



ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
FACULTY OF NATURAL SCIENCE  
DEPARTMENT OF EARTH SCIENCES

ASSESSMENT OF LAND DEGRADATION USING GIS BASED MODEL AND  
REMOTE SENSING IN BISHAN GURACHA-ADILO SUBCATCHMENTS,  
SOUTHERN ETHIOPIA



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ASSESSMENT OF LAND DEGRADATION USING GIS BASED MODEL AND  
REMOTE SENSING IN BISHAN GURACHA-ADILO SUBCATCHMENTS,  
SOUTHERN ETHIOPIA

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*(Remote Sensing and GIS Stream)*

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## **Lists of Acronyms or Abbreviations**

a.m.s.l	above mean sea level
BoFED	Bureau of Finance and Economic Development
C	Crop management factor
CREAMS	Chemicals, Run off, and Erosion from Agricultural Management System
DEM	Digital Elevation Model
EHR	Ethiopian Highland Reclamation Study
EMA	Ethiopian Mapping Authority
ERDAS	Earth Resource Data Analysis System
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
Fig	Figure
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
ITCZ	Inter Tropical Convergence Zone
K	Soil Erodibility factor
Km <sup>2</sup>	Square kilometer
LS	Length and Slope Steepness factor
LU/LC	Land use/ Land cover factor
mm	Millimeter
MSS	Multispectral Scanner
NDVI	Normalized Differencing Vegetation Index
NIR	Near infrared
NMSA	National Meteorological System Agency
P	Conservation Practice Factor
Pow	Power
R	Rainfall Erosivity factor
SCR	Soil Conservation Research Project
SNNPR	Southern Nation and Nationalities Peoples' Region
t/ha/yr	ton per hectare per year
TIN	Triangulated Irregular Network
TM	Thematic Mapper
UNESCO	United Nations Education, Science, Culture organization
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Project
WGS	World Geodetic Survey

## **Abstract**

This study is aimed at assessing the spatio-temporal changes of land use / land cover and identifying land degradation area in the form of soil erosion in Bishan Guracha-Adilo subcatchments. The three landsat images (1973, 1984 and 2000) were classified into five major land use / land cover classes based on supervised classification of 2000 image. Post classification change detection among three classified images was conducted. Accordingly, classes classified as intensively cultivated and degraded / barren lands were expanding in areal coverage at the expense of others. However, moderately cultivated, wood and grazing lands of the study area became reduced in size in the time span of 1973 to 2000. On the other hand, NDVI images analysis comparison also done to look into the vegetation/ land cover degradation or change between 1984 and 2000 images, its result implies a decline in land cover taking the standard deviation variation in to account.

Universal Soil Loss Equation (USLE) model was used for estimation of soil erosion amount by computing each input mostly on the basis of the adapted methodology of the previous researches for Ethiopian highlands. The estimated annual soil loss for the study area ranges from 0.02 to 133.2 t/ha/yr. These values were classified in to six classes or degree of soil erosion depending on the calculated soil erosion amount. Of which the last class having greater than 30 t/ha/yr, which is 2470 ha (6%) is considered to be as priority (spot) zone of the study area. In contrary, about 86% of the study area experiences annual soil loss less than 10 t/ha/yr. The estimated annual soil loss was evaluated against land use/ land covers classes, slope gradient and drainage density. Slope gradient and drainage density have got positive relationship with soil loss but land use / land covers did not show distinct pattern of relationship with that of the estimated annual soil loss of the study area. In connection with the two-subcatchments' more vulnerability to estimated annual soil loss, comparison has been made by considering areal size being exposed to different degree of the annual soil loss. This could result in making Bishan Guracha River subcatchment as more vulnerable to high soil erosion by taking its large percentage of area under greater than 30 t/ha/yr.

**Key words:** Land degradation (soil erosion), USLE, post classification change detection, land use/ land cover classes, estimated annual soil loss.

# **1. INTRODUCTION**

## ***1.1 Background***

Land degradation is the temporary or permanent lowering of the productive capacity of land (UNEP, 1999). It affects adversely the productive, physiological, cultural and ecological functions of land resources, such as soils, water, plants and animals. As a result it thus covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of farming and rangelands.

Land degradation is closely associated with soil degradation. The loss of vegetation enhances soil erosion and reduces the productivity value of the land (Hill et al, 1995). In the same manner, Morgan (1996) also describes that soil degradation or erosion is a hazard traditionally associated with agriculture in tropical and semi-arid areas and is important for its long-term effects on soil productivity and sustainable agriculture.

Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system. Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes, which are not fully understood. Interactions between the two systems determine the success or failure of resource management programs. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability) (WMO, 2005).

It is obvious that soils usually take a long time to form, perhaps up to 400 years for 10mm and under extreme conditions 100 years for 1mm. It can take 3000- 12000 years to produce a significant depth of mature soil for forming (Waugh, 1995). However, degradation of soil has been caused mainly by water logging and compaction, erosion, acidification, salinization and sodification and the accumulation of heavy metals and other inorganic contaminants would limit the productivity of the soil.

Land degradation has affected some 1900 million hectares of land world-wide. In Africa an estimated 500 million hectares of land have been affected by soil degradation, including 65% of the region's agricultural land. The rate at which arable land is being lost is increasing and is currently 30-35 times the historical rate. The loss of potential productivity due to soil erosion world wide is estimated to be equivalent to some 20 million tons of grain per year. And this is happening worldwide, not just in Africa or Asia (UNEP, 1999)

In Ethiopia, cultivation on steep slopes and clearing of vegetation has accelerated erosion. The soil loss from different land categories is very high. The soil formation rate for Ethiopia is less than 2 t/ha/yr, which was very low compared to soil erosion rates (Hurni, 1993). In addition, Hurni states that annually Ethiopia loses over 1.5 billion tons of topsoil from the highlands by erosion. This could have added about 1-1.5 million tons of grain loss to the country's harvest. This catastrophic phenomenon has been mainly attributable to rapidly increasing human population, the limited area of fertile soils on flat lands, deforestation, and excessive livestock population. The demands of a rapidly expanding population has set up pressures on the study's area natural resources and these in turn have resulted in a high level of environmental degradation. The most important manifestations are heavy soil losses; high sediment yields; soil fertility decline and reduction in crop yields; marginalization of agricultural land; gullies formation; landslides and deforestation and forest degradation.

In brief, average removal of soil all over the country was estimated to be about two billion tons per year (FAO, 1986). Among the land use types in which erosion occurs, the most serious one occurs on cultivated fields. Hurni (1993) reported that the rate of soil loss from cultivation fields was estimated to be 42 t/ha/yr on average. The same source revealed that by assuming an average soil depth of 60 cm, it is predicted that most of the area of cultivated slopes in Ethiopian highlands would be entirely stripped of the soil mantle with in 150 years.

The assessment of erosion hazard is a specialized form of land resource evaluation with the view to identify those areas of land where the maximum sustained productivity from a

given land use is threatened by excessive soil loss is so crucial to at least identify where the problem is acute thereby to propose appropriate measures.

This thesis is in general arranged in six chapters. The first one is an introductory part that packs together background of the study, statement problem, significance and objective of the study. The second gives emphasis on the related literature review conducted in different parts of the world in general and at national level in particular. Overall description of the study area is also briefly treated in chapter three. In chapter four, the frame of this thesis is organized by packing together the materials, data required, and data analysis techniques such as image classification, USLE parameter estimation, and general assessment of land cover change using NDVI analysis and automated generation of the micro and subcatchment. The result and discussion is clearly elucidated in chapter five. Finally, conclusion and recommendation will be drawn based on the achievement of this thesis work.

### ***1.2 Problem Statement***

The problematic nature of land degradation in connection with spatio-temporal change of land use / land cover needs a profound and ongoing research to act accordingly. In this respect, land degradation in the form of soil degradation owing to the depletion of vegetation cover has become a major ecological problem especially in many parts of Ethiopia. For a sustainable catchment management it is necessary to estimate soil loss and deposition even on large spatial and temporal scales.

Environmental degradation from human pressure and land use has become a serious problem worldwide, but the effects are felt more in the developing countries than in the developed countries because of the high population growth rate and the associated rapid depletion of natural resources. In this regard, land degradation and soil erosion in the study area has been a major threat to soil resource, soil fertility and productivity. This could be perhaps owing to the direct consequence of high population density ranges from 253 to 545 persons per square kilometer within which the study is contained, is totally dense, which can put a huge pressure on carrying capacity of the land. Therefore, assessment of current erosion damage or degree of soil (land) degradation is of paramount role in identifying the

severity of damage or spot zone thereby integrated mitigation measures or soil and water conservation actions will be undertaken.

### ***1.3 Significance of the Research***

Even though it is difficult to assess the dimension of soil erosion in terms of extent, magnitude, rate and its economic and environmental consequences, estimation of the on-site effect of soil erosion with the help of soil erosion model is deemed necessary to formulate appropriate and integrated soil and water conservation measures. Besides, it is helpful to predict the time at which the significance of soil turns to zero or intolerable state. It is also instrumental to go through vegetation cover dynamism in conjunction with land use / land cover change to supply basic information for those who intend to design effective and timely actions on highly degradable land resources.

### ***1.4 Research Objective***

#### **General Objective**

The main objective of this research is to identify land degradation areas with particular emphasis on soil degradation using Universal Soil Loss Equation (USLE) model, and to look into land use/ land cover changes over time and space.

#### **Specific Objectives**

- Assess the spatial extent of land degradation (soil erosion) by applying soil erosion model (USLE).
- Prepare land use/ land cover maps and evaluate its spatio-temporal changes
- Identify area where soil erosion becomes severe along with state possible measures to reduce land degradation
- Compare annual soil loss of the two subcatchments
- Generate a map depicting degree of soil erosion

## **2. LITERATURE REVIEW**

### ***2.1 Some Perceptions of land degradation***

The term land degradation is the reduction in the capability of the land to produce benefits from a particular land use under a specific form of land management (Douglas, 1994). Land degradation has a broader concept which comprises the degradation of soil, water, climate, fauna and flora (Ofori, 1993). Blaikie and Brookfield (1987) also stated that land is degraded when it suffers from the loss of intrinsic qualities and capabilities. Land degradation is also considered to be a collective degradation of different component of land such as water, biotic and soil resources (Hennemann, 2001). He also pointed out that the worsening biotic and water decline essentially will lead to a desertification process in susceptible climate zone. In broader sense, Conacher and Sala (1998) cited land degradation as an “alteration to all aspects of the natural (or biophysical) environment by human actions to the detriment of vegetation, soil, landform, water (surface and subsurface) and ecosystem”.

At global scale, key problems threaten natural resources and the sustainability of life support systems are: soil degradation, the availability of water and loss of biodiversity. In most cases, land degradation is closely associated with soil degradation. It is attributable to loss of vegetation that enhances soil erosion and reduces the productive value of the land (Hill et al., 1995). As a result, accelerated soil erosion is the greatest hazard in most environments to the long-term maintenance of soil fertility. It reduces soil depth, might remove the entire soil (Wild, 1993). This process occurs virtually in socio-cultural and economic contexts worldwide. However, there are great differences in the abilities of countries to cope with the problem of land degradation (Hurni.etal, 1996).

### ***2.2. Land degradation in Ethiopia***

The Ethiopian highlands, with an altitude of above 1600 Mts. above sea level, occupy only 44% of the area but host about 90% of the total population. The highland includes 95% of the cropped area and 75% of the countries livestock. Ethiopian Highlands have been facing repeated environmental crises associated with mainly drought, deforestation

and soil degradation, which in turn caused food shortage and degradation of natural resources ([www.africanhighlands.org](http://www.africanhighlands.org)).

In accordance with various studies taken about land degradation issues at the national level in Ethiopia, land degradation has become more acute and major problem threatening phenomenon particularly in agricultural sector. As listed in Berry (2003), these include the Highlands Reclamation Study: Ethiopia Highland reclamation Study (EHRS- FAO 1986); studies by the National Conservation Strategy Secretariat, the Ethiopian Forestry Action Plan, and Soil Conservation Research Project (SCRP).

Ethiopian Highlands Reclamation Study which was conducted on the Ethiopian highlands that is above 1500m a.m.s.l and associated valley has been an important source of information written in a series of working papers produced in 1984. It was intended to analyze and explain the types of soil degradation processes, their causes, severity and extent and estimate the soil loss rates in the highlands. One of the outputs of this study was a production of soil loss rate map at 1: 1,000,000 scales. The methodology used to produce the map was by superimposing the soil erodibility, rainfall erosivity, and land use/ land cover maps of the country. It in general produced erosion hazard and the present severity of erosion generalized maps in the high lands at scale of 1: 4000000. According to this study the study area categorized within none to slight to very high class, since the scale of the study area is small, it may not reflect exactly the real condition of the watershed under study.

On the other hand, Soil Conservation Research Project also made an important contribution to scientific understanding of the erosion processes in Ethiopia, since 1981. This project had six regional research units covering different climate zones in the Ethiopian highlands. From each site climate, run off, sediment loss and land use data were collected, some conservation measures have been tested, and results are available. Several research progress reports were produced.

The conclusion from the researches indicate that in mid 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million hectare seriously eroded and over 2 million hectare beyond reclamation. Erosion rates were estimated at 130 tons

/ha /yr for cropland and 35 tons/ha/yr average for all land in the high lands. Forests in general have shrunk from covering 65% of the country and 90% of the highlands to 2.2% and 5.6% respectively.

On the basis of Ethiopian Highland Reclamation Study (1984) the Ethiopian highlands, highly intersected by deep gorges and valleys, are suffering from serious forms of degradation. The inevitable human-induced land degradation through the persistent need for food, firewood and building poles has, over the centuries, led to the cutting down of forests on the mountain slopes and reduced the carrying capacity of parts of the highlands. With a population steadily increasing, putting more pressure on an already fragile environment, considerable damage has been done to the ecology. Fuel wood is already scarce, and many rural, inhabitants of the highlands now depend on animal dung as an alternative source of energy supply, consequently the situation reduces soil fertility.

In Ethiopian condition many environmentalists' policy makers and researchers agree that land degradation caused by soil erosion has been one of the chronic problems. For instance, majority of the farmers in rural areas are subsistence oriented, cultivating impoverished soils on sloppy and marginal lands that are generally highly susceptible to soil erosion and other degradation forces. These farmers constitute the poorest and the largest segment of the population whose livelihood depends directly on exploitation of natural resources.

Most of the agricultural lands of south Ethiopia are known to be located in the humid tropical zone where the problem is witnessed. Land degradation in southern region occurs mainly in the form of soil erosion, deforestation and overgrazing. Depending on climate, soil type, topography of the land, vegetation cover, the highlands of the region including the study area catchments have experienced very serious land degradation. As elsewhere in the country, environmental degradation is proved to be increasingly a major threat to food security in Bishan Guracha-Adilo subcatchments.

### ***2.3 Land degradation and Land use/ land cover change***

Changes in land use and land cover are central to the study of global environmental change including soil degradation and reflect the rapid population growth in tropics. As a result of increasing demand for firewood, timber, pasture, shelter, and food crops, natural land covers, particularly tropical rain forests, are being degraded or converted to cropland at alarming rate ( Islam and Weil, 2000).

Land degradation is largely a human problem, in both origin and effect. The impacts are felt by the community both rural and urban. These include a range of biological and ecological consequences, varying from the loss of genetic diversity and hydrological disruption, economic consequences, such as; a decrease in agricultural production and eventually loss of the underlying resource base, and all accompanying social problems and disruptions

### ***2.4. Soil erosion and Soil Loss estimation***

#### **2.4.1 Soil erosion**

Soil erosion is the removal of the soil, or the whole soil, by the action of wind or water. It is a natural process that occurs without human intervention but it can be greatly increased by cultivation of the land. In deed, there has been serious erosion as long as there have been farmers (Wild, 1993). In accordance with Morgan (1996) soil erosion is a two phase process consisting of the detachment of individual particles from the soil mass and their transport by running water and wind. When sufficient energy is no longer available to transport the particles, a third phase, deposition occurs. As reported by (FAO, 1986) six specific processes contribute to soil degradation: viz. Water erosion, wind erosion, water logging and excess salts chemical degradation, physical degradation and biological degradation.

Two major types of soil erosion can be distinguished that is geological (natural) and accelerated erosions. The former emphasizes on the natural process without the influence of human beings and it is in equilibrium between soil formation and erosion. Breaking the natural equilibrium, mostly due to agriculture will create accelerated soil erosion which is more aggressive than geological erosion (Hudson, 1996)

Tripathi and Singh (1990) rightly elucidate that soil erosion by water can occur as splash, sheet, channel, steam, water fall, land slide, and marine erosion. When rain drops strike the ground surface, the soil particles become loose and splashed its impact force. The falling rain drop at an average speed of 75 cm/sec is capable of creating a force of almost 14 times its weight. The amount of damage done by falling rain drops is proportional to their kinetic energy. On the other hand, as water passes over a soil with gentle and smooth slope, it follows along a sheet of more or less uniform depth. Under such conditions, there occurs relatively uniform removal of soil from all parts of the area having a similar degree of slope. Where as in contrast to sheet erosion, channel erosion occurs where surface water has concentrated and a large mass of water supplies the energy, both for detaching and transporting the soil. Channel erosion exists as rill erosion, gully erosion and stream erosion. However, there are no distinct boundaries between rill and gully erosion, and between gully and stream erosion, expect that in all the cases the detachment is caused by the energy of flowing water and not by the impact of raindrops.

#### **2.4.2. Soil Loss Estimation**

The term soil loss, expresses as quantity per unit area, is often used for small plots. Even in the most erodible situations, soil loss or sediment yield is limited by the transport capacity of the run off. As the run off flows through a watershed, changes in topography, vegetation, and soil characteristics often reduce this transport capacity (Lal, 1994)

Now a day, field studies for prediction and assessment of soil erosion are expensive, time-consuming and need to be collected over many years. Though providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion.

Models which are the simplification of reality have successfully been developed and employed in order to predict and evaluate soil erosion problem. According to Lal (1994) modelling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. There are at least three reasons for

modelling soil erosion: first erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, and for regulation. The second premises is that physically-based mathematical models can predict where and when erosion is occurring and hence helping the conservation planner target efforts to reduce erosion. Finally, models can be used as tools for understanding erosion processes and their interaction and for setting research priorities.

Most erosion models rely upon the concept of transport capacity, which is defined as the maximum amount of sediment that a flow can carry without net deposition occurring. Several transport capacity equations have been developed for transport of sediment in large channels and adapted for use in upland erosion model. In this regard, soil erosion models such as USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal Soil Loss Equation) which are empirical models, WEPP (Water Erosion Prediction Project) that is physically-based, CREAMS (Chemicals, Run off, and Erosion From Agricultural Management System) which was a combination of processed-based and empirically-based components, became widely used for field-sized areas are a few to mention.

The USLE (Wishmeier and Smith, 1978) is the most widely used model in predicting soil erosion. It is used in education and research as a starting point in developing understanding of erosion hazard prediction because of its simplicity and clarity (Hagos, 1998). Many scientists have proposed changes, but all are woven around the same concept of rainfall erosivity, soil erodibility, slope length, slope class, land cover and land management factors are taken as directly proportional to the rate of annual soil erosion (Sohan and Lal, 2001).

As mentioned above, many soil erosion models exists within the scientific domain which require a lot of input data and a computer analysis, however, USLE has been selected to be applied as a model for estimating the soil erosion rate because of its suitability, simplicity and availability of information as input to the model. It is the most common model for the estimation of erosion, which is a working methodology that was developed and tested in USA. The essence of the USLE is to isolate each variable and reduce its

effect on a number so that when the numbers are multiplied together, the result is the amount of soil loss expressed in tons per hectare.

