me have begun to worry about the increasing of water shortage issue and resulting negative consequence on our production and livelihood.” He hopes that the government can give them some good solution and advice them on reserving water shortage issue in the long run.

From March 2005 till today groundwater is the sole source for irrigation and drinking in Alemaya area. But with the increase exploitation of ground water the water table has declined from 1 and 1.5m below the surface in 2005 to 3 and 3.5m in recent time (2006). Hence, the farmers fear is that, as the water table drops as low as 4m and above they have to invest more and more money to dig deeper and deeper tube wheels.

The other significant body which seriously suffered from the dry up of the lakes is Harari Region. Because especially lake Alemaya was their main water supply till 2004. Even though the problem is there within each house holds in the region, and interview was held with the regional investment office to obtain better information about its impact on the regional development of Harari.

Ato Mefetueh sheriff, Manager of investment office of Harer, explained that “many investors took permission to run investment on especially marble and soft drinks but neither of them had started it. Even if some of them had started, they stopped it soon. The main reason for this is the water shortage of the region and the dry up of our main water source i.e. Alemaya Lake. So in this way the dry up of the lake has direct and serious impact on our investment issue.”

He further explained that if water was available and the investment was started, it would increase employment opportunity of the region, regional development and would pave a way for many other development strategies together with increasing government income. However, these all cannot be possible due to the disappearance of the lake, unless we get another water source. But still getting a new water source is not as such easy because it will take long time and requires huge amount of money.

Therefore, the Alemaya lake degradation and its final drying up brought all the above crises in the people of Alemaya and the near by Harari Region.

CHAPTER SIX

6. Conclusions and Recommendations

6.1. Conclusions

In this study landuse and landcover changes and land degradations are assessed by integrating GIS and remote sensing techniques.

In the study area, the largest landuse and landcover is occupied by temporal crops (maize and sorghum), which covers 51.6% of entire area in 1985 and 41.2% in 2003. It's conversion to bareland and to some extent to perennial crop land are main factors for it's decline in 2003. Next to temporal crop land, bareland and perennial crop land possesses larger landuses each of which contain 26.7% and 21.5% of entire study area respectively.

Even though many changes are observed among the landuses and landcovers in the year between 1985 and 2003, the highest change is observed in grass lands which is decreased by 42.4%.The highest rate of changes are seen in temporal cropland which is -393.4 ha in every year and bare land which is 171.6 ha/year.
Beside grassland; shrubs, temporal crops, water bodies are also decreased in size by 2073%, 25.4% and 59.1% respectively in 2003, when compared with 1985.

Conversely, perennial cropland, marsh area, residents and wood lands increased by 26.6%, 20.6%, 705.9%, 109.7% and 7.3% respectively, in the last 20 years. These land area / covers increased mainly at the expense of grass lands and shrubs.
Due to population growth of the area residents which means urban settlements increased from 334.6 ha to 701.7 ha. Plantations of eucalyptus and coniferous are more or less constant in the two years period.

Slope analyses also done based on selected and relevant land uses of Bareland, Temporal crop land, Grassland and shrubs. So the result illustrated that bareland increased in all slope classes though the highest change is seen the range between 5.5 - 9.4, shrubs and grasses highly changed (reduced) in the slope range of 0- 1.9 and temporal croplands showed the highest decline in the slop range of 9.7- 19.5.

These over all changes in landuse and landcover have a lot of consequences and implications in the study area. Particularly; the changes in water bodies (mainly lakes) caused a lot of sufferings upon many of the local people. Moreover, the rapid increase of land degradation is also the other serious problem of the area.

Lack of knowledge, unwise use of land and inability to use erosion prevention mechanisms are considered as responsible factors for land and lake degradation of the area.

6.2. Recommendations

In this study, various land use and land cover changes were observed. These changes didn't take place with out negative consequences up on the environment and local people. Therefore, the following recommendations are provided to improve the landuse and landcover status of the study area.

- **Improve literacy level of the society:** In the study area, level of literacy is low. Therefore, farmers should be thought and encouraged to use different erosion prevention mechanisms, such as, terracing in steep slope area and to use ox plough system (contour plough) than human hand digging. More over, farmers who use animal dung instead of fertilizer should be encouraged and motivated. So that the cumulated effect of these all will help to minimize land degradation.

