

**SOIL EROSION HAZARD  
ASSESSMENT USING USLE MODEL: A CASE  
STUDY OF LEGEDADI & DIRE RESERVOIR  
CATCHMENT**

**Dissertation submitted for Partial Fulfillment of the Requirements for  
the  
Award of the Degree of**

**MASTER OF SCIENCE**

**In**

**Remote Sensing and Geographical Information Systems (GIS)**

**Of Addis Ababa University, Addis Ababa, Ethiopia.**

**By**

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**JULY, 2007**

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## List of Acronyms

DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
EUROSEM	European Soil Erosion Model
FAO	Food and Agricultural Organization
FCC	False Color Composite
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
MOWR	Ministry of Water Resources
MUSLE	Modified Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
SCRP	Soil Conservation Research Project
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Program

## **Abstract**

Siltation due to erosion is the major problem facing many of the lakes and reservoirs in Ethiopia today. The erosion process in Legedadi and Dire catchment transports a lot of sediment to the reservoir and is the most important factor for reducing their storage capacity. The two-reservoir catchments are in a state of physical and biological deterioration due to over exploitation of lands by the inhabitants. A considerable part of the sediment load is due to present agricultural and livestock management practices and lack of soil conservation practices. Therefore, a reservoir catchment needs to be managed effectively in order to reduce the effect of sedimentation.

This study has integrated the USLE model and GIS techniques to assess erosion hazards in Legedadi and Dire Catchment. Soil loss estimation was carried out based upon the principles defined in the USLE, which relates soil erosion process to rainfall Erosivity, soil erodibility, topographic, land cover and conservation practices. The input parameters of the model, derived from GIS analysis of primary data, were compiled in GIS database in raster data model with grid resolution of 30 meters. The spatial thematic map of the respective factors of USLE was created as following: R factor map was interpolated from point data of station; K factor map by reclassification of soil map; LS factor, relief parameters, was derived from DEM; C and P factor map by reclassification of land-use/land-cover map of Landsat ETM+. The assessment approach involved two aspects-estimation of potential and actual erosion.

After application of USLE model, the potential and actual mean annual soil loss from the catchment was found to be 120t/ha/yr and 4.8t/ha/yr, respectively. From the level of soil tolerance limits set by Hurni (1986), mean annual soil loss estimated by the model is tolerable. 26km<sup>2</sup> or 9.1% of the catchment is prone to high erosion hazards. In terms of relative comparison of dire and Legedadi catchment the Dire catchment was found to be more endangered by erosion hazards at various intensity.

**Key Words:** USLE model; Soil erosion; Legedadi& Dire catchment

# **CHAPTER ONE**

## **INTRODUCTION**

### **1.1 Background**

Soil degradation resulting from soil erosion has become widely recognized problems in most parts of the world, particularly in developing countries such as like Ethiopia. Accelerated soil erosion has brought an increasing threat to the decline of soil productivity and agricultural production in many parts of the world. Erosion control is now necessary in almost every corner of the world under virtually every type of land uses.

Over the last century, an increasing proportion of the soil loss is attributed to accelerated erosion induced by an increased population pressure. In the world status of human induced soil degradation deforestation, removal of natural vegetation and overgrazing are reported to be the main causes of soil erosion (Morgan, 1986). According to Lal (2001), the total land area subjected to human-induced soil degradation is estimated at about 2 billion ha, globally. Africa and South Asia are among the regions where soil degradation is extremely severe.

Studies indicated that the rate of soil erosion and land degradation in Ethiopia to be frighteningly high. El-Swaify et al (1982) stated that soil erosion is often the most serious and least reversible form of land degradation in Ethiopia. The rate of soil erosion in the country is estimated to be far greater than the rate of soil formation. Estimation by the Ethiopian Highland Reclamation study indicated that (EHRS, 1984), 50 percent of the Ethiopian highland is eroded and may not be able to sustain economic production in the future. According to FAO (1986), the rate of average annual soil loss all over the country is about 2 billion

tons. Worst affected areas are the highlands of, which accounts for more than 90 percent of the agricultural productivity in the country.

In Ethiopia, the loss of considerably significant amount of soil is attributed to various factors, of which the dominant causes of land and soil degradation are population pressure, overgrazing and cultivation, deforestation, unsustainable agricultural production, erosive rainfall and rugged terrain features (EHRS, 1984).