The equation is presented as:  $A = R * K * L * S * C * P$

Where:

- A represents soil loss in tons/ha/yr,
- K-erodibility factor which is the soil loss rate per erosion index for a specified as a measured on a unit plot, which is defined as a 22.1m length under identical condition
- R-erosivity factor that is computed as total storm energy multiplied by the maximum 30min intensity,
- L-slope length is the ratio of soil loss from the field slope gradient to soil loss from a 22.1 m slope length under otherwise identical conditions,
- S-slope steepness is the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions,
- C- crop management factor is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land.
- P- Support practice factor is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope.

### **2.4.3 Soil Loss Tolerance**

Soil tolerance refers to the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically (Wischmeier and Smith, 1978). It considers the loss of productivity due to erosion but also considers the rate of soil formation from parent material. Any combination of cropping, ranching, and management for which the predicted erosion rate less than the rate of soil loss tolerance may be expected to provide satisfactory control of erosion.

According to Nill et.al., (1996), as cited in Ringo, (1999), on very deep and homogenous soils, the effects of erosion will be less pronounced than on shallow soils encountered on highlands of semiarid zones or highly weathered soils whose nutrient storage and availability depend largely on the organic matter of the surface layer. Widespread

experience has shown that the concept of soil loss tolerance may be feasible and generally adequate for identifying sustaining productivity levels. The determination of soil tolerance is intended to compare the expected soil loss with the soil loss tolerance. If the soil loss is less than or equal to the soil loss tolerance, the soil loss can be still accepted. However, if the soil loss is more than soil loss tolerance, measurement to reduce soil erosion should be taken into consideration until a level of equal or less than the soil loss tolerance has been reached. Hudson, (1986), stated factors that govern soil tolerance are soil depth, physical properties and other characteristics affecting root development, gully prevention, filed sediment problems, seeding losses, reduction of soil organic matter and loss of plant nutrients.

The maximum soil loss tolerance for tropical regions is 25 t/ha/yr, Arsyad (1981), as cited in Ringo, (1999), But, Hurni (1980), Lal,(1983) as cited in Ringo, (1999) and Hudson (1986) , established annual soil loss tolerance limits that vary between 0.2 and 11 t/ha/yr. Different types of soils have different tolerance to be totally erodible even when they are excessively exposed to soil erosion. The internal characteristic of soil has certain effect on resistance of soil to be erodible.

### ***2.5. Use of satellite remote sensing and GIS in Assessing Land Degradation***

Soil erosion is spatial phenomenon, thus geoinformation techniques play an important role in modeling (Yazidhi, 2003). Information regarding soil erosion status is vital for affecting soil conservation planning. Remotely sensed data both in the form of aerial and satellite data have potential utility for mapping and assessing soil erosion conditions. Visual interpretation of analog satellite images and digital analysis of remote sensing satellite digital data are employed in soil erosion mapping by studying soil, land cover and drainage characteristics (Rao, 1999).

The potential utility of remotely sensed data in the form of aerial photographs and satellite sensors data has been well recognized in mapping and assessing landscape attributes controlling soil erosion, such as physiography, soils, land use/land cover, relief, soil erosion pattern (Pande et al., 1992). Remote Sensing can facilitate studying the factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to

seasonal land use dynamics. Satellite data can be used for studying erosional features, such as gullies, rainfall interception by vegetation and vegetation cover factor.

Geographic Information System (GIS) has emerged as a powerful tool for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output, and for interaction with models. A fundamental characteristic of GIS is its ability to handle spatial data i.e. the location of object in geographic space, and the associated attributes. There is considerable potential for the use of GIS technology as an aid to the soil erosion inventory with reference to soil erosion modeling and erosion risk assessment. Erosional soil loss is most frequently assessed by USLE in GIS environment.

### 3. DESCRIPTION OF THE STUDY AREA

#### 3.1 Location

Bishan Guracha- Adilo Rivers are the sub catchments of major Bilate River Basin. They are located mainly in between Hadiya zone (Badawocho woreda) and Kembata zone (Kedida Gamela Woreda) and Alaba Special Woreda. They have a total area of 417 Km<sup>2</sup> and geographically positioned between latitude 7<sup>0</sup>05'45'' to 7<sup>0</sup>21'48''N and longitude 37<sup>0</sup>52'52'' to 38<sup>0</sup>06'11''E (Fig.3.1).

In terms of accessibility, it is found to be to some extent in a good condition due to the presence of main road that crosses nearly equal parts and all weather roads from Mazoria to Durame via Demboya.

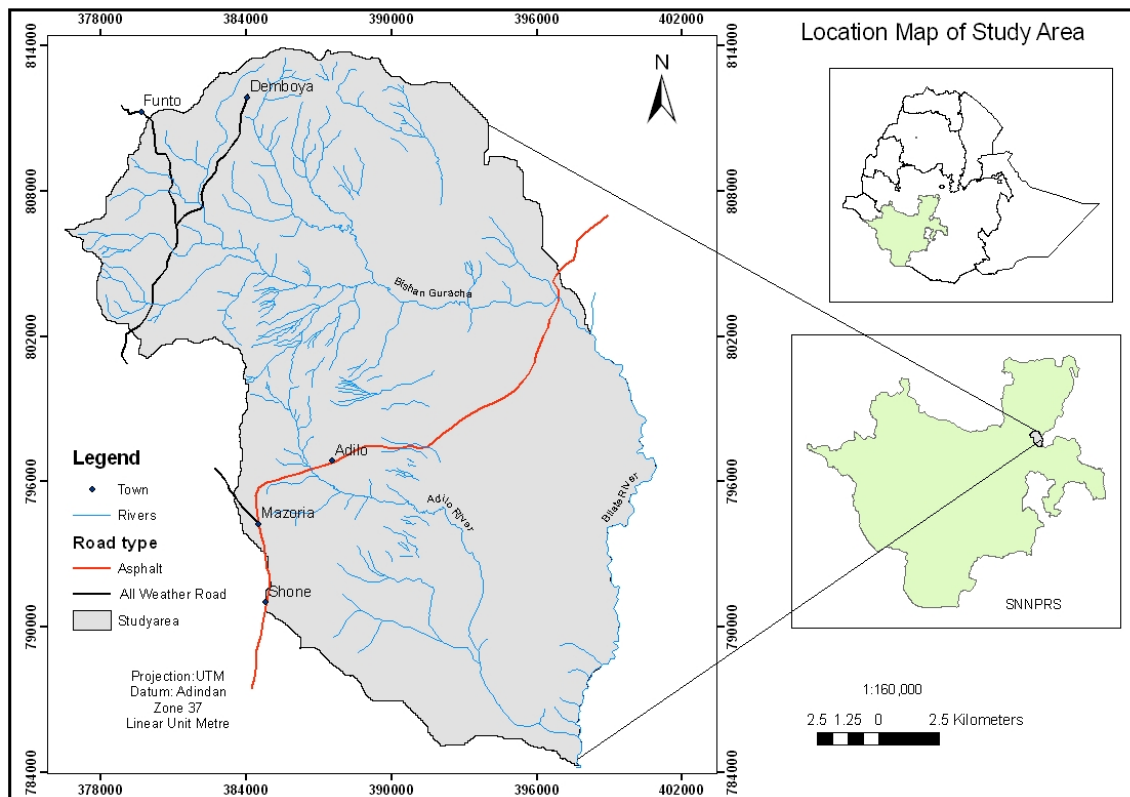


Fig3.1 Location Map

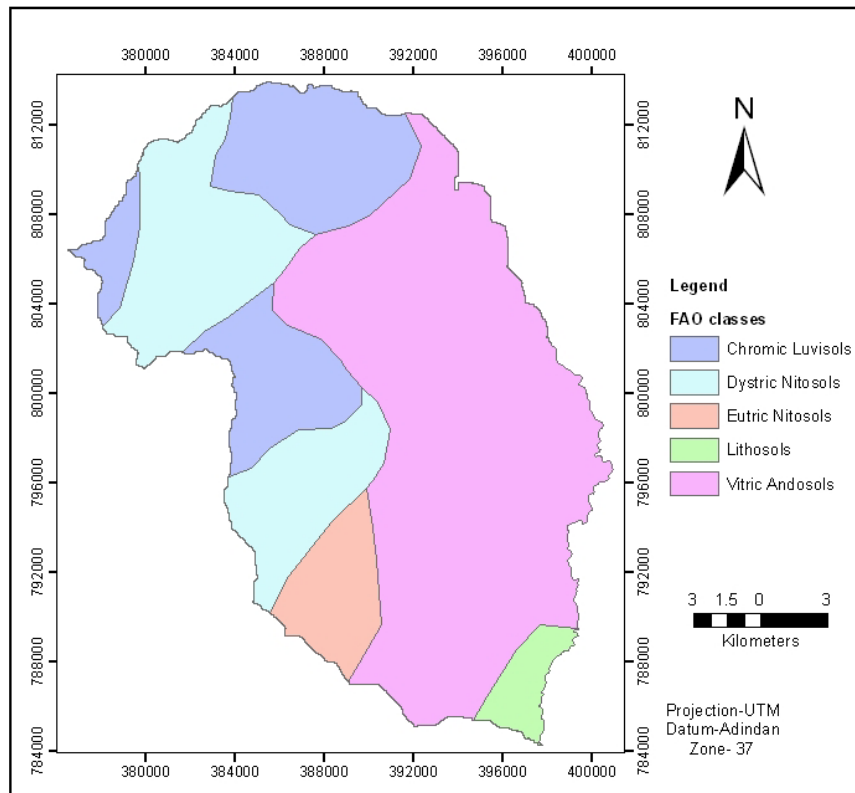
#### 3.2 Geology

As described in SNNPR regional map (2004), the study area is geologically part of the magdala shield group of Cenozoic era of tertiary volcanic predominate by acidic rocks including acid tuffs, mostly ignimbrites, pentelleritic rhyolites and trachytes. These rocks

are bedded with lava and agglomerates of basaltic composition. The volume of acidic rocks tends to decrease away from the rift valley.

### 3.3 Soil

As to the distribution of soil, FAO / UNESCO classification of soil of the world taken in to consideration, accordingly, there are 5 types of soils in Bishan Guracha-Adilo subcatchments. Of which, vitric andosols accounts for 21200 ha (51%) of the entire study area. The rest chromic luvisols, dystic nitosols, eutric nitosols or pellic vertisols, and lithosols constitute the remaining areal share of the study area. The spatial distribution of the soils are shown in Fig.3.2



*Fig. 3.2 Soil Distribution Map*

*Source: Ministry of Agriculture and Rural Development*

### 3.4 Topography

The main land form of the catchments is nearly a slope having 0-10% with small undulating and sloping relatively steep. As seen from the Table 3.1 more than 75 % of the study area lies within the slope range of 0-10 % which is generally float to gently undulating topographic feature. The elevation of the area in general ranges from 1580-

2933 m a.m.s.l Part of Ambericho Mountain becomes the highest and water divide between the study's area drainage and those rivers empty in to major Omo River. The entire topography in general is dissected by two relatively major rivers; Bishan Guracha and Adilo, and many gullies.

Table: 3.1 Slope Range Distributions of FAO, 1990 Classification

Slope Range (%)	Area Cover (ha)	Percentage	Class name
0-2	13500	32	Flat to almost flat terrain
2-10	18800	45	Gently undulating to undulating terrain
10-15	4100	10	Rolling terrain
15-30	4100	10	Hilly terrain
>30	1200	3	Steep dissected to mountainous terrain
Total	41700	100	

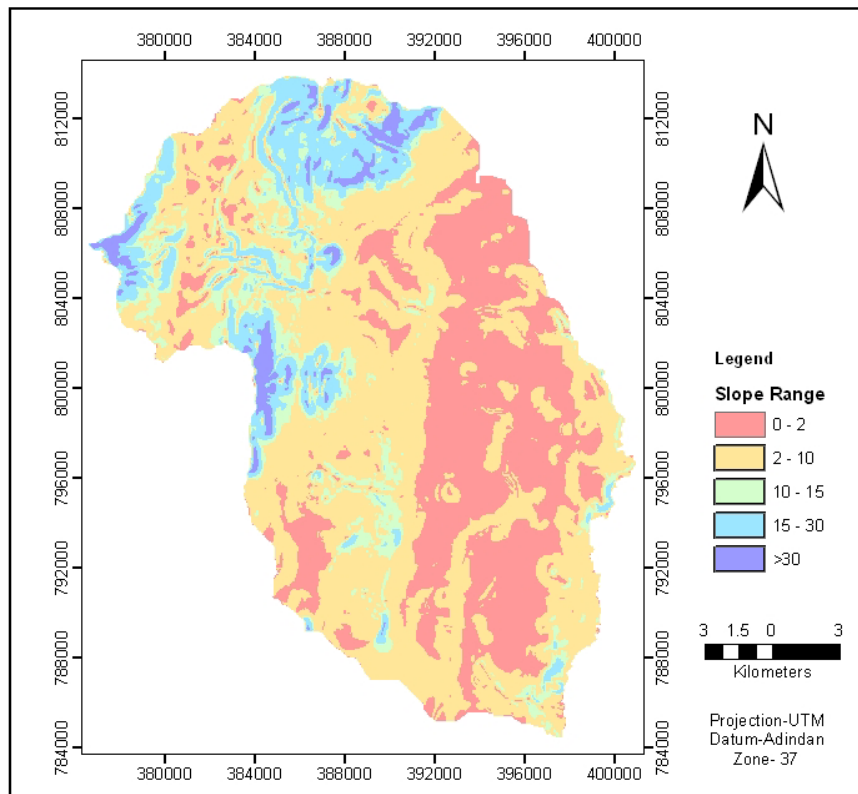


Fig.3.3 Slope Range Map

### 3.5 Climate

Rain fall which plays a great role in the formation of soil at the same time making the soil more readily removable varies in the study area within the range of 1152mm (Kulito) and 1375 mm (Shone) (Fig.3.5). Though some part of the study area along Bilate River lies on relatively low rainfall, the largest part of the study area fall in areas where rain fall receiving above 1000mm. This in general made the area to have experienced above Weyina Dega to Dega type of climate. It could also be grouped as an area in the country getting bimodal rain fall (Fig 3.4). Despite the fact that bimodal rain fall would allow two growing seasons for the area the probability of removing soil and aggravating mass movement (wasting) is so high. As most part of Ethiopia experience the study's area climate is also governed by the north-south oscillation of ITCZ (Inter tropical Convergence Zone). The effect of rainfall in the study area is clearly noticed in Plate 3.1.

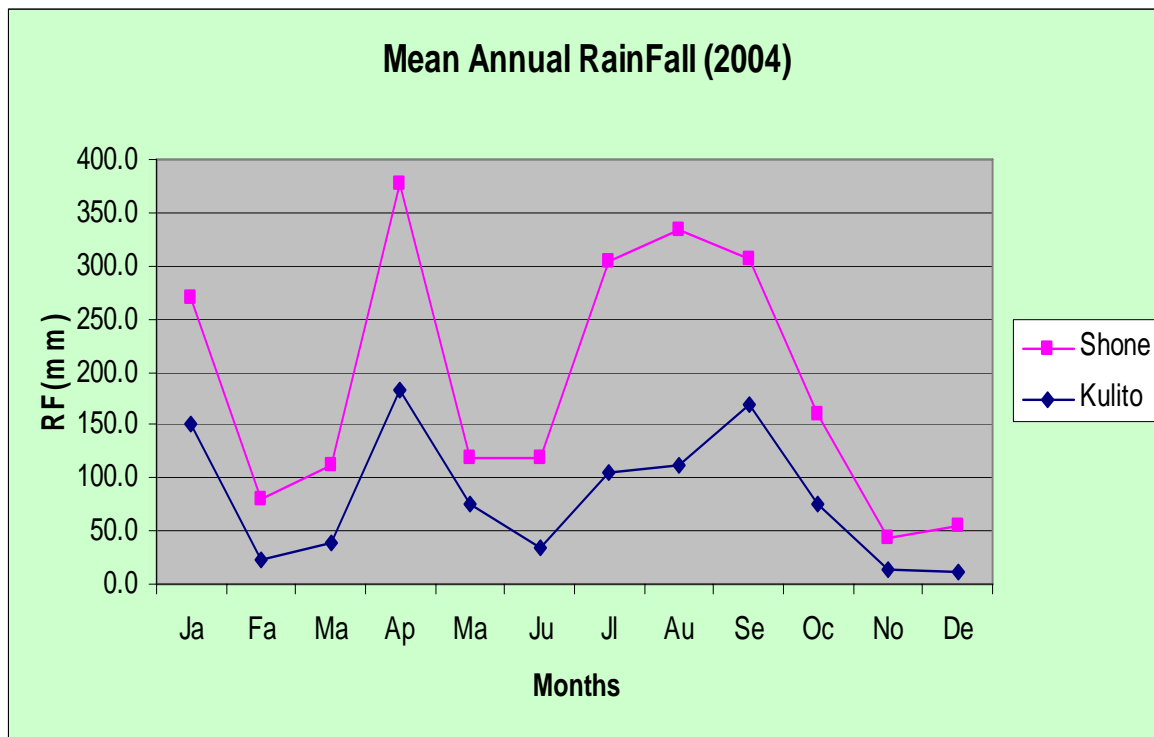
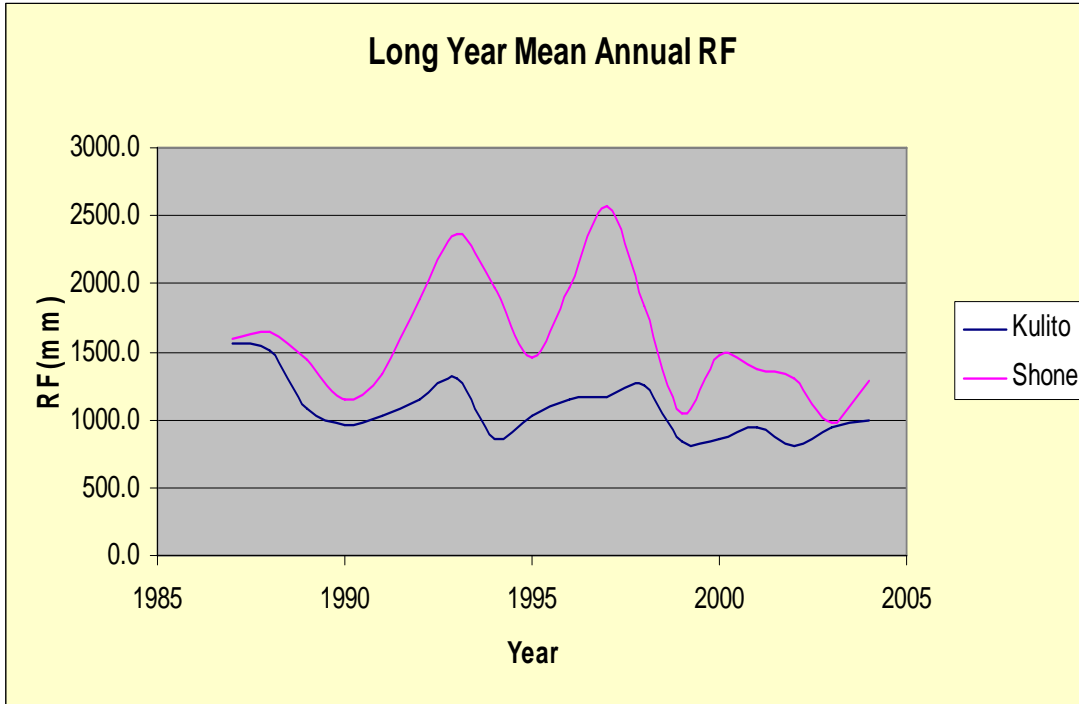


Fig 3.4. Mean annual RF representing bimodal type.