- **Environmental Rehabilitation program** should be done especially in severely eroded area. The already started plantation activities by Alemaya University and Harer Beer factory are good initiatives so it should be encouraged and expanded in wider area.

- **The surface water is already gone**, now what left is the ground water. So unless the ground water is utilized properly it might face similar fate like the surface water i.e. if the depletion increases it will be more and more difficult to access it since the depth also increases. Therefore, to make the ground water for sustainable use, irrigation of the ground water should be done properly and economically. In this aspect farmers should get orientation and lesson to not over use the ground water in their farm land.

- **Population policy:** Rapid increase of population number in the study area is one of the causes for change in landuse and landcover. The current house hold family size and it's annual crop production are not proportional, that is why, the local farmers are always endanger of food security. Therefore, lesson should be given to the society regarding with the impact of population growth on their living situation. Family planning and sex education should be given widely and continuous through formal and informal ways.

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APPENDICES

Appendix A. Climatic data observations at Alemaya metrological station

Table A-1. Monthly mean Maximum temperature of Alemaya area, Source: EMSA

Year	**Months of the year**												**Total**
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
1974	23	23.9	22.7	25.7	23.8	22.6	22.5	22.4	22.3	23.8	22.2	21.7	**276.6**
1979	20.9	22.4	24.1	24.9	24.6	23.7	22.7	x	x	x	23.3	23	**209.6**
1980	23	25.3	x	25.2	x	26	23.8	23.8	23.4	23.9	24	22.5	**240.9**
1981	24.4	24.4	23.7	24.1	24.2	26.4	22.6	21.9	21.8	23.6	22.9	22.2	**282.2**
1982	23.2	24.3	24.5	22.7	24.1	24.1	22.9	23	23.3	22.2	22.4	21.9	**278.6**
1983	22	22.5	25.8	25.1	24.2	24.3	23.1	22.2	23.2	23.3	22.7	21.7	**280.1**
1984	21.4	23.2	26.6	27	24.4	23.3	x	23.5	23.1	24.6	23.3	22.1	**262.5**
1985	23.4	22.6	25.3	x	24	23.8	23.4	22.8	23.4	23.7	23.7	23.7	**259.8**
1986	22.9	24.3	25.2	22.7	23.3	22.4	21.6	22.7	21.9	23.6	23.6	21.9	**276.1**
1987	21.3	24	24.1	23.9	23.5	24.6	23	23	24	24.7	24.1	23.3	**283.5**
1989	20.7	23.5	24.9	22.1	24.5	24.5	22.6	23.2	23	24.1	23.2	22.5	**278.8**
1990	22.9	24.4	24.2	23.9	25.7	25.4	24.5	23.3	23.8	23.8	23.7	22.3	**287.9**
1991	24.3	24.4	24.9	24.4	25	26.1	21.1	23.1	23	24.4	x	x	**240.7**
1997	23.5	24.6	26.7	24	25.3	23.8	23.4	23.9	25	24	22	x	**266.2**
1998	22	24.2	25.5	26.9	26.1	26.9	23.9	23	23.5	23.3	23	22.1	**290.4**
1999	23.2	25.6	23.5	26	25.3	24.9	22.8	23.3	23.1	22.2	22.3	21.8	**284**
2004	23	24.8	26.1	25.9	24.6	25	24	23.1	23.4	22.6	22.6	x	**265.1**
Average	**22.6**	**24.0**	**24.8**	**24.6**	**24.5**	**24.5**	**22.9**	**23.0**	**23.20**	**23.6**	**23.0**	**22.3**	**268.4**