The study area, Legedadi & Dire Reservoir catchment, which consists of the two main surface water sources to the city of Addis Ababa, is also facing serious problems with respect to soil degradation. In recent years there has been an increasing concern over soil erosion, sedimentation, deterioration of reservoir water quality and increasing costs of water treatment for safe water supply. The storage capacities of the reservoirs are constantly and rapidly decreasing due to Siltation of eroded material from catchment area each year. According to bathymetric survey report (2000) of the Legedadi reservoir 2 MCM active volume of the reservoir has been lost by sedimentation and the annual sediment load estimated to be 762 ton/ha/year. In addition, many of the upland watersheds are in a state of physical and biological deteriorating due to the over exploiting of lands by the inhabitants, primarily in response to meeting their basic needs. The survey report also indicated that a considerable part of the sediment load is due to present agricultural and livestock management practices and the lack of soil conservation measures.

Therefore, assessment of soil erosion is urgently needed to mitigate the on-site and off-site impacts of erosion and to assist the conservation and rehabilitation of the reservoir catchment. In this regard this particular thesis work, aimed at integrating USLE model and GIS technique for estimating annual soil losses, will contribute a lot for alleviating the existing problem by identifying soil degradation areas.

## **1.2 Objective**

The main objective of this research is assessment of soil erosion hazards in the study area using Universal Soil Loss Equation (USLE) and Geographic Information System (GIS) data integration and analysis applications. The specific objectives include:

- *Estimate potential and actual soil losses from catchment*
- *Compare soil erosion in Legedadi and Dire catchment*
- *Prepare a soil erosion hazard map*

## **1.3 Significance Of The Study**

A study of soil erosion hazard assessment in Legedadi and Dire catchment is important for several reasons. First, by considering and evaluating controlling factors of erosion, the study will present an updated estimate of potential and actual soil losses of the reservoir Catchment. Second, the erosion hazard map prepared for the reservoirs Catchment with the objective of identifying erosion hazard zones will serve as a base map in planning appropriate conservation methods for mitigating rate of erosion. Thirdly, the data's prepared for this research work can be used as an input or base line data for other related studies in the reservoir catchment.

## **1.4 Limitations**

Of the many limiting factors faced during the research work, insufficient fund allocated for the research and time is the major one. The department has provided inadequate funds for each graduate without considering the research problem. Moreover, the research was conducted in a very limited time schedule set by the department.

## 1.5 Materials, And Software

### 1.5.1 Materials

The following materials are collected from various sources and used as basic primary input data in this research

#### ❖ **Satellite Image**

- ✓ Datasets: *Landsat ETM+*
- ✓ Acquisition Date: *05 December, 2000*
- ✓ Type: *Geo TIFF*
- ✓ WRS: P/R: *2: 168/054*
- ✓ Producer: *EarthSAT*
- ✓ Source: *GLCF ([www.landcover.org](http://www.landcover.org))*

#### ❖ **Topographic map**

- ✓ Projection: *UTM, Datum: Adindan Zone-37*
- ✓ Scale: *1: 50,000 ; V.I: 20m;*
- ✓ Date: *1982*
- ✓ Source: *Ethiopia Mapping Agency(EMA)*
- ✓ Sheet No.:  
*0938D4-Addis Ababa\_NE,*  
*0939C3 Sendafa*

#### ❖ **Soil Data**

- ✓ Type: *FAO/UNESCO Soil Map of the world, 1986.*
- ✓ Scale: *1: 2,000,000*
- ✓ Source: *Ministry of Agriculture and Rural Development, Soil and Water Conservation Department, Addis Ababa.*

### ❖ **Meteorological Data**

- ✓ Type: *Monthly total Rainfall data (21 years, 1985 – 2005)*
- ✓ Station: *Addis Ababa observatory, Chefe Donsa, Aleletu, Shola Gebeya, Sendafa and Gurandameta.*

### ❖ **Other Data type and sources**

- ✓ Hydrologic data and survey reports: Addis Ababa Water and Sewerage Authority (AAWSA), Addis Ababa
- ✓ Population and Livestock data: CSA, Addis Ababa

### **1.5.2 Software /Instrument**

Some of the software's and field instruments that are used for the study include:

- *ArcGIS 9.1 GIS Analysis Package*
- *ArcView 3.3*
- *ERDAS imagine 8.7 Image processing software*
- *Garmin 12 GPS receiver*

## **1.6 Methodology**

The basic methodological approach used for the study has been detailed with in the flow chart shown in figure1.1

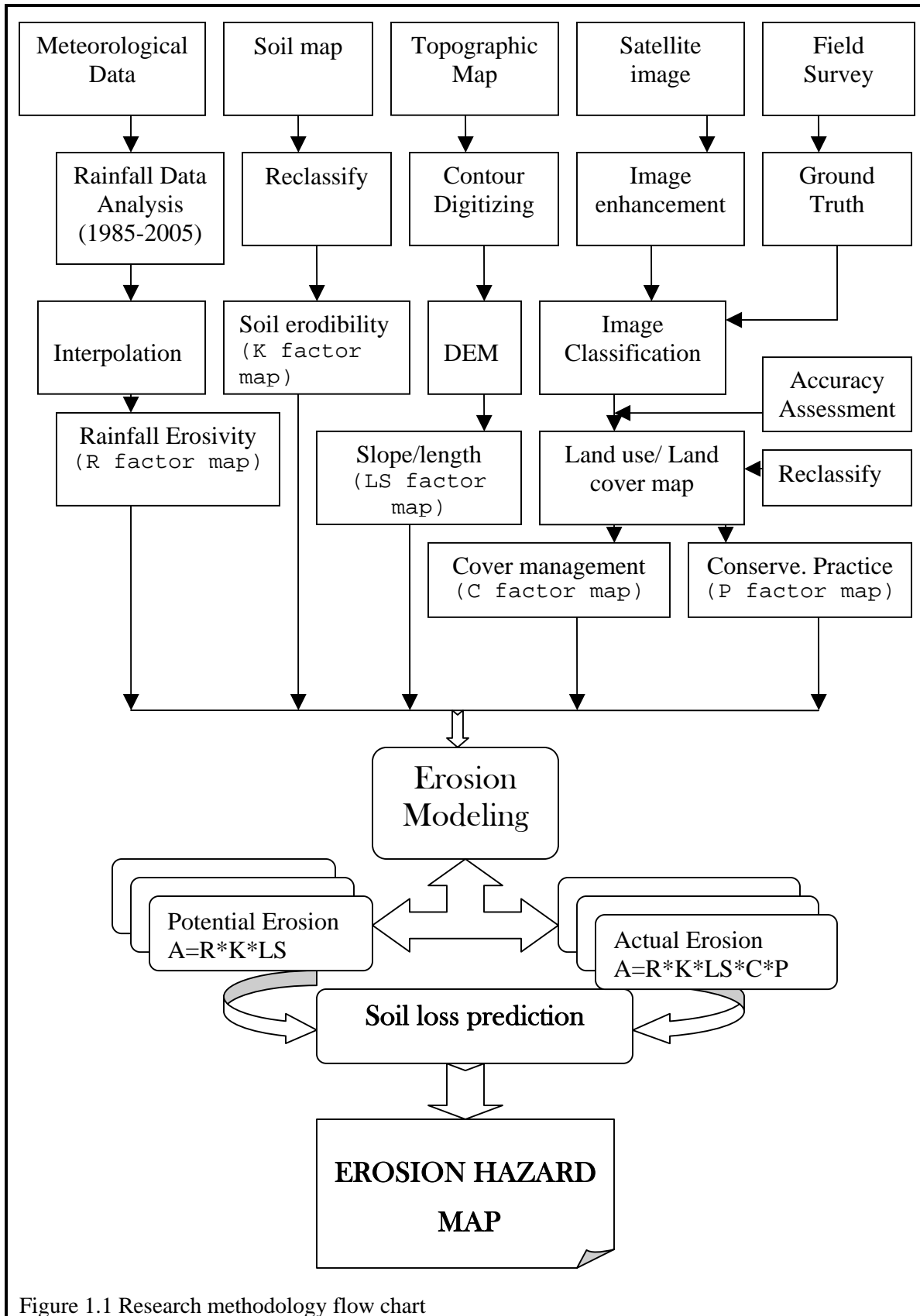


Figure 1.1 Research methodology flow chart

## **CHAPTER TWO**

### **THEORETICAL BACKGROUND**

#### **2.1 Land/ Soil Degradation**

Land degradation refers to the loss of land productivity, either quantitatively or qualitatively through various processes such as soil erosion, salinization, water logging, depletion of soil nutrients and soil contaminants (EHRS, 1987).