*Fig 3.5 Mean Annual Rain fall distribution of the two representative towns.*



*Plate3.1 Accelerated Erosion due to high rainfall near Adilo town*

### 3.6 Drainage Pattern

The main River Bishan Guracha and the small one Adilo drain entire part of the subcatchments toward Bilate River (Fig.3.6). Bilate River one of the big rivers in the region flowing toward L. Abaya is distinctly known by being always unclean. In collaboration with the subcatchments, its effect off-site rate of sedimentation noticeably seen in L. Abaya. The drainage pattern of the study area as a whole is governed by water divide of Ambericho Mountain, lying near Durame town. The big river Bishan Guracha, as its oromigna's word implies black water, has proven that it always carries a considerable amount of soil from the highland of the study area. Drainage density of the catchments is highly concentrated in North West part of the study area.

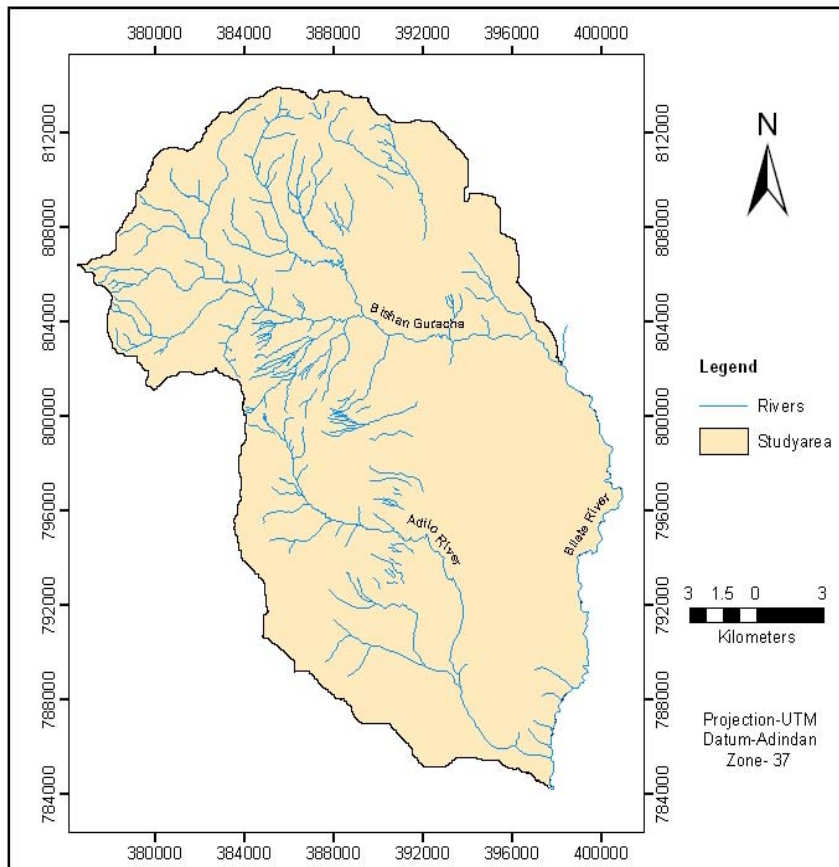


Fig3.6. Drainage pattern

### 3.7 Land use/ Land cover

Land use / land cover classification which is dynamic in nature has strong influence particularly on soil and water conservation as well as the entire natural resources system. Based on the 2000 ETM+ Landsat image, the study area has been classified into five major categories (Fig.3.7). While classifying due to the complex nature of the land use system in southern part of Ethiopia, scattered and pockets of the land use / land cover part have been generalized under the major category. Of the total classification, agricultural sector takes the lion's share that is more than 81% and the rest goes to degraded, wood and grazing section of the classification. Since the study area is highly populated, there is almost no potentially suitable land for cultivation remained uncultivated. Enset (false banana) grows dominantly especially in garden plot also included in intensively and moderately cultivated area.

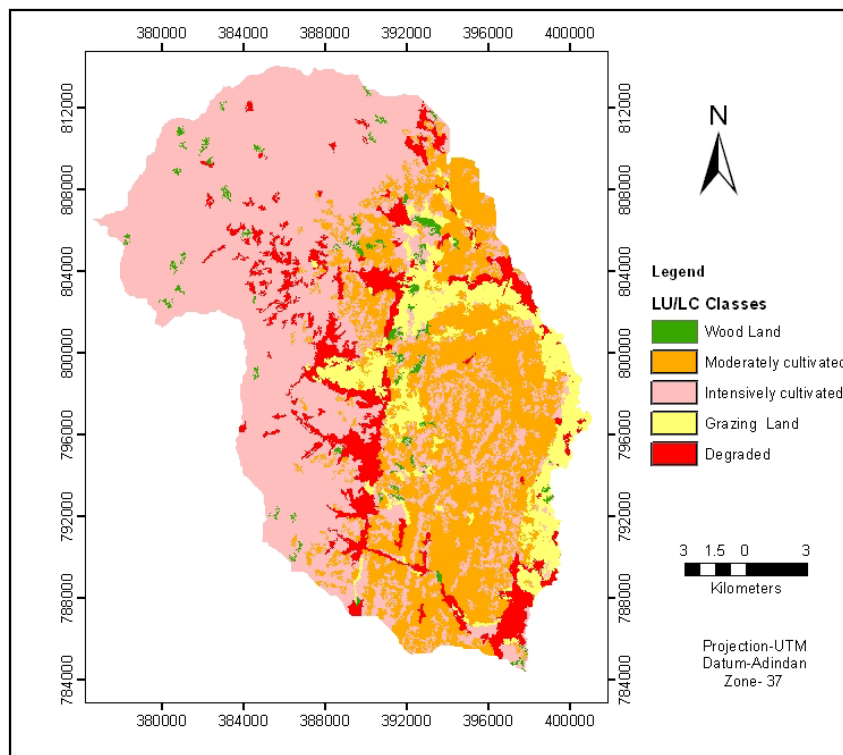


Fig.3.7 Land use/ Land Cover Map (2000)

### 3.8 Socioeconomic Settings

#### Population

Population, which has been main segment of environmental system, varies with time (Fig.3.8). Their considerable inference on natural resources proportionately increases as

the number of population grows faster. Since the study area lies within the three woredas and the population number has not been well organized at kebele levels, change in population is recognized by taking the trend of total population of woredas with the assumption whenever showing population changes in the entire area, the change might also affect the whole part of the system. As seen from the graph population growth shows a considerable increase in due course of time which ultimately needs additional space for practicing agricultural activities this in turn has greatly been attributable to natural resource depletion. The population density at woreda level varies from 253 persons per square kilometer in Alaba to 545 in that of Kedida Gamella. This directly shows that there has been a significant population pressure on resources causing to degradation of land resources.

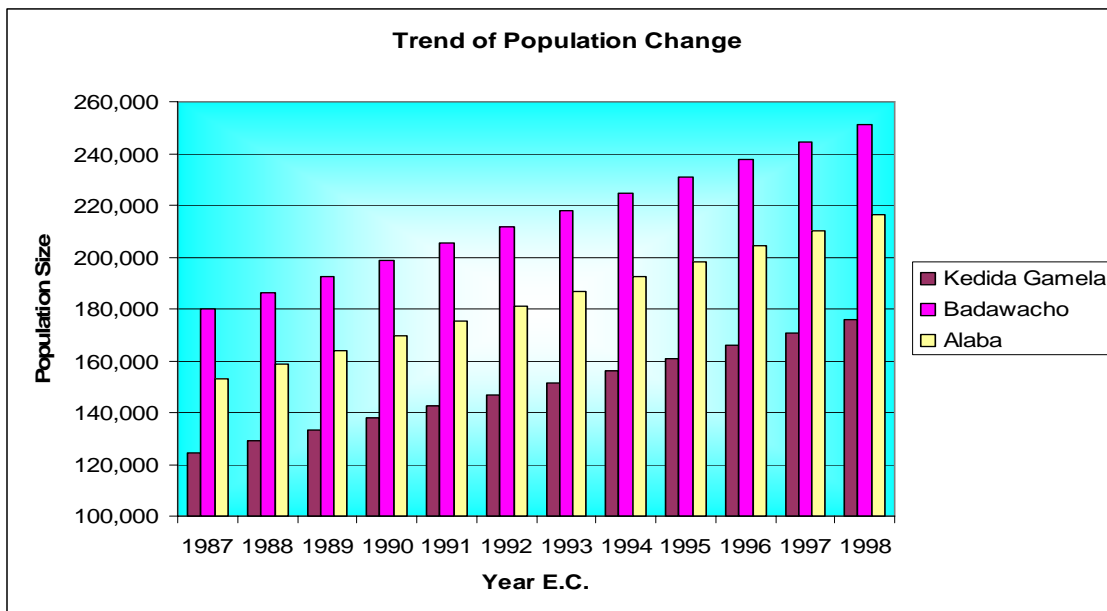


Fig. 3.8 Change in Population Number

Source: SNNPR, BoFED, Statistics and Population Division

### ***Socioeconomic condition***

The socioeconomic activities of an area play an important role on the land use/ land cover type as well as on land degradation. In relation to this, economic activities of the study area are based on primary productions such as crop farming and animal husbandry, which indicate the agrarian background. However, due to unprecedented population growth and the demand to secure more farm lands except for limited low land area, the

live stock sector has shown a decline. Studies in similar setting of wolaita Gununo area indicate that the farming system is small-scale mixed crop and livestock production, with relatively fewer livestock than elsewhere in Ethiopia. Farmers used to keep 7-8 heads of cattle some 15 years back, but it has declined to 1-2 heads per household due to feed shortage, conversion of grazing land to farm land, forced sale of livestock to pay taxes and debts and disease losses (Farm Africa, 1992).

Agriculture which is the main stay of the society is being largely practised in garden and plot lands. The former is carried out just in surrounding area of a home where farmers live but the latter one needs more space. Apart from the low land part highly intensive farming is clearly observed particularly in the intermediate and high land areas. The bimodal nature of rain fall in the study area helps much produce varieties of agricultural products that sustain highly dense population of the study area. Crops such as maize, wheat, barely, enset and different kinds of root crops are grown in line with seasonal changes and depending on the normal condition of climate.

## 4. MATERIALS AND METHODS

In order to fulfill the objectives in the present study primary and secondary data sets have been obtained from different sources. Methods followed and the software used to create the geodatabase to prepare soil erosion map has been discussed.

### 4.1. Data Collection

The pertinent data types gathered from their respective sources so as to conduct this study was:

Table 4.1 Data types and their sources

NO	Type of data	Source
1	Topographic sheets : 1:50000 scale	EMA (Ethiopian Mapping Authority)
2	Soil type and soil loss	Ministry of Agriculture and Rural Development
3	Demography data	SNNPR, Regional sector of Statistics and population
4	Mean annual Rain fall	NMSA( National Meteorological System Agency)
5	Satellite imageries and their acquisitions date: <ul style="list-style-type: none"><li>• MSS (date of acquisition 2/1/1973 and 57m resolution)</li><li>• TM ( date of acquisition 22/11/1984 and 30m resolution)</li><li>• ETM+ ( date of acquisition 26/11/2000 and 30m resolution)</li></ul>	Down loaded from Internet
6	GPS ground truth ( 9 to 11m resolution)	Study area
7	Information as to conservation and support practices	Woredas' Rural and Agriculture Sector

### 4.2. Methods

This section deals with the various activities involved in order to achieve the stated objectives of this study, methods and techniques used included:

- ❖ Pre-field work
  - Organizing the Literature review so as to substantiate this study
  - Geo-referencing, digitizing and mosiacking part of the scanned topographic sheet in order to delineate the study area
  - Digitizing of rivers and gullies from the topographical map sheets that cover the study area
  - Down loading Landsat image from Global land Cover Facilities web site
  - 2000 ETM+ Landsat Image processing and making unsupervised classification
- ❖ Field work
  - Gathering basic information such as the cropping pattern, conservation practices, from three woredas in which the study area is situated.
  - Ground truthing record by using Garmin GPS
- ❖ Post- field work
  - Digitization of contours with 20 meters interval from 1:50.000 scale topographic map and generation of Digital Elevation Model (DEM)
  - Automated generation of the two subcatcments from DEM and digitized rivers using Arc Hydro extension in Arc GIS 9.1 version
  - Supervised classification based on the ground truth
  - Making change detection between 1973,1984 and 2000 satellite imageries. Besides, land cover change analysis was carried out using NDVI and post classification change detection comparative methods.
  - Estimating parameters of USLE based on the previous research conducted for Ethiopia high land in particular

#### ***4.3 Materials and Software***

The materials required and soft wares for this research were:

- ArcGIS 9.1, ERDAS 8.6
- GPS, Digital Camera
- Other software like Microsoft Internet, Word, Excel, and Power point

### Methodological Flow Chart

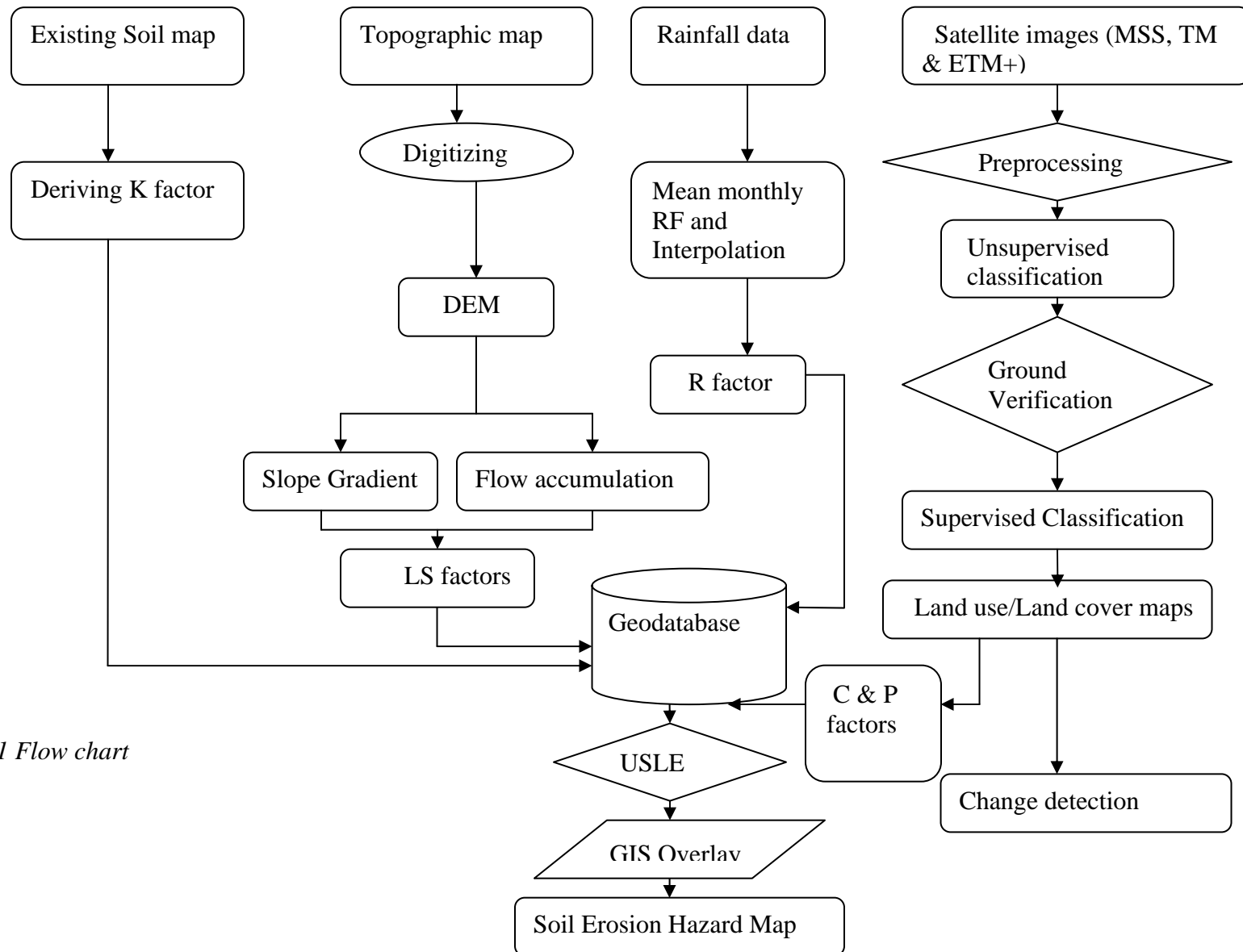


Fig.4.1 Flow chart

## ***4.4 Data Analysis***

### **4.4.1 Image Processing and Classification**

#### ***Image Processing***

Digital image processing involves the manipulation and interpretation of digital image with the help of a computer (Lillesand & Kiefer, 1994). Satellite imagery has to be well processed prior to use for further applications. It is in fact essential to rectify the raw satellite image under the pre-processing stage such as geometric and radiometric correction. Image restoration also involves the correction of distortion, degradation, and noise introduced during the image processing. Image restoration produces a corrected image that is as close as possible, both geometrically and radiometrically, to the radiant energy characteristics of the original scene. To correct the remotely sensed data, internal and external error must be determined (Jensen, 1996).

In pre-processing phase, it is usually necessary to georeference the images on projection and datum that Ethiopia has already selected, UTM projection and Adindan datum. In this respect, all the images used which are in WGS84 projection have been re-projected in to the country's datum and projection. This is mainly because datum and projection conflict would undoubtedly limit the use of various themes (layers) at time. In other way, if remotely sensed data are to be used in association with other data within the context of a geographic information system, then the remotely sensed data and the products derived from such data will need to be expressed with reference to the geographical coordinates that are used for the rest of the data in the information system.

Histogram equalization that is to apply a nonlinear contrast stretch that redistributes pixel values so that there are approximately the same number of pixels with each value within a range; haze and noise reduction with the view to overall reduce the amount of haze and noise from an input image were in general done so as to enhance the interpretability of the images. However, those enhancement techniques did not bring as such significant change consequently; spatial enhancement of resolution merge to increase the spatial resolution of multi-spectral image was also carried on.

With regard to bands selection, all the bands that are present in each image are not used for land use / land cover classification. Depending on the nature of each band's application, some bands were selected. After attempting different band combinations by considering their specific applications, false colour composite of band 4(green), 5 (red) and 7 (near infrared) of MSS (multi spectral scanner) and 2 (green), 3 (red) and 4 (near infrared) of TM and ETM+ were applied to classify the study area.

### **Image Classification**

The overall objective of image classification procedures is to automatically categorize all pixels in an image into land use / land cover classes or themes (Lillisand and Kiefer, 1994). Remotely sensed data of the earth may be analysed to extract useful thematic information. Notice that data are transformed in to information. Multispectral classification is one of the most often used methods of information extraction (Jensen, 1996).

In classifying the images, both unsupervised and supervised image classifications techniques were applied, for the latter case training site was established based on the ground truth taken during field work. The unsupervised was done before field work. Among different algorithms in the drop down lists of supervised classification, maximum likelihood image classification was utilized.