X Represents the missed climatic data

Table A-2. Monthly mean minimum temperature of Alemaya area, Source: EMSA

Year	Months of the year												Total
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
1974	3.8	6.6	11.2	8.8	12	12.2	13.1	11.9	11	5.5	0.8	1.2	**98.1**
1979	8.6	7.9	11	10.3	13.1	13	12.6	X	x	x	2.2	5.8	**84.5**
1980	6	8.9	x	12.8	x	13.7	13.1	12.9	12.3	6.4	4.1	1.5	**91.7**
1981	4.5	8.1	12.5	12.6	13.5	13.4	12.9	12.9	12.1	6.5	0.7	0.9	**110.6**
1982	7.2	9.6	10.1	12.2	12.1	13.7	13.3	13.2	12	7.3	6.8	5.6	**123.1**
1983	3.7	9.5	12.3	13.2	14.4	13.9	13.5	13.3	12.7	7.2	5	3.6	**122.3**
1984	3.7	3.8	3.5	10.2	13.1	13.3	x	12.6	11.5	5.7	4.2	1.2	**82.8**
1985	1.1	4.5	9.7	x	13.1	12.5	11	10.6	9.2	3.6	0	-0.9	**74.4**
1986	1.6	7.5	8.2	11	11.6	11.3	10.1	10.1	9.5	4.1	0.1	-1.3	**83.8**
1987	3.2	7.7	13	11.1	12.5	14	13.6	13.7	12.4	9	3.7	3.9	**117.8**
1989	4.1	6.7	10.9	12.8	12.3	13.1	12.8	12.3	11.9	7.3	4.6	8.5	**117.3**
1990	4.8	11.7	7.9	11.8	12.9	13.6	8.6	13	13.2	6.4	4.4	2	**110.3**
1991	5.8	9.2	12.7	12.1	13.2	4.2	13.4	13.2	12.6	5.5	x	x	**101.9**
1997	7.5	3.6	10.4	11.6	13.7	13.6	13.2	13	13	11	9.1	x	**119.7**
1999	4.6	5.1	11.3	11.3	13.2	13.9	13.3	13.4	12.1	10	3.4	2.9	**114.5**
2004	2.6	3.4	7.9	11.9	14.1	13.9	13.2	13.2	13.3	7.8	6.8	x	**108.1**
Average	**4.55**	**7.11**	**10.17**	**11.58**	**12.99**	**12.71**	**12.51**	**12.62**	**11.92**	**6.89**	**3.73**	**2.68**	**103.81**

X Represents the missed climatic data

Table A-3. Monthly total rainfall of Alemaya area, Source: EMSA

Year	Months of the year											Total
	Jan	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
1974	0	42.9	177.4	11.6	130.4	93	121.2	105.6	132.7	4.9	0	0	**819.7**
1979	38.5	6.7	72.4	82.4	178	55.8	81	x	x	x	3.5	17.9	**536.2**
1980	0	10.5	x	74.2	x	53.9	68.9	95.9	127	35	11.6	0	**477**
1981	4.2	8.4	239.3	168.3	120.2	16.2	122.7	204.7	142	15.2	2.6	0	**1043.8**
1982	3.1	57.8	61.6	92	141.7	31.2	85.4	122.1	87.6	158.8	38.1	11	**890.4**
1983	0	25.7	13.3	80.9	176.3	75.3	116.1	300.6	151.4	23.5	4.2	0	**967.3**
1984	0	0	0	25.6	167.7	71.9	x	101.6	100.2	0	17.5	6.7	**491.2**
1985	0	0	46.9	x	87.6	29.7	88.3	80.2	69.6	9.9	6.1	0	**418.3**
1986	0	38.6	14.1	153.9	110.1	80.8	66.1	161.4	96.7	34	5.8	0	**761.5**
1987	0	8.1	180.2	148.6	248.2	29.6	63.3	123.2	111.9	28.8	2.7	0	**944.6**
1988	9.8	43.8	30.4	154.3	31.3	54.1	101.5	173.7	173.4	41.9	0	6	**820.2**
1989	0	14.4	154.9	114.5	69.4	52.6	104	146	104.4	41.2	3.6	45	**850**
1990	1.7	73.1	45.4	132.3	59.6	54.1	80.9	162.3	133.8	53.3	0	7	**803.5**
1991	0	51.7	36.2	73.2	58.6	25.7	108.3	104.8	120.1	25.8	x	x	**604.4**
1992	3.9	11	18.2	85.2	65.1	68.3	77.5	97.6	107.1	36.6	10.4	4.1	**585**
1997	0	0	78.1	125.4	155.9	59.8	148.7	102.7	61.7	194.1	60.4	x	**986.8**
1998	86.5	51	20.3	59.9	55.4	24.8	116.5	104.4	175.7	54	21.3	0	**769.8**
2004	0	3.7	68.3	71.5	77.4	30	95.2	238.3	145.8	135.7	12.8	4.9	**883.6**
Average	**8.2**	**24.8**	**73.9**	**97.2**	**113.7**	**50.3**	**96.8**	**142.6**	**120.0**	**52.5**	**11.8**	**6.4**	**758.5**