Soil degradation is one form of land degradation, which refers to spectrum of issues including chemical, biological, and physical degradation (Birhanu, 2000) Chemical degradations are primarily associated with leaching, exploitative cropping practices, and improper irrigation water management practices. Soil chemical degradation by leaching is common in the southwestern highlands of Ethiopia in areas where the mean annual rainfall is over 2000mm.

Biological degradation refers to the decline of biological activity of the soil. It mainly occurs in areas where the natural vegetation cover of an ecologically balanced soil system is destroyed. Soil biological degradation is also a serious problem in most highlands of Ethiopia. It results from the abuse of land in particular poorly adopted cropping and grazing systems.

Physical degradation results from many interrelated processes, including sealing, crusting, compaction, reduction in permeability and aeration, as well as from chemical and biological degradation processes. Many of these processes results in reduced soil porosity, surface sealing and crusting of the soil surface to the impacts of raindrops.

## **2.2 Factors of Soil Erosion**

The soil erosion process is modified by biophysical environment comprising soil, climate, terrain and ground cover and interaction between them. Susceptibility of soil to agent of erosion is determined by inherent soil properties such as texture, structure, soil organic matter content, clay minerals, exchangeable cations and water retention properties. Climatic factor includes intensity of rain, amount and frequency of rainfall, run-off amount and velocity. Important terrain characteristics for studying soil erosion process are slope gradient, length, aspect and shape. Ground cover exerts a strong moderating impact on dissipating the energy supplied by agents of soil erosion. The effect of biophysical processes governing soil erosion is influenced by socio-economic and political factors (Saha, 2005).

According to Evans (1980) soil erosion is a two-phase process consisting of the detachment of particles from the soil mass and their transport by erosive agents. All detachment process agents loosen the soil particles so that it is easily removed from the surface by transporting agents, which comprises those which act spatially and contribute to the removal of particles and those which concentrate their action in channels. The severity of erosion depends up on the quantity of material supplied by detachment and then capacity of eroding agents to transport it.

Morgan (1986) grouped the factors controlling the rate of soil erosion under three headings: Energy, resistance and Protection. The energy groups, termed erosivity, include the potential ability of rainfall, runoff, and wind to cause erosion. The energy available for erosion takes two forms: potential and kinetic. Potential energy is the product of mass, height difference and acceleration due to gravity while kinetic energy is related to the mass and velocity of eroding agent.

Fundamental to the resistance group is the erodibility of the soil to detachment and transport. Erodibility is a function of a number of factors such as intensity of the rainfall, the infiltration capacity of the surface, the physical and chemical properties of the soil and the vegetation, which directly affects both the stability and infiltration capacity of the soil. The protective groups focus on factors relating to plant cover as different plant covers offer different degree of protection.

### **2.3 GIS and Remote Sensing on erosion hazard assessment**

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer, 1999). Remotely sensed data has been well recognized in mapping and assessing landscape attributes controlling erosion, such as physiography, soil, land use, erosion pattern. Multi temporal satellite images provide valuable information related to seasonal land use dynamics.

The assessment of erosion hazard, as stated by Richter (1977), is a specialized form of land resource evaluation, the objective of which is to identify those areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss. The assessment aims at dividing a land area into regions, similar to in their degree and kind of erosion hazard, as a basis for soil conservation planning.

Geographic Information System (GIS) has emerged as basic tool for data management, mapping and analysis of automated spatial and non-spatial geo\_referenced data. There is considerable potential for use of GIS technology to erosion modeling and hazard assessment (Bocco, 1985).

Soil erosion may causes physical changes on the surface landscape and such changes can be measured both spatially and temporally using remote sensing data and GIS analysis. The development of Remote sensing and GIS technology as well as emerging availability of basic GIS database also enabled to apply formalized assessment based on several empirical models.

## **2.4 Modeling Soil Erosion**

Field studies for predicting and assessment of soil erosion is expensive and time consuming, because of complexity of the soil erosion system, with its numerous interacting factors. Models will take into account many of the complex interactions that affect rates of erosion and can simulate erosion process. Soil erosion is a three stage process, namely detachment, transport, and deposition of soil. Soil erosion modeling is, therefore, the process of mathematically describing soil particle detachment, transport and depositions.