By having applied the techniques of image classification, land use / land cover types have been identified so as to use the classified images for change detection and as inputs for generating crop management (C) factor and support practice (P) factor of Universal Soil Loss Equation. With the help of visual interpretation elements and the different reflection characteristics of the features in the satellite images of 1973, 1984 and 2000, the study area has been classified in to five land use / land cover classes, namely, moderately cultivated, intensively cultivated, grazing land, wood land cover and degraded / barren land.

- Moderately Cultivated: area of land mostly found in relatively lowland area where to some extent large farm lands are being cultivated for maize, teff, barely and pepper despite the fact that the area is labelled under densely populated (plate 4.1). According to SNNPR Atlas description (2004) about 8.8 percent of the

region's land is moderately cultivated. It includes lands under rainfed peasant cultivation of grains, perennial crops, such as coffee, Enset and livestock grazing lands. Compared to the intensively cultivated areas, bushes or patches of forest and wide land under natural vegetation are visible.



Plate 4.1 Farm land with moderately cultivated unit

- Intensively Cultivated: this type of land use system is a typical feature of the southern part of Ethiopia as a result of unprecedented population growth that make put a huge pressure on getting additional farm land , therefore, farm land has become small in size dominantly carried out just around home as garden and plot a bit distance. It dominates the study area.
- Grazing land: a land used for grazing of animals
- Wood land cover: this class corresponds to plants which has undergone modifications from man's influence. It is composed predominantly of secondary vegetation indicative of a recovery stage from past disturbance. It occurs mostly near farm land and around settlements. It predominantly consists of the *Eucalyptus trees*.
- Degraded and Barren Land: this type of land system has been last category classified from both satellite images which is really the most deteriorated or simply totally exhausted. Due to its bad situation, effort is being made along the

road side to restore it. Plate 4.2 shows the extent of land degradation in some part of the study area.



Plate.4.2 Degraded area

### **Post Classification Smoothing**

According to Lillesand and Kiefer (1994) classified data often manifest a salt-and-paper appearance due to the inherent spectral variability encountered by a classifier when applied on a pixel-by- pixel basis. To remove this one means of classification smoothing involves the application of majority filtering, smoothing the classified image with an operation of a moving window passing through the classified dataset and the majority class within the window is determined.

### **Accuracy Assessment**

The fact that accuracy assessment is so important that it tells us to what extent the truth on the ground is represented on the corresponding classified image, it has been here done for 2000 land use / land cover classification based on the ground truth taken for each category. According to Jensen (1996) in order to perform classification accuracy assessment, it is necessary to compare two source of information that is the remote sensing driven classification map and what we call reference test information which may

in fact contain error. Their relationship between the two sets of information is commonly summarized in an error matrix.

Table 4.2 Accuracy Assessment

Class	Moderately cultivated	Intensively cultivated	Grazing land	Wood land	Degraded /barren	Row Total
Moderately cultivated	6	4	2	0.0	0.0	12
Intensively cultivated	0.0	24	0.0	0.0	0.0	24
Grazing land	0.0	0.0	59	1	0.0	60
Wood land	0.0	1	14	41	0.0	56
Degraded/barren	0.0	0.0	0.0	0.0	6	6
Column Total	6	29	75	42	6	158

Overall Accuracy: 86.06 %  
 Kappa coefficient: 0.8004

From the assessment of accuracy that measure how many ground truth pixels were classified correctly, overall accuracy of 86.06 % and kappa coefficient of 0.8006 were achieved. The kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give percentage measure of classification accuracy. Kappa value is characterized in to three grouping: a value greater 0.8 represents strong agreement, 0.4-0.8 represents moderate agreement and that of less than 0.4 is considered as poor agreement, Congleton as cited by Lelca Geosystem (2000).

### **Post Classification Change Detection**

In accordance with Lillesand and Keifer (1994) change detection involves the use of multitemporal data sets to discriminate areas of land cover change between dates of imaging. Moreover, ideally, change detection procedures should involve; data acquired by the same or similar sensor and be recorded using the same spatial resolution, viewing geometry, spectral bands, and time of day.

One way of discriminating changes between two dates of imaging is to employ post classification comparison. This kind of change detection methods identifies and provides where and how much change has occurred. It also provides to and from information and results in a base map that can be used for the subsequent year. In this approach, two dates of imagery are independently classified and registered. Then an algorithm can be employed to determine those pixels with a change in classification between dates.

When evaluating the change detection made in this research against with the ideal scenario, the requirements stated by many authors are least met owing to inavailability of satellite images that fulfil the standard. Anyway change detection was carried out between the MSS image taken in 1973 with 57m spatial resolution, four spectral bands, varying radiometric resolution and so on with that of TM 1984 and ETM+ 2000 having 30m spatial resolution, eight bands including panchromatic only for ETM+. As the process progressed to finalize change detection, basic steps such as having identical land use/ land cover classification category in their order, adjusting varied pixel size into 30m were done. Upon completion of all the necessary steps, the two classified images were taken into GIS analysis of matrix in ERDAS software for making matrix of land use / land cover changes between 1973, 1984 and 2000.

#### **4.4.2 Land Cover Assessment**

First and for most, vegetation or land cover protects the soil from erosion by intercepting raindrops and absorbing their kinetic energy harmlessly. And hence timely monitoring of vegetation cover is so vital despite requiring synoptic and repetitive coverage of satellite imagery. In doing the assessment, one of the most common vegetation indices or ratios is the normalized differencing vegetation index (NDVI). This technique was developed for identifying the health and vigor of vegetation and for estimating green biomass (Hayes and Sader 2001). Vegetation indices are empirical formulae designed to emphasize the spectral contrast between the red and near infrared regions of the electromagnetic spectrum. They attempt to measure biomass and vegetative health, the higher the vegetation index value, the higher the probability that the corresponding area on the ground has a dense coverage of healthy green vegetation (Gibson & Power, 2000). Spectral vegetation indices permit clear discrimination between bare soil surfaces, water bodies, and vegetation.

The value of the result will be between zero and one. The greater the amount of photosynthesizing vegetation present, the brighter the pixel will be (Jenson 1996). NDVI is calculated using the following equation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}),$$

Where NIR, the near infrared band response for a given pixel,  
RED, the red response

#### 4.4.3 Generating automated Micro-catchments

After generating TIN from digitized contour lines and converted into DEM for the study area its application has become immense. For instance, in order to delineate the two major subcatchments and the micro catchments within the major one, Arc hydro extension of Arc GIS with various facilities was used. The process in brief has been done first by making the DEM agreed to the digitized rivers, streams and gullies, then processing Fill sink, Flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation and catchment polygon processing and the like depending on the needs that one wants to deserve (Fig.4.2). The results would basically help grasp some of catchment hydrologic properties, vital for understanding the surface water movement in the catchment and delineating automated depositional areas where upland eroded soils accumulated as well and to identify micro wise catchments for further analysis particularly for prioritizing the most problematic area of the catchment.

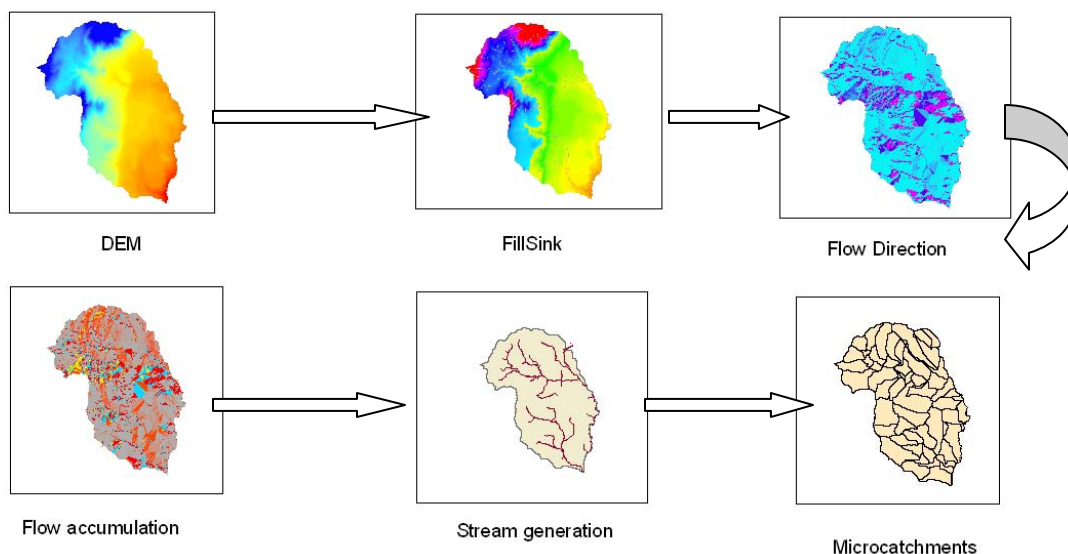


Fig.4.2 Automated Stream and Catchment Generation

#### **4.4.4 USLE Model Parameters Estimation**

The Universal Soil Loss Equation (USLE) is accentuated as one of the most significant developments in soil and water conservation in the 20<sup>th</sup> century. It is an empirical technology that has been applied around the world to estimate soil erosion by raindrop impact and surface runoff. As already stated in literature reviews, this model is selected and applied in estimating soil loss has been attributed to its clear and relatively computational simple inputs compared to others conceptual and possessed based models. Parameterization of each variable has been performed just as follows.

##### **Rainfall Erosivity (R)**

The ability of erosion agents to cause soil detachment and transport is erosivity. It is an index that represents the energy that initiates the sheet and rill erosion. The erosivity of rain fall is due to partly to direct raindrop impact and partly to the run off that rainfall generates. The ability of erosion agents to cause soil erosion is attributed to its rate and drop size distribution, both of which affect the energy load of a rainstorm. The erosivity of a rainstorm is caused by its kinetic energy. In simple way, rainfall erosivity is a term used to describe the degree of soil loss from cultivated fields due to rainfall effect when other factors of erosion are held constant.

Even though there are different computational techniques to compute erosivity factor across the globe depending on the use of various inputs, estimating rainfall erosivity in here is based on the calculation of R generated by Hurni (1985), derived from a spatial analysis regression (Hellden, 1987) adapted for Ethiopia on the basis of annual precipitation

$$R = -8.12 + 0.562 * P$$

Where p is mean annual rainfall in mm

In order to compute R factor using such formula five stations with mean annual rainfall of 18 years were used. After having averaged 18 years (1987-2004) for each station, interpolation was made to make the points distribution into surface. When performing this spatial analyst of IDW (Inverse Distance weighted) with the principle of things found to be close to one another are more alike than those that are farther apart has been used by specifying the cell size (grid) into 30m.

When applied the formula to generate rainfall erosivity factor from the values of long year mean rainfall, R factor seen in Table 4.3 and its converted grid raster in Fig 4.3 was obtained.

Table 4.3 Erosivity Factor (R) Estimation

Station's name	Mean annual rainfall(mm)	R_factor
Kulito	1152	639
Shone	1375	887
Durame	1593	764
Boditi	1220	599
Angacha	1081	677

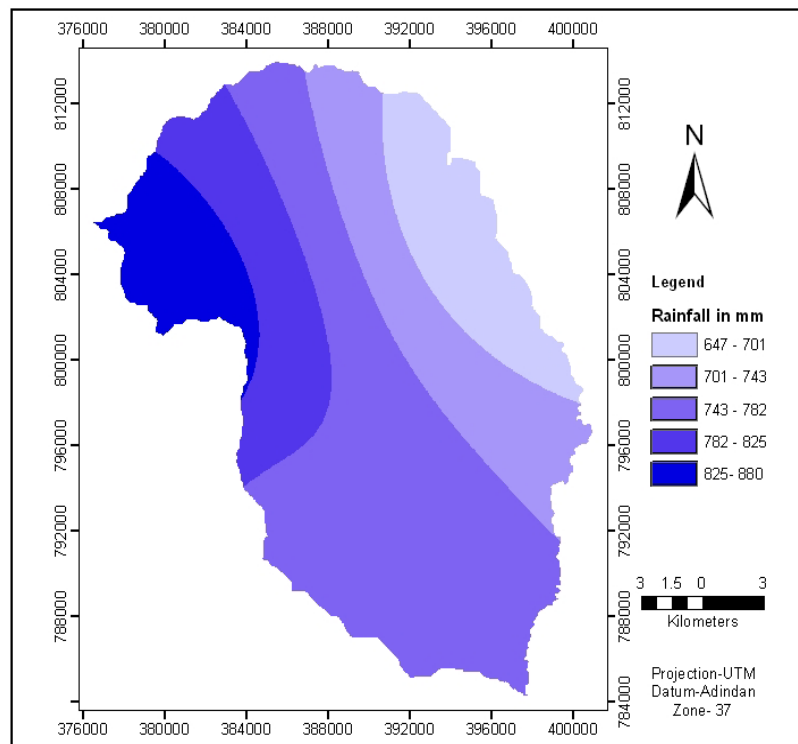


Fig. 4.3 Raster format of Rainfall Factor

### Soil Erodibility Factor (K)

Soil erodibility factor denoted by letter “K” in the USLE reflects the liability of a soil type to erosion, the unit depending upon the amount of soil occurring per unit of erosivity and under specified conditions. The inherent properties of the soil would have more influence for being liable to erosion than other factors. However, some soils erode more readily than others even when all other factors are the same.

Table 4.4 Soil Susceptibility to land degradation

<b>FAO-UNESCO Soil name: Soil Unit &amp; Subunit</b>	<b>Main Properties &amp; Susceptibility to Land Degradation</b>
Andosols - ochric - mollic - humic - vitric	From volcanic ash parent material; high in organic matter. Highly erodible, and limited in phosphorus. Chemical fertility is variable, depending on degree of weathering. Andosols have low resilience, and variable sensitivity.
Cambisols - eutric - dystric - humic - calcic - chromic - vertic - ferralic	Tropical ‘brown earth’ with a higher base status than Luvisols, but otherwise similar limitations. They have relatively good structure and chemical properties, and are not therefore greatly affected by degradation processes until these become large. Because of increasing clay with depth, they tend not to be greatly impacted by degradation. Cambisols have high resilience to degradation, and moderate sensitivity to yield decline
Luvisols - orthic - chromic - calcic - vertic - ferric - plinthic	The tropical soil most used by small farmers because of its ease of cultivation and no great impediments. Base saturation >50%. But they are greatly affected by water erosion and loss in fertility. Nutrients are concentrated in topsoil and they have low levels of organic matter. Luvisols have moderate resilience to degradation and moderate to low sensitivity to yield decline.
Nitosols - eutric - dystric - humic	One of the best and most fertile soils of tropics. They can suffer acidity, and when organic carbon decreases, they become very erodible. But erosion has only slight effect on crops. Nitosols have moderate resilience and moderate to low sensitivity.

Source: [WWW.unu.edu/env/plec/1-degrade/index-toc](http://WWW.unu.edu/env/plec/1-degrade/index-toc)

The erodibility of soils as defined by Hurni (1985), in the adaptation of USLE to Ethiopia considers the soil colour to have relation with erodibility even though others consider soil texture and structure so as to determine the value of soil erodibility factor.

Table 4.5. Values of Soil colour to estimate soil erodibility

Soil colour	Black	Brown	Red	Yellow
K value	0.15	0.2	0.25	0.3

According to UNESCO/FAO soil classification, five types of soil are found in the study area, namely chromic luvisols, dystric nitosols, eutric nitosols or pellic vertisols, lithosols and vitric andosols. All these soils have different quality to stand with erosion. Their characteristics and susceptibility to land degradation within their major categories are summarized in Table 4.4.

Soil erodibility index which is a mean annual soil loss per unit area of R for a standard condition of bare soil, recently tilled up and down slope with no conservation practice and on slope of 9° and 22m slope length. It is related to the integrated effect of rain fall, run off and infiltration. However, the establishment of K value is based on colour of each soil type and its value determined to it, given below in Table 4.6.

Table 4.6. Estimated values of soil erodibility

Soil Type	Colour	K value
Chromic luvisols	Brownish	0.2
Dystric nitosols	Reddish	0.25
Eutric nitosols or pellic vertisols	Black	0.15
Lithosols	Reddish	0.2
Vitric andosols	Black	0.15

After having established K value on the basis of previous research considering the colour of each soil, the K values were put in geodatabase and converted the feature class into grid raster format with 30m cell size (Fig.4.4).

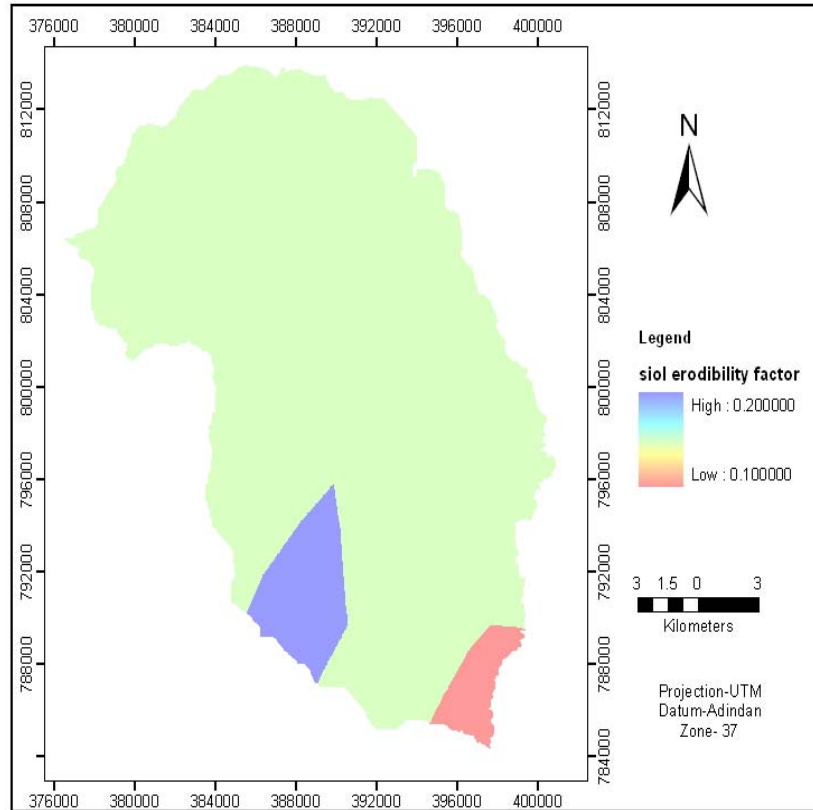


Fig.4.4 Raster format of soil Erodibility Factor

### Topographic Factor (Slope Length and Slope Steepness)

The speed and extent of run off depend on slope of the land. Generally, the greater the slope, the greater the velocity of run off water and erosion expected. The slope length and steepness are variable on the different land units of the study area. The slope length and gradient have an important bearing on soil erosion. The USLE of Wischmeir and Smith was developed for a slope of 9% and slope length of 22.13 m.

The factors of slope length(L) and slope steepness (S) are combined in a single index which expresses the ratio of soil loss under a given slope steepness and slope length to the soil loss from the standard condition of a 9° slope, 22m long, for which LS=1.0. The appropriate value can be obtained from nomographs (Wischmeir and Smith 1978) or from the equation (Morgan, 1996).

$$LS = (x/22.13)^n (0.065 + 0.045s + 0.0065s^2)$$

Where x is the slope length (m) and s is the slope gradient in percent. The value of n should be varied according to the slope steepness. This computational technique is a bit complex and still highly dependant on slope length variation and slope steepness. It is, however, recently in modelling erosion in GIS a new technique is introduced; it is common to calculate the LS combination using a formula:

$$LS = (\text{Flow accumulation} * \text{Cell size} / 22.13)^{0.4} * (\sin(\text{slope} / 0.0896))^{1.3}$$

Where flow accumulation is the number of cells contributing to flow in to a given cell and cell size is the size of the cells being used in the grid based representation of the landscape. This formula is based on the suggestion by Moore and Burch (1986) that there was a physical basis to the USLE model L and S factor combination. However, approach often used does not produce appropriate values for the LS product for a grid cell.