X Represents the missed climatic data

Table A-4. Monthly mean Sunshine of Alemaya area, Source: EMSA

Year	Months of the year											
	Jan.	**Feb.**	**Mar.**	**Apr**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
1972	9.3	6.4	8.4	6.3	8.4	7.5	6.3	7.6	6.9	7.9	9.2	9.5
1973	9.5	9.6	10.1	7.6	7.0	7.6	6.6	6.1	6.9	8.0	10.1	x
1974	9.7	8.7	4.6	9.2	x	7.7	7.6	6.7	6.6	7.9	10.6	10.2
1975	10.1	9.1	8.4	7.2	8.6	7.9	6.8	4.7	6.1	8.3	9.9	10.4
1976	9.7	7.7	8.1	7.3	x	x	x	x	x	x	x	x
1979	x	x	x	x	6.6	2.5	6.2	x	x	x	9.8	8.6
1980	9.8	9.7	x	x	x	x	7.3	7.9	7.1	7.8	9.6	10.2
1981	10.0	9.1	x	5.7	7.3	8.4	6.4	6.8	5.1	8.7	9.8	9.4
1982	7.6	7.3	8.8	6.1	7.2	7.9	6.9	7.2	7.6	4.7	7.5	8.2
1983	8.8	6.8	8.2	7.1	x	x	x	5.2	7.0	7.6	9.3	10.0
1984	10.1	10.5	9.5	8.9	7.0	8.3	x	x	7.2	9.2	9.0	8.5
1985	9.4	9.7	8.1	x	7.2	6.8	x	x	7.4	x	x	x
1986	9.6	x	8.5	5.6	6.1		7.2				9.7	
1987	x	x	x	x	x	x	x	x	x	x	x	9.4
1988	9.5	x	x	x	x	x	x	x	x	x	10.4	x
1989	9.0	x	7.4	x	8.7	x	x	x	x	x	x	x
1990	9.3	6.3	7.8	6.4	x	x	x	x	x	x	x	x
1999	x	x	x	x	x	x	6.8	8.9		7.2	x	x
2004	x	11.1	10.5	8.0	7.9	8.7	7.7	7.0	7.4	7.4	x	x
Average	**9.4**	**8.6**	**8.3**	**7.1**	**7.5**	**7.3**	**6.9**	**6.8**	**6.8**	**7.7**	**9.6**	**9.4**

X Represents the missed climatic data

Table A-5. Monthly mean wind speed of Alemaya area, Source: EMSA

Year	Months of the year											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	1.72	1.72	1.97	1.87	2.07	2.72	2.56	x	x	x	1.50	1.84
1980	1.91	2.33	x	2.06	2.65	3.04	3.18	2.71	1.66	1.35	1.71	1.76
1981	1.78	2.13	2.31	1.59	2.06	3.14	2.88	2.16	1.09	1.09	1.63	1.37
1982	1.54	1.93	2.19	2.12	1.76	2.90	3.12	2.59	1.77	1.25	1.20	1.38
1983	1.93	2.02	2.43	2.27	1.97	2.29	2.63	1.79	1.20	1.02	1.27	1.55
1984	1.95	2.21	2.69	2.37	2.26	3.76	x	2.31	1.43	1.31	1.38	1.56
1985	1.69	2.58	2.25	x	2.27	3.54	2.97	2.86	1.61	1.48	1.31	1.70
1986	2.09	1.97	2.11	2.03	1.66	2.32	2.26	1.76	1.16	1.05	1.18	1.48
1987	1.63	1.76	1.76	1.42	1.22	2.13	3.55	2.43	1.53	1.16	1.33	1.54
1988	1.73	1.79	1.96	1.95	2.25	2.69	2.33	1.69	1.01	0.58	1.22	1.18
2004	1.80	1.70	1.60	1.70	2.10	2.60	2.30	2.10	1.50	1.10	1.60	1.70
Total	19.77	22.14	21.27	19.38	22.27	31.13	27.78	22.40	13.96	11.39	15.33	17.06
Average	**1.80**	**2.01**	**2.13**	**1.94**	**2.02**	**2.83**	**2.78**	**2.24**	**1.40**	**1.14**	**1.39**	**1.55**