The formula was applied to generate LS factor using raster calculator of Arc GIS in final form of:

$$LS = \text{pow}(\text{Flow accumulation} * \text{Cell size} / 22.13), 0.4 * \text{pow}(\sin(\text{slope} / 0.0896), 1.3)$$

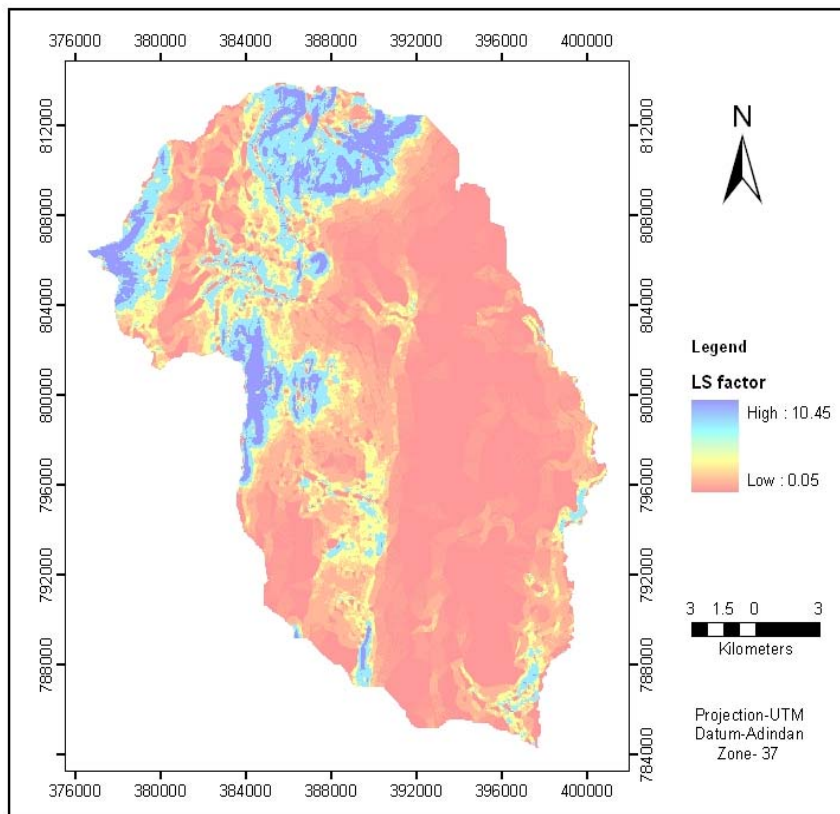


Fig. 4.5 LS Combined Factor Map

### **Crop management Factor**

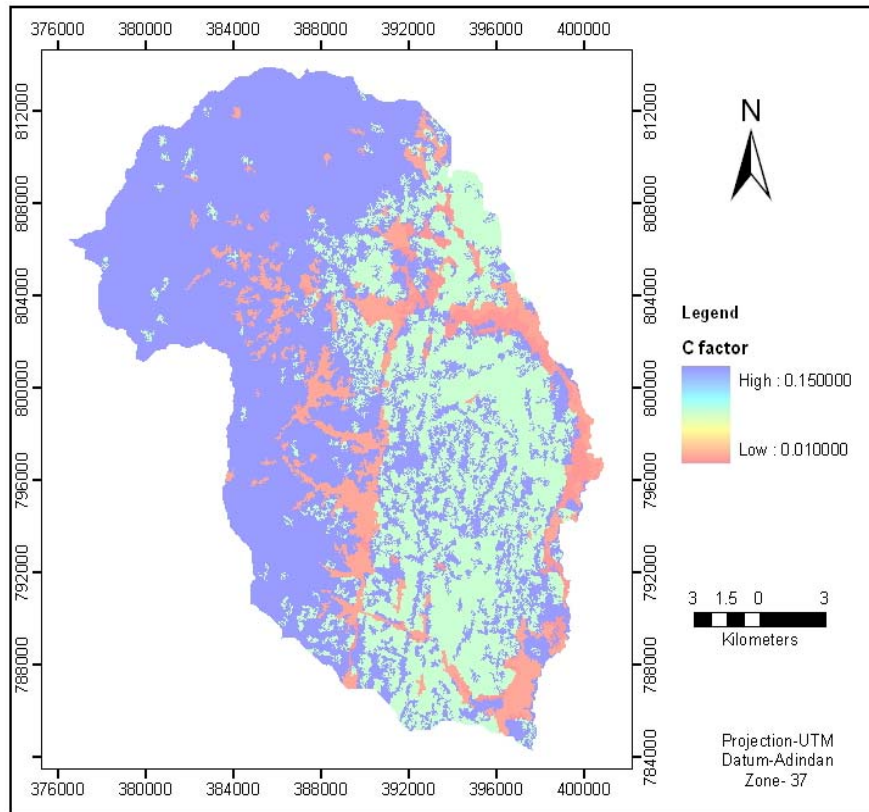
It represents the ratio of soil loss under a given crop to that from bare soil. Since soil loss varies with erosivity and the morphology of the plant cover, it is necessary to take account of changes during the year in arriving at an annual value. Any protection against the impact of falling raindrops will reduce soil loss. This protection occurs by the plants cropped, weeds (both together give the canopy cover), stones (for Skelton soil) and or special mulches. When generating crop management factor it is so important to consider the year's periods corresponding to different stages of crop growth.

According to the information obtained from woredas' Rural Development and Agriculture Sector major crops grown in the study area are maize, wheat, barely, teff , enset and root crops during spring and summer seasons. By combining both cropping pattern and the land use / land cover classes done based on 2000 ETM+ imagery and the previous land degradation studies of Hurni (1985), crop management factor has been estimated. In estimating the crop management factor of some land covers which don't have exact value, average values are taken into consideration.

Table 4.7. Estimated Crop Management Factor

Land Cover	C -Factor
Intensively Cultivated	0.15
Moderately Cultivated Land	0.1
Grazing Land	0.01
Wood Land	0.1
Degraded and Barren Land	0.05

In similar fashion as done in establishing value for each USLE input, first of all the C value was placed in its respective dataset of the geodatabase then by its value a conversion process using Spatial analyst was carried out to make this factor have the same format and cell size for cell by cell multiplication of overlaying process.



*Fig 4. 6 Raster format of Crop Management Factor*

### **Support Practice (P) Factor**

The conservation practice factor is the ratio of soil loss for a given practice to that for up and down the slope farming. P value varies depend on a range of practices applied on the farm such as contouring, strip cropping, and terracing. Values for the erosion control practice factor are obtained from tables of the ratio of soil loss where the practice is applied to the soil loss where it is not. With no erosion control practice, p is equal to one. This means the P value indicates reduced erosion potential, with a range between 0 to 1 because of farming practices or soil and water conservation measures. The only farming practices increasing erosion instead of reducing it is ploughing in the direction of up and down slope. Studies conducted by Hurni (1985) have found P values for various support practices and land use cover, is presented in Table4.8

Table 4.8 Estimated Support Practice Generated by Hurni (1985)

Conservation measures/ management	P values
Ploughing Up and Down Slope	1.0
Contour Ploughing	0.9
Applying Mulch	0.6
Inter cropping	0.8
Strip cropping	0.8
Grass strips	0.8
Bunds degraded	0.9

Since recently it has been observed that different conservation techniques are being employed particularly in areas where land degradations are extremely severe and the land productivity totally turns to zero. Places near small Adilo town have been already demarcated for land productivity restoration and also efforts are made to control degradation along Bishan Guracha River by establishing nurseries for the growth of different land support practices and degradation restorations have been underway, plates 4.3 and 4.4, respectively.



Plate 4.3 Grass strips cultivated near Bishan Guracha River



Plate 4.4 Grasses used to restore the most degraded part near Adilo town

With the consideration of different support practices through observation and with the information got from the respective woredas' of the study area, P value has been fixed and displayed in Fig.4.7.

Table.4.9. Estimated Support practice management

Land Cover	P Value
Intensively Cultivated	0.8
Moderately Cultivated Land	0.9
Grazing land	0.9
Wood Land Cover	0.8
Degraded/Barren Land	0.9

These values were also put in the geodatabase and converted in to grid format having a cell value of 30m.

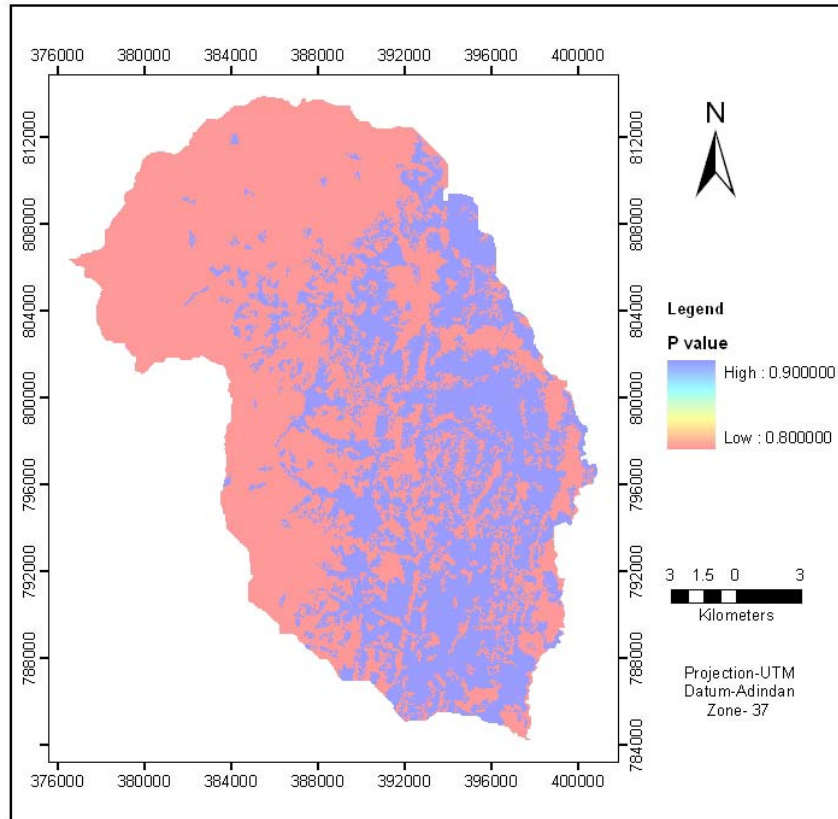


Fig. 4.7 Raster format of Support Practice Management

GIS Overlay of USLE Factors

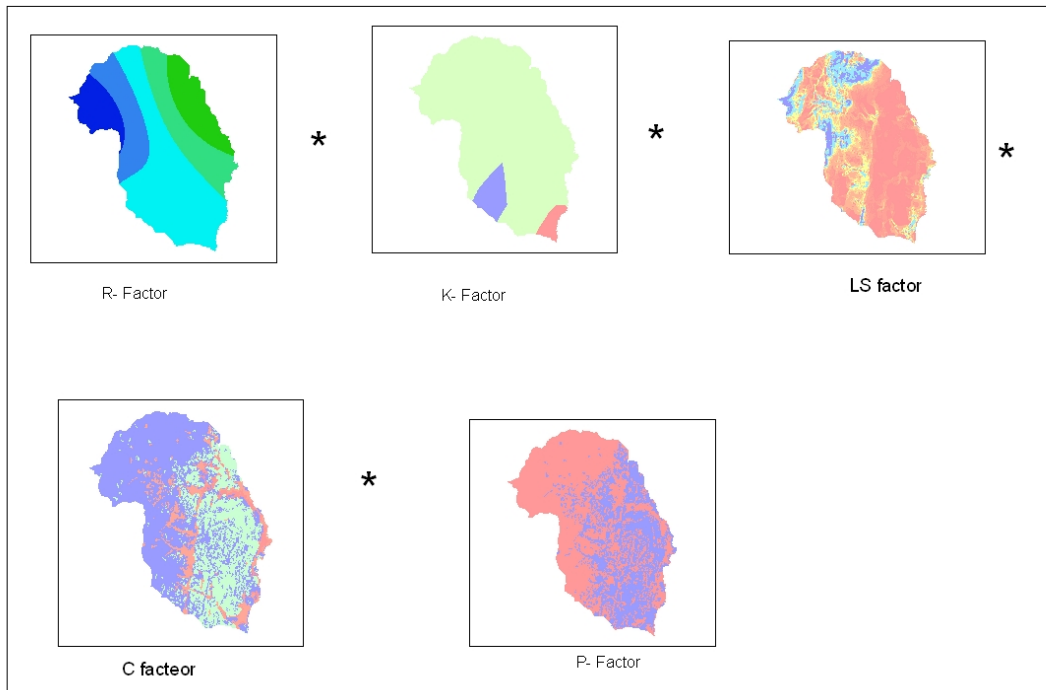


Fig 4.8 Estimated USLE parameters

## 5. RESULTS AND DISCUSSION

This section describes the results obtained through data processing and analysis techniques. It consists of two main parts. The first part discusses the result of post classification comparison of land use / land cover changes between three dates of imaging and NDVI analysis of 1984 and 2000. In the second part the result of USLE model in comparison with land use / land cover classes, slope gradient, drainage density and comparing estimated annual soil loss within the two subcatchments will be briefly presented.

### *5.1 Land Use / Land Cover Changes*

Change in land use / land cover in general and land cover in particular would have either direct or indirect impacts on the extent and conditions of land degradation as a whole. The changes could be transformation of land cover to land use or vice versa. However, it is very difficult to generalize whenever there is change in land use/land cover, the change could be eventually followed by land degradation.

The areal extent of land use / land cover changes of 1973 to 2000 for Bishan Guracha-Adilo subcatchment is presented in Table 5.1. In addition, the statistics of land use/ land cover were computed and summarized to detect the nature of major changes occurred between 1973 and 2000.

The rate of change was calculated for each land use land cover using the following formula:

$$\text{Rate of change (ha/year)} = (X-Y)/Z$$

Where X = Recent area of land use/ cover in ha.

Y = Previous area of land use/ cover in ha.

Z = interval between X and Y in years

According to the result of this computation, moderately cultivated and grazing lands revealed negative rate of change which implies decline in areal coverage while intensively cultivated and degraded land were in a position to increase their areal extent at the expense of the others (Table 5.1).

Table 5.1 Summary Statistics of land use / land cover from 1973 to 2000

Class	1973		1984		2000		Rate of change	
	Area (ha)	%	Area (ha)	%	Area(ha)	%	1973-1984	1984-2000
Moderately Cultivated	16100	38	16800	40	11100	27	63	-356
Intensively Cultivated	13700	34	15100	36	22600	54	127	468
Grazing Land	9500	23	7500	19	3700	9	-527	-237
Wood Land	1500	4	800	2	556	1	-63	-15
Degraded/Barren Land	900	1	1500	3	3744	9	54	140
Total	41700	100	41700	100	41700	100		

From the 1973 land use / land cover classes, about 72 % was devoted to cultivation of different crops where as grazing land shared 23%. The smallest share went to wood and degraded lands.

In 1984, both intensively and moderately cultivated lands revealed an increase in areal coverage due to the need to secure more farm lands. However, grazing land which was liable to be converted in to other land use / land cover unit depicted change in decline. Apparently, degraded/ barren land coverage has got increment of 2 %.

Regarding 2000 land use / land cover unit, the size of three classes, namely; moderately, grazing, and wood land became reduced as compared to the previous one. But the cultivated sector has been on the pace of increase accounted for 81%. From the general landscape of the study area, the figure tells us even marginalized land has been under way for cultivation. The pattern of land use / land cover would be depicted graphically in Fig 5.1

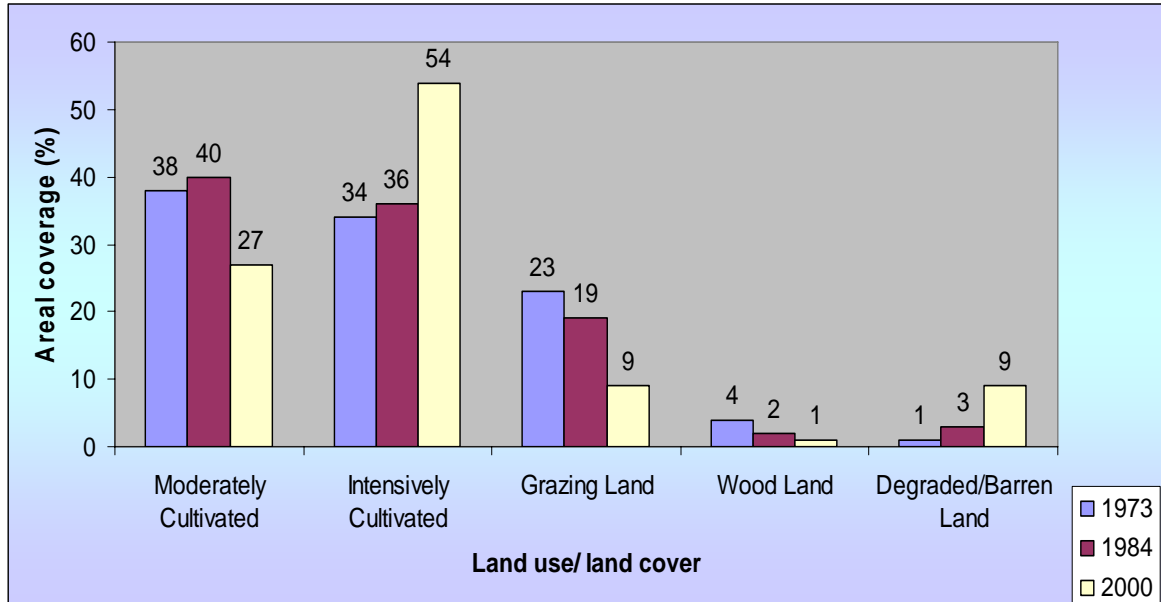


Fig.5.1 Pattern of Land Use/ Land Cover Change

In order to put a clear picture and understanding as to the land use / land cover change, change matrix has been generated on the basis of 1973, 1984 and 2000 satellite images classification and presented in Tables 5.2 5.3 and 5.4. These tables show areal distribution of each land cover / land use classes that have undergone transformation from one type to another or being lost their areal extents or remained intact. The following important points are indicative to extract and analyze information from these land use / land cover change matrix.

- Area is measured in square kilometre
- Each column values represents land use / land cover unit for initial state class (Previous year)
- Each row values gives land use / land cover type of the final state of image ( the recent year)
- The diagonal represents where no change has occurred

From the statistics table lists given below (Table 5.2), it can be seen that the amount of land in hectare converted to other form or the land use type gained from other type; in short, there can be loss and gain of land use land cover among each other. For instance, reasonably 17 square kilometres of grazing and 11 square kilometres of wood lands of 1973 classes were transformed to intensively

cultivated land. In other way, degraded / barren land of 1984 unit gained 9.2 and 3.5 square kilometres of exhausted land from moderately cultivated and grazing lands, respectively. Whereas the bolded diagonal values represent the unchanged land use / land cover that maintained its original unit even during 1984.

Table 5.2 Matrix of Land Use / Land Cover Change between 1973 and 1984

Final State Image 1984	Initial State Image1973						
	Classes	Moderately cultivated	Intensively Cultivated	Grazing Land	Wood Land	Degraded/ Barren Land	Total
	Moderately cultivated	<b>109</b>	16.6	40.100	0.200	3.9	169.600
	Intensively Cultivated	8.200	<b>113.300</b>	17.900	11.500	0.2	151.100
	Grazing Land	34.200	2.1	<b>33.900</b>	1.300	3.6	75
	Wood Land	0.100	3.900	0.300	<b>1.800</b>	0	6.100
	Degraded/ Barren Land	9.200	0.500	3.500	0.100	<b>1.7</b>	15.000
	Total	160.700	136.4	95.700	14.900	9.200	417

Table 5.3 Matrix of Land Use / Land Cover Change between 1984 and 2000

Final State Image 2000	Initial State Image1984						
	Class	Moderately cultivated	Intensively Cultivated	Grazing Land	Wood Land	Degraded/ Barren Land	Total
	Moderately cultivated	<b>75.7</b>	6.8	25.9	0.2	1.6	110.2
	Intensively Cultivated	67.6	<b>137.8</b>	14.7	4.8	1.6	226.5
	Grazing Land	10.8	1.5	<b>22.3</b>	0.3	2.1	37.
	Wood Land	1.6	2.7	0.7	<b>0.4</b>	0.04	5.44
	Degraded/ Barren Land	13.9	2.2	11.4	0.2	<b>9.6</b>	37.3
	Total	169.6	151.	75.	5.9	14.94	417

In the same fashion as interpreted in Table 5.2, Table 5.3 also indicated that a large portion of grazing land (14.7 km<sup>2</sup>) and that of 4.8 km<sup>2</sup> of wood land had been converted to intensively cultivated land from 1984 to 2000. In contrary, degraded / barren land expanded its areal coverage by taking 13.9 km<sup>2</sup> from moderately cultivated and 11.4 km<sup>2</sup> from grazing land.

The following three classified maps have been used for post change detection comparisons.

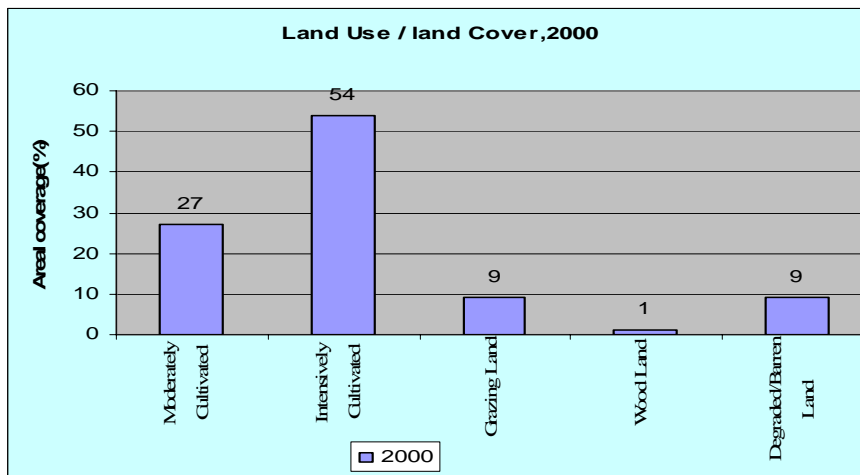
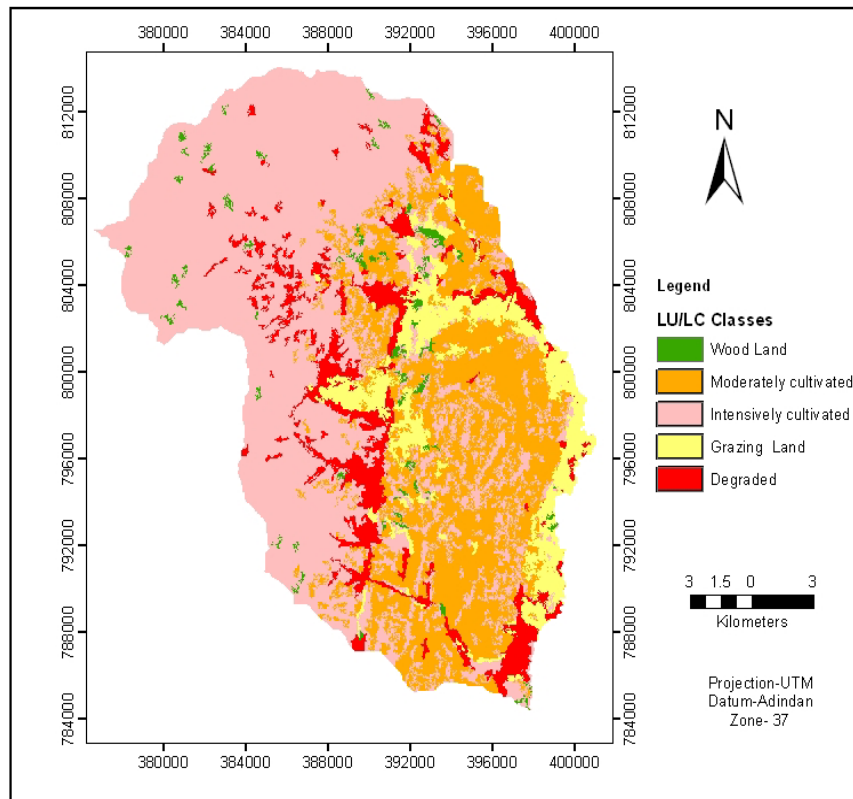


Fig.5.2 Land Use / Land Cover Classes, 2000

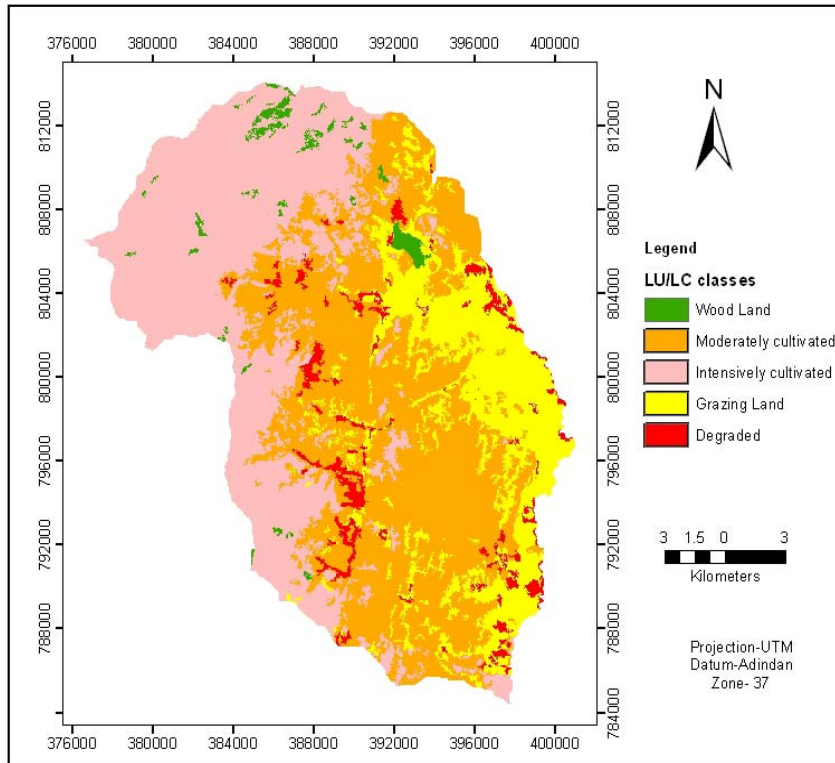


Fig. 5.3 Land use/Land covers Map, 1984

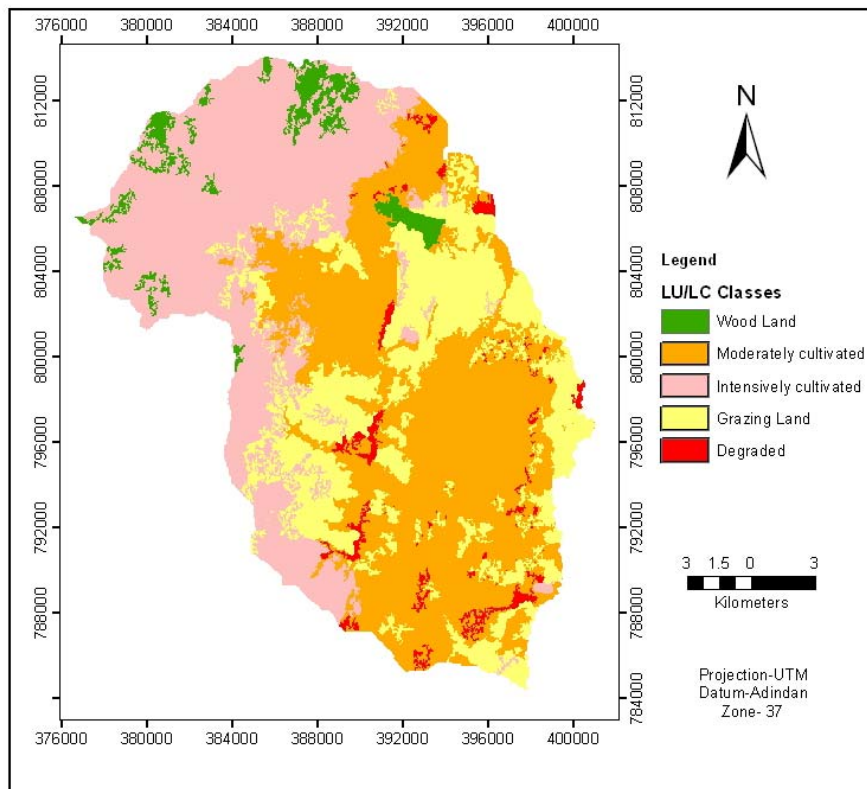


Fig. 5.4 Land use/Land covers Map, 1973

Table 5.4 Matrix of Land Use / Land Cover Change between 1973 and 2000

Final State image 2000	Initial State image 1973					
	Class	Moderately cultivated	Intensively Cultivated	Grazing Land	Wood Land	Degraded/ Barren Land
Moderately cultivated	<b>78</b>	2.8	26	0.2	3.2	110.9
Intensively Cultivated	49.9	<b>127</b>	35.7	12.3	1.500	226.4
Grazing Land	11.1	1.5	<b>22.8</b>	0.4	1.200	37
Wood Land	0.9	1.4	2.1	<b>1.01</b>	0.010	5.4
Degraded/ Barren Land	20.8	3.6	8.7	0.9	<b>3.2</b>	37.2
Total	160.4	136.3	95.3	14.8	9.1	417

In 2000, as indicated in the table above and Fig 5.5 below, through 1973 to 2000 only intensively cultivated land and degraded/ barren land expanded in areal coverage whereas the remaining including moderately cultivated became shrunk in size.

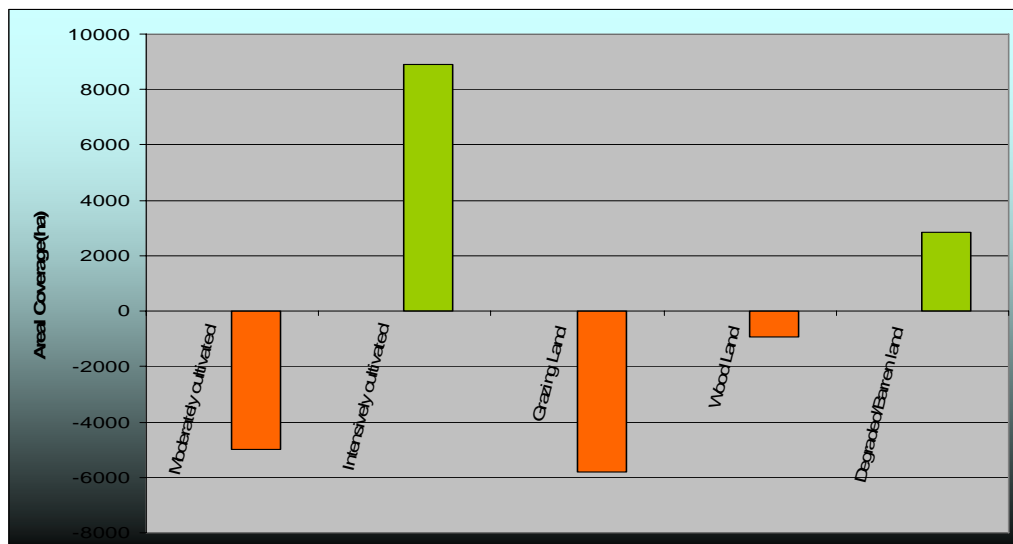


Fig.5.5 Area increase and decrease in LU / LC between 1973 and 2000

In land use / land cover dynamics there has been often conversion of a given class to another when the natural system is perturbed due to the intervention of human beings. Likewise in the study area there had been conversion of some classes like wood land and grazing land to cultivated land as a result of high population increase on one hand and they also transformed to degraded / barren land unit when they were unable to be used for other purposes or simply lost their productivity. In addition, moderately cultivated land was also subjected to change in decline owing to the same reason stated for wood and grazing land covers (Fig.5.6).

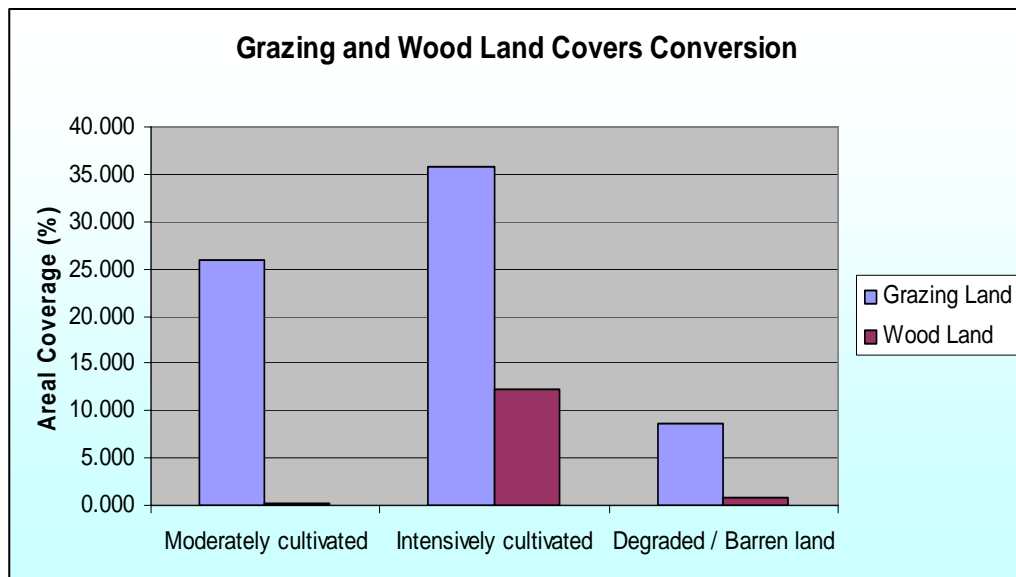


Fig.5.6 Grazing and wood lands conversion between 1973 and 2000

## 5.2 Land Use / Land cover Change and Land Degradation

Change in land use / land cover doesn't always necessary result in land degradation. But if the change is particularly large enough in land cover it might lead to land degradation. In other word, depending on the magnitude of changes land degradation manifests itself in many ways. Vegetation, which may provide fuel and fodder, becomes increasingly scarce. Water courses dry up. Thorny weeds predominate in once-rich pastures. Footpaths disappear into gullies. Soils become thin and stony. All of these manifestations have potentially severe impacts for land users and for people who rely for their living on the products from a healthy landscape.

The mounting population pressure in the study area in line with some deep rooted social, economic, political problem of the country resulted in land use / land cover change which in turn has led to change in environmental system. The change detected in accordance with the classified classes between 1973 and 1984, 1984 and 2000, and 1973 and 2000 revealed that wood and grazing land covers were forced to be transformed into cultivated land and degraded/ barren land. The latter definitely showed how changes in land use / land cover aggravate land degradation. In addition, NDVI analysis has also proved that there had been change in land cover between 1984 and 2000 images.

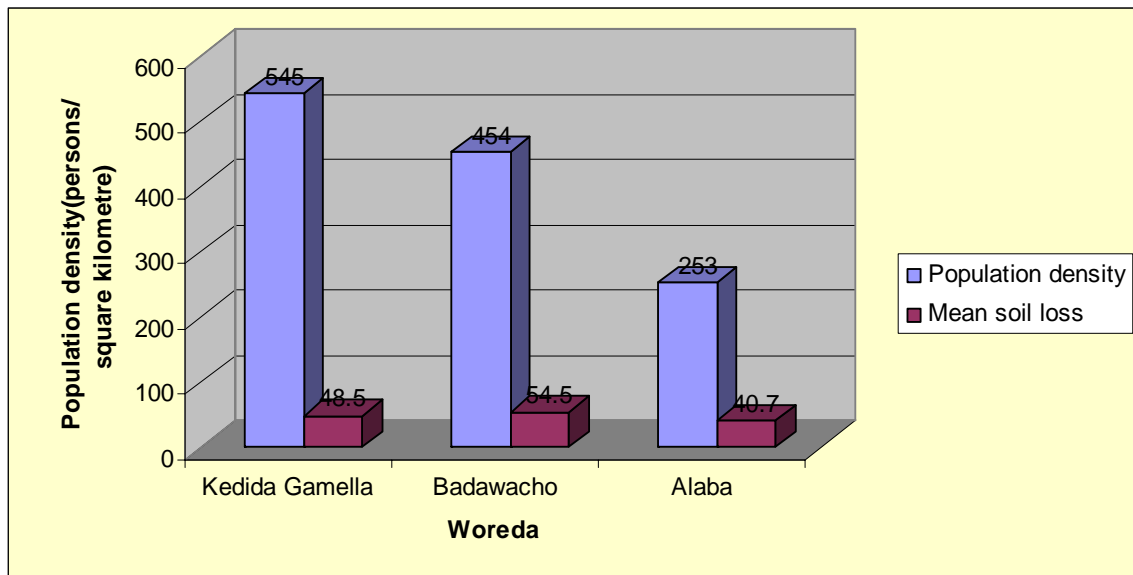


Fig.5.7 The relationship between population density and mean annual soil loss

The fact that high increase in population number and its negative impacts has been a debatable issue among various researchers and concerned bodies attempt has been made to relate estimated soil loss with population density of the three woredas in which the study area situated. When compared mean soil loss of the study area with population density, mean soil loss was exaggerated ten times to make it compatible graphically with high population density. From Fig.5.7 it is difficult to draw conclusion whether they do have positive or negative correlation. But to some degree increase in population density like the case in Alaba and Badawacho showed a direct relationship with increase in mean annual soil loss.

### 5.3 NDVI image comparisons

General assessment of land degradation (land cover degradation) could be assessed using NDVI values comparison between different dates of imaging. The fact that NDVI doesn't give exactly the areal extent of land cover degradations; it implicitly shows the overall change in vegetation cover of a given place.

Table 5.5 NDVI statistics

Statistics	1984	2000
Minimum	-0.37	-0.5
Maximum	0.71	0.60241
Mean	0.07	0.032
Standard deviation	0.109	0.107

As indicated in the above table, there was change in land cover in two dates of imaging. To this effect, the standard deviation value decreases in certain amount in 2000 image as compared to 1984 showed that there had been change in land or vegetation cover (Fig.5.8).