X Represents the missed climatic data

Table A-6. Monthly mean Humidity at 0600, Source: EMSA

Year	Months of the year											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961	83.0	x	x	94.0	91.0	98.0	96.0	97.0	96.0	99.0	95.0	85.0
1962	8.0	x	x	x	x	x	x	x	x	x	x	x
1966	x	x	x	x	x	x	x	x	x	x	78.0	76.0
1967	75.0	x	x	72.0	70.0	73.0	85.0	80.0	74.0	90.0	89.0	88.0
1968	80.0	83.0	86.0	94.0	94.0	90.0	99.0	99.0	97.0	93.0	93.0	76.0
1969	74.0	77.0	83.0	86.0	88.0	88.0	88.0	83.0	90.0	90.0	91.0	83.0
1970	86.0	78.0	90.0	87.0	89.0	86.0	x	x	x	x	x	x
1971	81.0	77.0	76.0	83.0	91.0	x	88.0	87.0	89.0	x	86.0	86.0
1972	x	90.0	x	x	92.0	93.0	90.0	x	91.0	83.0	94.0	92.0
1973	88.0	78.0	69.0	80.0	92.0	90.0	88.0	89.0	91.0	90.0	87.0	x
1974	88.0	86.0	78.0	74.0	93.0	86.0	87.0	87.0	87.0	86.0	85.0	93.0
1975	x	x	x	x	x	x	x	x	x	x	89.0	x
1976	84.0	84.0	83.0	87.0	x	x	76.0	84.0	x	x	x	x
1979	x	x	x	x	x	x	x	x	x	x	41.0	53.0
1980	55.0	50.0		55.0	58.0	80.0	67.0	67.0	66.0	51.0	49.0	37.0
1981	40.0	59.0	73.0	78.0	74.0	77.0	87.0	87.0	80.0	x	x	x
1984	53.0	x	x	53.0	74.0	x	x	x	x	x	x	x
1999	89.0	x	x	x	x	x	x	x	x	x	x	x
2000	97.0	88.0	73.0	82.0	90.0	87.0	88.0	85.0	89.0	89.0	82.0	x
2004	x	85.0	79.0	83.0	88.0	90.0	89.0	90.0	92.0	87.0	x	x
Average	**72.1**	**77.9**	**79.0**	**79.1**	**84.6**	**86.5**	**86.8**	**86.3**	**86.8**	**85.8**	**81.5**	**76.9**

X Represents the missed climatic data

Appendix B. Maps and satellite images of the area.