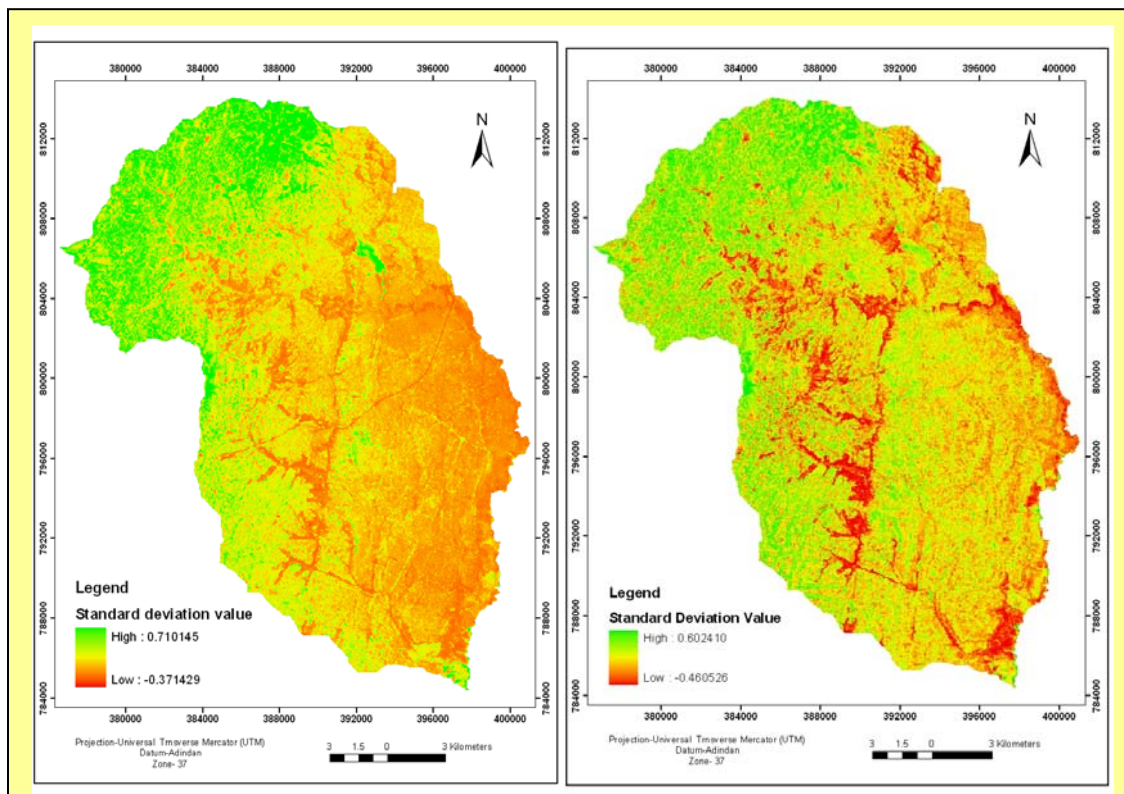


Fig.5.8 NDVI Comparison between 1984 and 2000

#### 5.4 Soil Loss Estimation Result

The model, USLE, estimated the amount of annual soil loss for the study area by taking each parameter's influence into account while multiplying each input cell by cell using raster calculator in GIS environment. It is fact that distribution of rate of soil loss in a given area is a function of the spatial distribution of all factors controlling soil erosion processes. Nevertheless, some factors might have dominating role over the others especially in USLE model result. The probable speculated reason might be computation of each factor independently ought to be in contrary to reality where things are highly interactive among each other and form a given environmental system. In addition, generating a DEM from 20m contour lines interval would also make some part of the study area which seems to be flat or plain to have  $0^0$  slopes, consequently, when multiplied it with other factors values it makes zero value that is rarely experienced in reality. The estimated soil loss in the study area is displayed in Fig 5.9

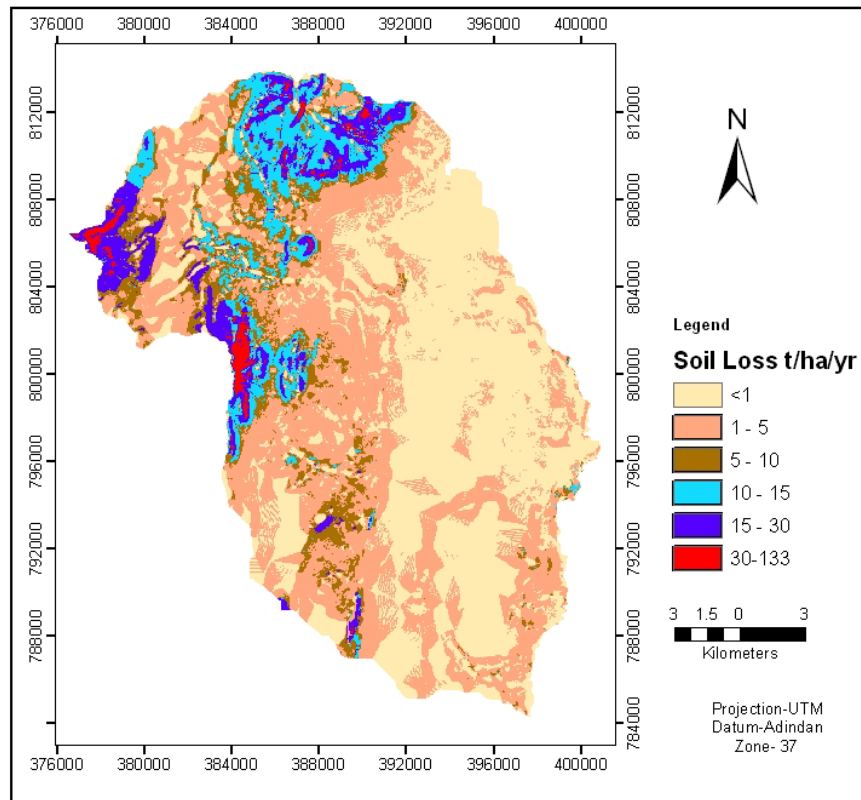


Fig.5.9 Soil Erosion Hazard Map

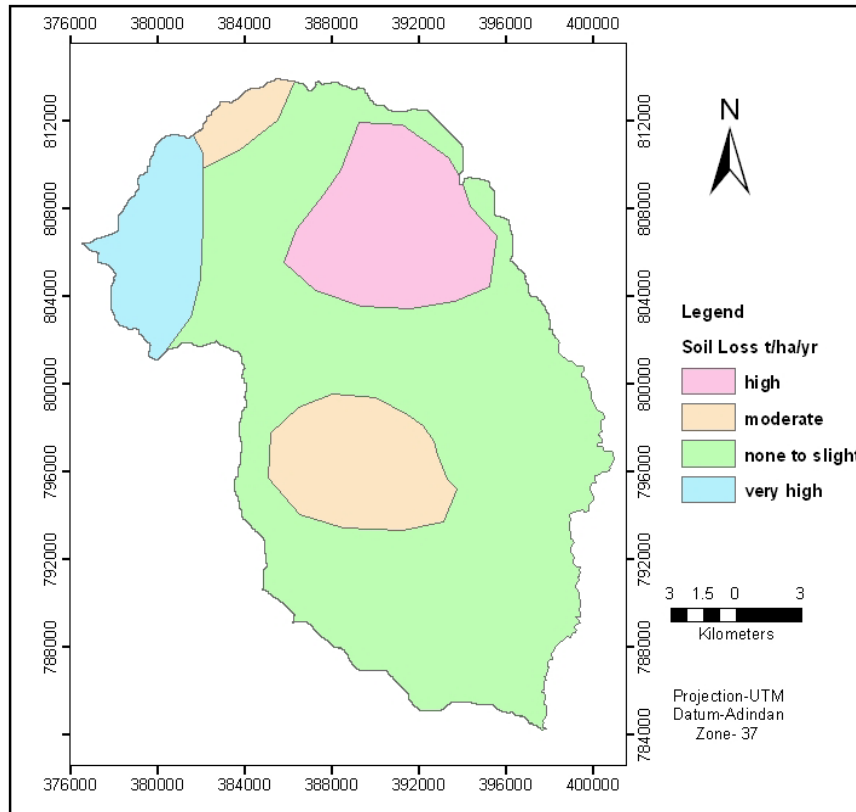
Table.5.6 Classes of Soil Erosion Rate in the Study Area

Class	Soil loss in t/ha/yr	Degree	Area in ha	%
1	<1	Very low	16800	40
2	1-5	Low	15230	37
3	5-10	Moderately high	3600	9
4	10-15	Very high	3000	7
5	15-30	Severe	600	1
6	>30	Extreme	2470	6
Total			41700	100

As indicated in Table 5.6, 77 % of the study area experiences annual soil loss of less than 5 t/ha/yr which is very low to low. But 17% belongs to moderately high to very high and the remaining 6 % exercise extreme soil loss rate within the range of 30 to 133 t/ha/yr that would ultimately needs a soil and water conservation practices.

The result of estimated annual soil loss for the two subcatcments ranges from 0.02 to 133.2 t/ha/yr. Whereas mean annual soil loss of the subcatcments is 5.4 t/ha/yr compared to 12 t/ha/yr average estimated soil loss of Ethiopia and even higher on steep slope with soil loss rates greater than 300 or 200 t/ha/yr where vegetation is scant (USAID, 2000).

When assessing the previous researches estimating annual soil loss in comparison with result of USLE model for this thesis, the gap is not minimal. However, it seems to be more or less similar to the soil erosion hazard map produced by Ethiopian Highland Reclamation Study though it was done at small scale. According to such soil erosion hazard map the two subcatcments generally categorized under degree of none to slight to very high. The clipped hazard map produced by Ethiopian Highland Reclamation Study is depicted in Fig.5.10



*Fig.5.10 Soil Erosion hazard map Produced by EHRS (1984)*

Source: Ministry of Agriculture and Rural Development

While comparing this hazard map with USLE model result of this study, their overall pattern of soil erosion is similar despite difference in scale. Greater area in both cases experience low soil erosion rate in the form of sheet and rill.

On the other hand, Hurni (1985) estimated that soil loss up to 296 t/h a/yr (i.e. a topsoil depth of about 3cm/yr) was recorded on slopes of 16% on cultivated Eutric nitosols. A year after, Hurni also measured a soil loss rate of 282 t/ha/yr on a 22% slope on a nitosols cropped with teff and annual rainfall of 1550mm. Solomon (1994) calculated soil loss from newly cleared forest land for crop production purpose to be 130 t/ha/yr. In a nutshell, the mean value of soil loss obtained from USLE model is lesser than those already computed.

### 5.5 Land Use / Land Cover Classification and Annual Soil Loss Estimation

It is clear that land use, which is the actual economic activity for which the land is used and land cover referring to what covers the surface of the earth, has a tremendous positive or negative impact on soil erosion rate of a given area. In the study area, there are almost no places having more natural land cover remained other than scattered plantation of eucalyptus trees. The role of land use / land cover category has been immense particularly in estimating the C and P factors of the USLE model. Thus their influence on soil loss would be to some extent decisive, however, slope length and slope gradient have put strong reflection of their pattern at final result of the USLE model.

Table 5.7 Land use/ Land cover and Annual Soil Loss Estimation

LU/LC	Soil Loss in t/ha/yr					
	<1	1-5	5-10	10-15	15-30	>30
Moderately	8165	3052.5	95.5	29.6	1	15.3
Intensively	5407	10156	3093.5	2852.9	464.2	2417
Grazing	1278	64.9	1	0	0	0.95
Wood Land	455	130.8	24	11	2.9	24.8
Degraded	1622	1861.5	386.8	25.8	1.9	10.5
Total	16927	15265.7	3600.8	2919.3	470	2468.55

In the first place, this table tries to show the amount of hectare of land in each land use / land cover being exposed for the rate of annual soil loss and hence it is possible to know certain amount of land which is vulnerable to certain specific soil loss category. As a result, more than 64 % of the cultivated land (both intensive and moderately) of the total area have soil loss less than 5 t/ha/yr. This implies that soil loss on cultivated land is not considered to be serious at all beyond the USLE model result of this study. Nevertheless, their share under extreme soil erosion which is greater than 30 t/ha/yr would be about 98%. In short, more than 24 km<sup>2</sup> of intensively cultivated occupying elevated place is highly exposed to extreme soil loss.

### ***5.6 Slope Gradient and Annual soil Loss Estimation***

Slope is one of the major regulators of surface water flow. It determines direction and velocity and steers the processes of detachment, transport and accumulation of soil particles. Slope expressed either in the form of length or steepness is mostly in a position to have put a very decisive effect on the result of USLE model.

Table 5.8 Slope Gradients and Estimated Annual Soil Loss

Slope (%)	Annual Soil Loss in t/ha/yr					
	<1	1-5	5-10	10-15	15-30	>30
0-2	13260	232	17200	1330	129	5
2-10	0.0	0.0	380	2980	240	9
10-15	0.0	0.0	0.9	660	2250	10
15-30	0.0	0.0	0.0	60	50	420
>30	0.0	0.0	0.0	270	1420	780
Total	13260	232	17580.9	5300	4089	1224

From Table 5.8, it can be easily realized that as the slope steepness tend to be higher, the amount of annual soil loss to be correspondingly increasing. This could be simply checked by observing how the last column of annual soil loss areal coverage increases from 5 to 780 ha of land. On the other hand, since more than 75% of the study area lie below 10 % of slope, consequently, such areas are to be vulnerable to less soil loss.

### ***5.7 Annual Soil Loss Estimation within Bishan Guracha and Adilo Subcatchments.***

First of all, the two SubCatchments have been selected for assessing land degradation with much emphasis to soil erosion is basically owing to with the assumption of similarity in ecological, natural, socio-cultural and economic conditions as well as to some extent similar status of land degradation. However, this doesn't mean that they are totally identical in every regards. During field visit it has been observed that land degradation in both Subcatchments has been a common problem (plates 5.1 and 5.2)



Plate 5.1 Deep Gully within Adilo River Catchment

Table 5.9 Area exposed for annual soil loss within the two Subcatchments

Subcatchments	Estimated annual soil loss in t/ha/yr						Total
	<1	1-5	5-10	10-15	15-30	>30	
Bishan							
Guracha	8970	7640	2460	2590	410	2190	24260
Adilo	7950	7630	1140	330	60	290	17400



Plat 5.2 Side way and vertical erosion by River Bishan Guracha

Both table 5.9 and Fig 5.12 represent the estimated amount of soil loss in each sub catchment. While trying to compare which subcatchment is highly susceptible to soil degradation, it could be asserted that Bishan Guracha catchment is to some degree found to be at relatively high soil erosion hazard area. The conclusion would be drawn due to areal wise extent being exposed for greater than 5t/ha/yr, accordingly, it is only 11% of area in Adilo catchment and 32 % with that of Bishan Guracha. This directly implies that more than one-third areal coverage in the latter experiences moderately high to severe erosion and even extreme one as compared to Adilo catchment.

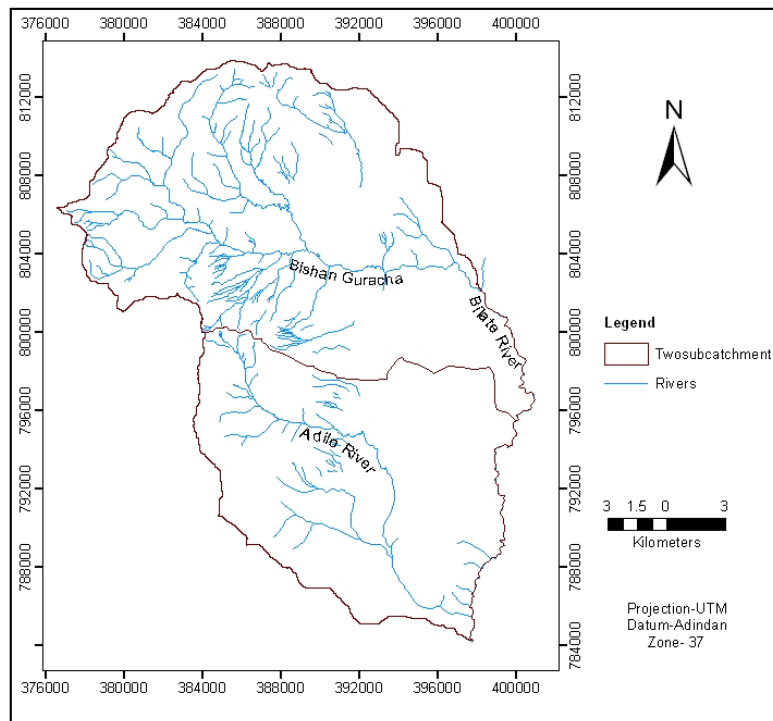


Fig.5.11 Areal coverage of the two subcatchments

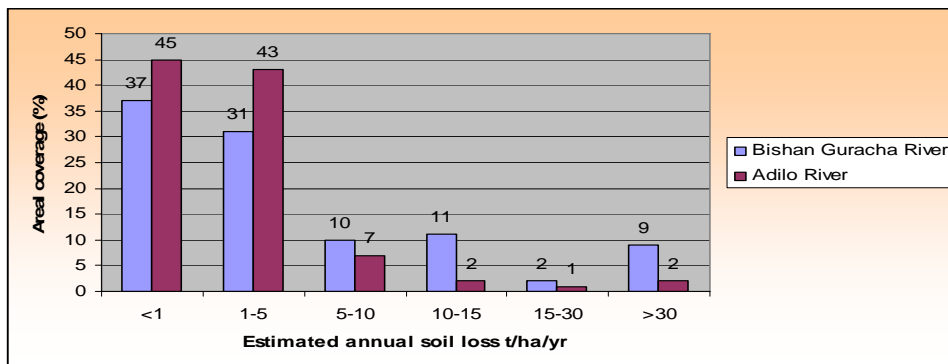


Fig.5.12. Areal share of each subcatchment and its respective Annual Soil Loss.

### 5.8 Estimated Annual Soil Loss and Drainage Density

The other way of assessment of soil degradation in both subcatchments has been using drainage density. According to Morgan (1996) one of soil erosion indexes to assess erosion risk is drainage or gully density, defined as the length of stream per unit area. In his analysis, high values of drainage density are associated with the transport of run off from regular, moderate rainfall.

With regard to drainage density map given in Fig. 5.13 and soil erosion hazard map (Fig 5.14), a certain limited area in both would have similar pattern of high soil erosion. For example, in drainage density map, its northern, north western and south western parts has high drainage density associated with high run off as well as soil loss and similarly those parts in soil erosion hazard map also exercise very high to extreme soil loss. Therefore, drainage density can be an important indicator of generalized soil erosion assessment.

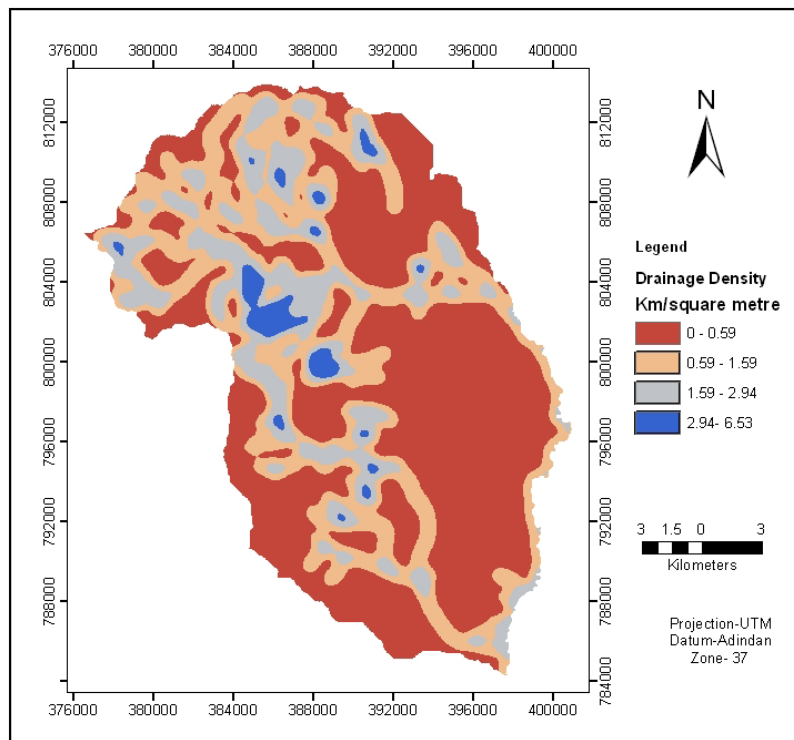


Fig 5.13 Drainage density of the study area

### 5.9 Identifying Soil Erosion Spot zone

According to the estimated result of the model a few limited part do have much soil loss and then they tend to be the spot area. But to clearly specify such area micro-catchments wise identification has been carried out. It is remembered in data analysis that micro-

catchments have been generated using Arc Hydro extension in Arc GIS even by taking valleys with no water flow in to account, therefore, all the micro-catchments valleys displayed in Fig 5.14 are not always with flow of water but they are readily available to transport soil during rainy season.

To identify soil erosion spot of the study area other than visual interpretation of the soil erosion hazard map micro-catchments against estimated annual soil loss cross tabulation was performed in Arc GIS zonal tabulate area. Accordingly, micro-catchments having more than one square kilometre area exposed to annual soil loss under greater than 30 were selected, namely, micro-catchment 22, 31, 35, 38, 41, 46, 49,53 and55( Fig 5.14). Thus it could be possible to say that these micro-catchments are priority area where they basically need soil and water conservation practices. This, however, doesn't mean that they are the only places in the study area which demand further feasibility study and soil and water conservation measures, there are other micro-catchments which are highly susceptible to land degradation but their total area vulnerable to greater than 30 t/ha/yr is less than a square kilometre. Therefore, with the help of further feasibility study all parts in the study area experiencing more than 10 t/ha/yr soil loss should be given much emphasis so as to use integrated soil and water conservation strategies.

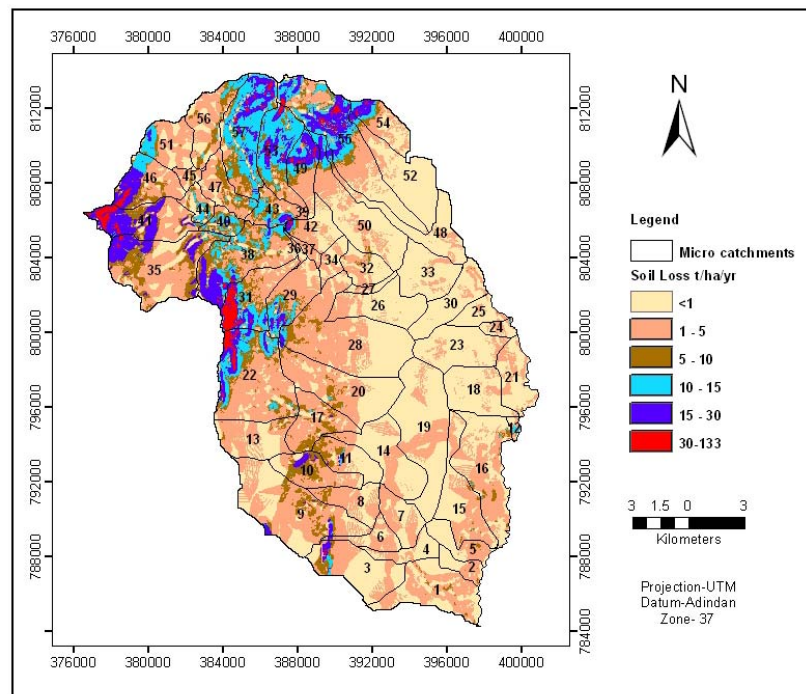


Fig.5.14 Micro-catchments wise soil loss.

## **6. CONCLUSION AND RECOMMENDATIONS**

### ***6.1 Conclusion***

Land use/land cover change detection among the land use / land cover classes of 1973, 1984 and 2000 images, was carried out based on post classification change detection comparisons methods. The five major land use / land cover units classified on the basis of 2000 image classification in the study area were forced to either an increase or a decrease in areal extent due to the pressure exerted by the high population growth of the study area and its surroundings. Accordingly, intensively cultivated and degraded/ barren land showed 20 and 8 % increase in areal coverage between 1973 and 2000, respectively. On the other hand, grazing land which was highly transformed in to other land use / land cover unit; in the same way wood land and moderately cultivated land in connection with small land holding system prevalence lost their share of areal coverage.

Moreover, NDVI analysis on its turn depicted the status of land cover or vegetation cover for the study area between 1984 and 2000 imageries. And hence, the result on the basis of standard deviation variation showed a considerable amount of vegetation loss between the stated two dates of images.

Land degradation in the form of soil erosion has been assessed in this study by using Universal Soil Loss Equation (USLE) model with the purpose of detecting the spatial extent of soil erosion in the two subcatchments, thereby producing soil erosion hazard map. The soil erosion hazard map expressed in t/ha/yr has been generated through the computation of all the six factors of USLE model and organized them in a geodatabase in such a way that they were finally taken to GIS overlay analysis for performing cell by cell multiplication of each parameter. The result obtained from USLE model ranges from 0.02 to 133.2 t/ha/yr. Of which less than 10t/ha/yr soil loss accounted for 85 % of the total area of the two subcatchments. The mean annual soil loss of the study area which is 5.4 t/ha/yr falls below 12 t/ha/yr of the national standard. This doesn't mean that the two subcatchments don't exercise high land degradation or soil erosion. The slope length and gradient computed from the DEM generated from 20m contour interval might have

affected particularly the low land area to have very low soil loss by making them have 0 degree slope gradient.

The result of the model, estimated annual soil loss in t/ ha/yr, was also evaluated against slope gradient, land use / land cover classes and drainage density. In the case of slope gradient there is a direct relationship, as the slope steepness increases the soil loss amount also mounting. In connection with the land use / land cover classes and the soil loss, there is no distinct pattern observed but the cultivated land use in general shared 98% of areal coverage under greater than 30t/ha/yr soil loss. Pertaining to drainage density and estimated annual soil loss, a direct observation has been made as if the two maps were superimposed or by comparing the two maps visually, consequently, areas having higher drainage density in most cases coincide more or less with areas experiencing high annual soil loss.

Comparison on the basis of estimated annual soil loss was attempted to differentiate which subcatchment is more susceptible to land degradation or soil erosion. As a result of the overall assessment of soil erosion between the two subcatchments, Bishan Guracha subcatchment is found to be more likely to a bit more soil erosion hazard. Further more, in order to identify which part of the subcatchments is priority area or spot zone, micro-catchments wise identification of most erosion hit area was done. In light of this, micro-catchments such as 22, 31, 35, 38, 41, 46, 49, 53 and 55 have got priority zone with a threshold value of one square kilo metre area being exposed to more than 30 t/ha/yr.

## ***6.2 Recommendations***

Despite serious financial and time limitations of this study, the following points are forwarded as recommendations on the basis of the result of this thesis work.

- The three dates of satellite imageries classification demonstrated the expanse of degraded / barren land in the study area in due course of time, thus detail soil and water conservation study at feasibility study level shall be carried out to prepare projects with full participation of beneficiaries so as to restore the most degraded area.
- Even if USLE model has already been adapted to predict soil loss through statistical approach in the highland area of Ethiopia, its estimated value needs

validation, therefore, it should be asserted that the result obtained from USLE model has to go through further investigation by incorporating high resolution contour interval and the effect of population pressure on aggravating land degradation

- In order to rescue some parts of the study area before their productivity of soil will turn to intolerable state of existence, priority should be given to those places whose annual soil loss in t/ha/yr is greater than 15 in addition to the spot zone already identified at micro-catchment levels.
- Change in land use / land cover also contributes a lot in affecting land degradation so that monitoring of such change using remote sensing is of a paramount role just by providing timely information with little consumption of time and money.
- Since land degradation has no single readily identifiable feature, to control its rate, some remedial measures should be launched depending on factors that are modifiable in nature and the extent of human intervention in addition to the effort being made to restore the most degraded part of the study area.

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## ANNEX 1

### Methodology of Erosion Assessment

The sheet erosion calculated by an erosion estimate model adapted from the universal soil loss equation (USLE) by Wischmier and smith (1978), modified to the condition of Ethiopian highlands by Hurni (1985). The annual soil loss by sheet erosion is calculated by:

$$A=R*K*L*S*C*P$$

**A = total soil loss (t/ha/yr)**

**R= rainfall erosivity factor**

**K= soil erodibility factor**

**L= slope length factor**

**S= slope gradient factor**

**C= land cover factor**

**P= management factor**

#### 1 .Rainfall Erosivity Factor

$$R= -8.12 + (0.562* P)$$

P= annual precipitation (mm)

#### 2. Soil Erodibility Factor

**Soil erodibility factor is generated by considering their colour and the value attached to them**

Soil colour	Black	Brown	Red	Yellow
K value	0.15	0.2	0.25	0.3

#### 3. Slope Length and gradient

$$LS= (\text{Flow accumulation} * \text{Cell size} / 22.13)^{0.4} * (\sin(\text{slope} / 0.0896))^{1.3}$$

#### 4. Land Cover Factor:

Coffee, tea, banana, citrus, enset

0.01

Paddy rice, sugarcane, pineapple, sisal, grape	0.05
Sorghum, maize, millet, sweet potato	0.10
Wheat, barley, oats, beans, peas, lentils, vetch, Soybeans, niger seed, pepper, tomato, white potato, Groundnuts, sunflower, safflower, flax, cotton, tobacco	0.15
Upland rice, cabbage	0.20
Teff, Shallet	0.25
Dense Grass cover	0.01
Nondense Forest	0.01
Degraded grass cover, grazing, hard badland, fallow	0.05
Soft	0.40
Continuous fallow	1.00
<b>5. Management Factor</b>	
Mulch Application	0.6
Dense intercropping	0.7
Strip cropping	0.8
Contour Ploughing	0.9
Up and Down Poughing	1.0

For the non-land use specific and non-management specific estimate of sheet erosion hazard, the values 0.15 (for the land cover) and 0.8 (for the management) were taken.

## ANNEX 2

### Long Year climatic data for Five Stations

#### Station\_Durame

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
1987	4	49.3	164.8	108.1	300.1	79.7	91	202.5	179.3	145.3	9	10.5	1343.6
1988	18.9	55.5	28	198.8	103.4	84.1	211.4	192.7	230.8	117.2	8	2.3	1251.1
1989	32.9	147.1	133.9	176.6	48.5	133.2	185.6	223	186.5	90	25.8	18	1401.1
1990	41.2	202.2	100.5	74	166.5	58.3	109.3	114.9	95.9	68.4	6.7	12	1049.9
1991	20.7	79.3	159.8	94.6	222.3	120.1	211.8	126.3	176.2	27.2	3.1	35.9	1277.3
1992	55.9	133.4	99.8	113.8	67.3	115.3	122.5	241.9	126.7	201.6	42.6	5.9	1326.7
1993	64.8	72.3	11.2	207.9	270.6	116.1	44.4	142.4	93.9	76.9	16.7	7	1124.2
1994	24	0.7	100.9	84.9	154.1	108.6	130.2	124.2	89.4	82	7.5	6.9	913.4
1995	13	44.4	56.3	199.1	57.3	78	88	164.3	114.5	89	11	27.3	942.2
1996	28.3	41.5	126.3	113.4	168.1	203.8	56.3	75	64.8	40.6	15.7	5	938.8
1997	31.5	34	36.4	126.9	109.1	140.4	100.5	143.7	141	178.8	162.3	21.2	1225.8
1998	31.8	73.6	103.6	164.4	133.1	90.9	152.4	197.4	107.7	204.8	30.9	2.1	1292.7
1999	26.2	2.2	118.8	87	92.4	170.3	166.7	107.9	101.6	188	3.5	1.4	1066.0
2000	15	23	28.8	202.9	114.7	134.3	145.6	146.6	156.9	104	96.2	29.4	1197.4
2001	11.3	53.9	84.3	104.4	74.8	115	257.3	194.5	110.4	163.4	12.9	10.3	1192.5
2002	57.3	48.6	134.1	103	101.8	103.7	116.9	209.2	120.6	22.5	13	120.3	1151.0
2003	23.7	12.1	77.6	205.8	77.2	131.3	200.6	120.6	123.7	20.2	44.2	15.6	1052.6
2004	22	29.2	57.8	183.9	80.2	93.4	159.1	126.5	109.6	136.3	10.6	12	1020.6
												<b>Total</b>	20766.9

#### Station\_Shone

1987	21	104	204	112.4	411.6	73.2	1.3	246.1	206.3	143.5	13	56.6	1572.0
1988	42	130.5	55.4	202.7	103.2	190	206.8	118.1	345.1	236.4	14	1.1	1645.3
1989	78.9	162.4	57.3	129.3	68.2	118.3	151.7	79.2	179.1	146.1	16.9	247.1	1434.5
1990	36.8	121.6	119.4	162	121.1	104.6	147	104.4	172.5	48.1	8.4	9.1	1155.0
1991	42.2	87.2	263.8	51.7	265.5	75.2	160.9	102	165	60.2	54	8.7	1336.4



**Station  
Alaba\_kulito**

1987	4.7	200.8	231.7	75.8	312.8	54	84.4	231.5	278.5	63.1	18.8	8.9	1565.0
1988	29.9	74.5	35	152.1	34.8	102.9	110.2	476.9	307.2	171.4	5.3	1.1	1501.3
1989	24.3	74.7	114.4	125.6	66.7	103.2	138.5	108.2	134.7	84.3	1.4	106.5	1082.5
1990	72.3	188.1	90.4	148.6	142.1	39.6	70	58.9	101.4	37.3	4.8	14	967.5
1991	45.6	65.7	106.4	55.6	138.4	77.1	97.4	137.1	192.2	15.1	23.6	73.1	1027.3
1992	19.5	148.6	115.8	92.3	98.4	67.6	88.2	204.8	89.2	155.1	49.1	27.8	1156.4
1993	72.4	34.7	85.5	297.1	248.6	60.9	105.7	162.5	77.3	121.7	34.6	7.5	1308.5
1994	23.4	32.4	84.6	140.9	116.5	147.1	130.6	105.3	58.1	8.6	9.3	6.4	863.2
1995	32.2	55.7	130.2	257.8	106.3	58.2	132.2	74.2	89	26.5	21	47.1	1030.4
1996	123	8	141.2	138.7	162.2	165.1	134.8	110.6	56.6	76.3	30.3	7.5	1154.3
1997	45.8	8.8	85.3	167.1	83.5	101	95.3	104.8	106.4	180.2	181.4	6.2	1165.8
1998	75.1	74.1	121.5	184.5	123.4	140.2	189.2	102.4	86.5	99.2	19.4	35.3	1250.8
1999	6.1	54.3	68.9	71.1	125.4	113.9	109.5	96.4	40.5	127.6	23	7.3	844.0
2000	5.6	45.4	9	180.9	140.3	72	132.9	65.1	104	43	36	20.5	854.7
2001	8.5	7.2	190.2	89.9	98.6	117.9	121.5	124.8	129.7	47.2	3	2.7	941.2
2002	29.4	61.8	81.1	86.3	57.2	78.1	71.1	109.3	87.9	10.9	15.4	122.9	811.4
2003	42.3	62.1	110.7	139.5	75.5	73.5	67.0	168.9	99.5	9.5	48.8	44.0	941.3
2004	150.4	22.3	39.4	183.6	76.3	34.5	106.0	112.4	168.2	75.2	14.4	12.3	995.0
<b>Total</b>													19460.6

**Station  
Boditi**

<b>1987</b>	5.6	14.6	217.1	105.2	67	148.6	60.8	136.7	131.3	142.8	23.5	17.2	1003.4
1988	34.8	51.5	44.1	238.0	101.2	176.6	215.0	179.0	207.6	124.2	23.4	5.7	1401.1
1989	31.9	100.3	87.2	150.7	66.3	113.8	92.6	111.2	87.5	93.2	18.1	145.0	1097.8
1990	53.4	163.6	165.0	125.0	111.0	101.3	120.1	142.9	53	62.0	11.5	26.6	1082.4
1991	34.0	70.1	145.3	78.3	223.6	166.1	125.1	136.8	137.8	6.8	5.7	83.4	1213.0
1992	13.7	147.1	97.6	110.2	145.8	114.3	195.6	231.1	133.1	133.7	86.8	54.6	1463.6
1993	63.0	86.6	64.5	228.7	294.0	112.6	141.4	132.3	112.9	53.1	11.8	3.1	1304.0
1994	1.5	28.3	125.1	154.9	158.4	198.3	213.1	177.8	72.0	27.7	33.7	8.4	1199.2

1995	7.9	63.4	106.8	264.1	105.6	122.8	107.1	115.0	111.3	52.0	4.0	26.9	1086.9
1996	72.0	28.9	101.9	196.7	121.3	245.1	168.4	218.4	149.2	15.7	20.5	1.0	1339.1
1997	3.5	10.0	84.1	247.6	206.4	101.8	120.8	128.3	41.2	227.5	265.3	13.4	1449.9
1998	79.3	109.8	133.1	230.3	290.4	160.9	150.9	145.8	67.5	131.8	20.2	6.0	1526.0
1999	32.3	35.7	42.7	105.9	98.5	94.3	200.7	180.5	40.1	174.4	17.9	15.2	1038.2
2000	13.0	23.6	26.4	92.6	202.8	96.9	83.1	142.1	69.8	130.5	81.7	22.5	985.0
2001	10.1	67.2	100.2	123.0	245.7	134.2	212.4	209.5	141.6	106.4	33.1	28.6	1412.0
2002	58.8	10.9	147.7	113.6	119.8	59.6	137.1	160.6	130.5	52.2	1.5	113.3	1105.6
2003	59.1	20.3	85.6	182.4	64.1	143.1	200.9	159.1	108.3	69.4	36.6	34.0	1162.9
2004	78.3	41.1	43.0	154.5	85.3	71.3	217.4	76.1	173.1	69.8	24.1	50.7	1084.7
												<b>Total</b>	<b>21954.8</b>

### ANNEX 3

#### Population Number at Woreda Level

Woreda	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
<b>Kedida Gamela</b>	124,497	128,945	133,408	137,902	142,423	147,004	151,635	156,294	161,000	165,783	170,638	175,591
<b>Badawacho</b>	180,156	186,377	192,634	198,914	205,223	211,602	218,037	224,520	231,036	237,646	244,345	251,159
<b>Alaba</b>	153,070	158,580	164,105	169,672	175,275	180,953	186,697	192,474	198,315	204,254	210,283	216,439

## DECLARATION

I hereby declare that the thesis entitled “ASSESSMENT OF LAND DEGRADTION USING GIS BASED MODEL AND REMOTE SENSING IN BISHAN GURACHA-ADILO SUBCATCHMENTS, SOUTHERN ETHIOPIA” has been carried out by me under the supervision of Dr. K. S. R. Murthy, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2007 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Tsegaye Birkneh Gebreyes

Signature:\_\_\_\_\_

Place: Addis Ababa

Date: July 16, 2007