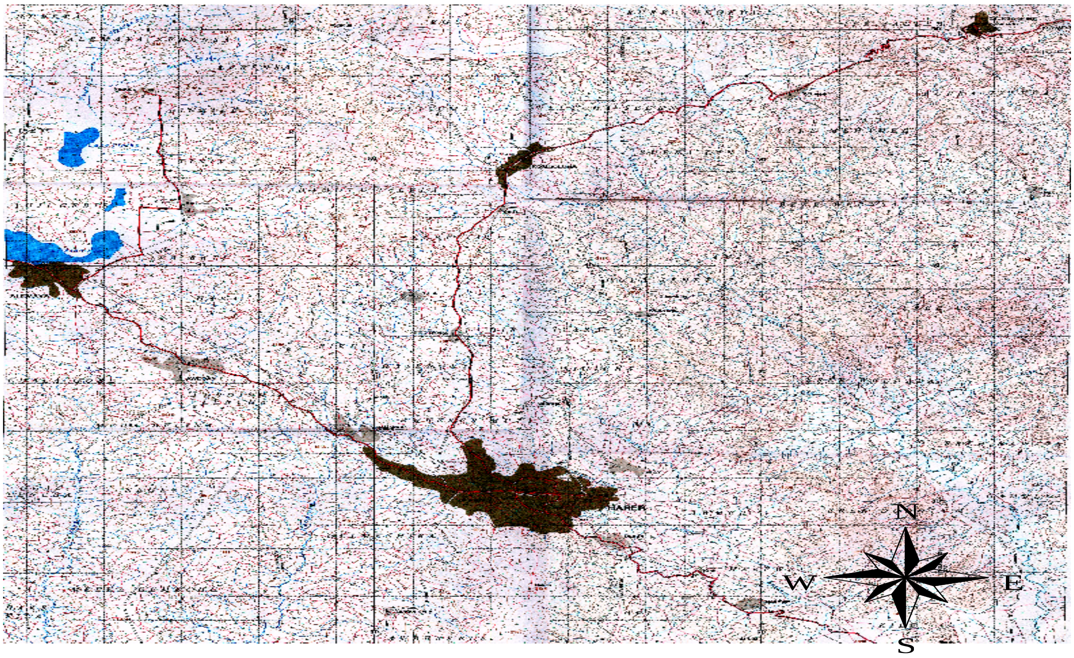

Figure B-1. Topographic maps of the area for the year 1996 (printed in 2000).

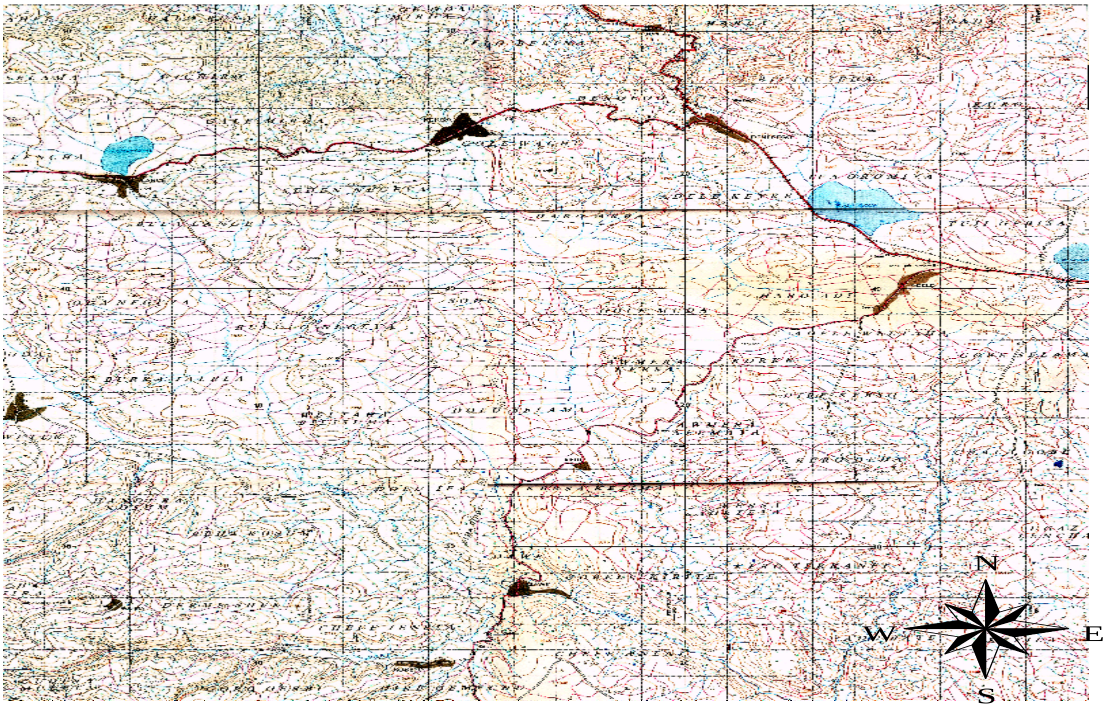

Figure B-2. Aerial photograph of Lake Alemaya area for the year 1996.

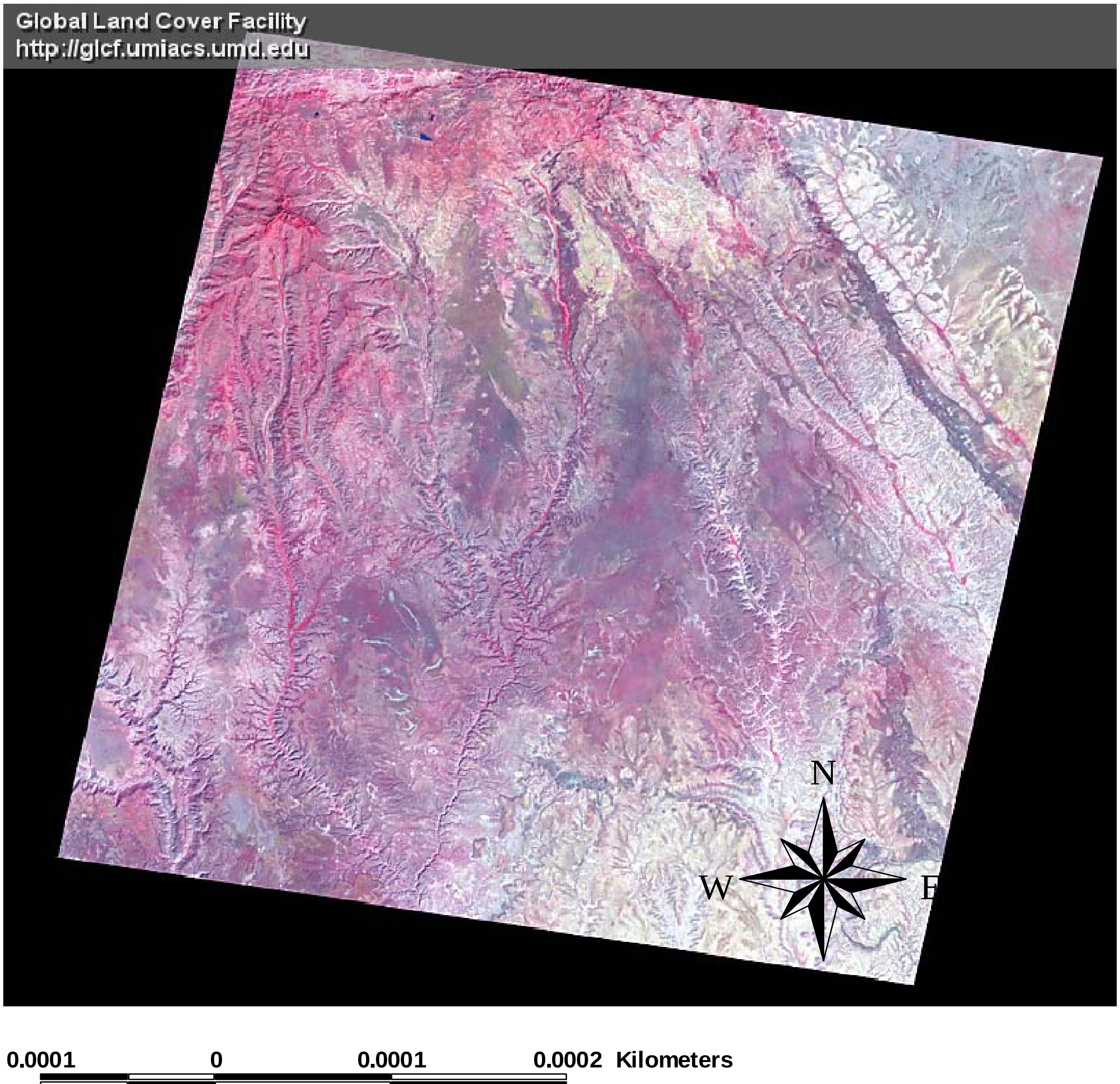

Figure B-3 Land sat image for the year 2003.

Figure B-4 land sat image for the year 1985.

DECLARATION

I, the undersigned, declare that this thesis is my work and that all sources of materials used for the thesis have been duly acknowledged.

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