According to Morgan (1986) there are at least three reasons for modeling erosion;

- Models can be used as a tool for understanding processes and their interactions.
- Erosion models can predict where and when erosion occurs
- Erosion models can be used as predictive tools for assessing soil loss for conservation planning.

Soil erosion prediction and assessment has been a challenge to researchers since the 1930's and several models have been developed (Lal, 2001). These models are categorized as empirical, semi-empirical and physical process-based models. Empirical models are primarily based on observation and are usually statistical in nature. Semi-

empirical models lies somewhere between physically process-based models and are based on spatially lumped forms of water and sediment continuity equations. Physical process-based models are intended to represent the essential mechanism controlling erosion. They represent the synthesis of the individual components which affect erosion, including the complex interactions between various factors and their spatial and temporal variability's. Some of the widely used erosion models are discussed below:

### **2.4.1 Empirical Models**

#### ***Universal soil Loss Equation (USLE)***

USLE is the most widely used empirical overland flow or sheet-rill erosion equation. The equation was developed to predict soil erosion from cropland on a hill slope. The equation is given by

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

Where, A is the average annual soil loss (mass/area/year); R is the rainfall erosivity index; K is the soil credibility factor; factor; L is the slope length factor; S is slope gradient factor; C is the vegetation cover factor, and P is the conservation protection factor.

The derivation of the factors in the USLE equation is as follows:

**R-** This is the rainfall erosivity index which is equal to the mean annual erosivity value divided by 100.  $R= EI_{30}/100$

**K-** This is the soil erodibility index defined as mean annual soil loss per unit of erosivity for a standard condition of bare soil, no conservation practice, 5° slope of 22m length.

**LS**- The factors of slope length (L) and slope steepness (S) are combined in a single index. A value of 1.0 applies to standard 5° slopes, 22m long. The appropriate value can be obtained from nomographs (Hudson, 1981) or from the equation:

$$LS = \sqrt{L/22.3 (0.065 + 0.045s + 0.006(s^2))}$$

Where, L is in meter and S is Slope in percent.

**C**- This is the cover factor. It represents the ratio of soil loss under a given crop to that from bare soil.

**P**- This is the conservation practice factor. Values are obtained from tables of the ratio of soil loss where contouring and contour-strip cropping are practiced to that where they are not. With no conservation measures, the value of P is 1.0. Where terracing is adopted, the value for strip-cropping is used for the P-factor, and the LS index is adjusted for the slope-length which represents the horizontal spacing between terraces.

### ***Revised universal Soil Loss Equation (RUSLE)***

The RUSLE updates the information on data required after the 1978 release, and incorporates several process-based erosion models (Renard et al., 1979). RUSLE remains to be a regression equation. A principal modification is in R factor which includes rainfall and run-off erosivity factors. Run-off erosivity also includes snow melt where run-off is significant. There are also changes in C factor which is based on computation of sub-factors called soil loss ratios (SLR). The SLR depends on sub-factors: prior land use, canopy cover, surface cover, surface roughness and soil moisture (Renard et al., 1997).

## 2.4.2 Semi-Empirical Models

### ***Modified universal Soil Loss Equation (MUSLE)***

Williams (1975) proposed a modified version of USLE that can be written as

$$S_{ye} = X_e \cdot K \cdot L \cdot S \cdot C_e \cdot P_e$$

Where,  $S_{ye}$  is the event sediment yield

$$X_e = \alpha(Q_e \cdot q_p)^{0.56}$$

Where  $\alpha$  is an empirical co-efficient ;  $Q_e$  is the run-off amount and  $q_p$  is the peak run-off rate obtained during the erosion event and  $K$   $L$   $S$   $C_e$  &  $P_e$  are as defined for USLE.

### ***Morgan, Morgan and Finney (MMF) Model***

Morgan et al., (1984) developed a model to predict annual soil loss which endeavors to retain the simplicity of USLE and encompass some of the recent advances in understanding of erosion process in to a water phase and sediment phase. Sediment phase considers soil erosion to result from the detachment of soil particles by raindrop impact and the transport of those particles by overland flow. The process of splash transport and detachment by runoff are ignored. Thus, the sediment phase comprises two predictive equations, one for rate of splash detachment and one for the transport capacity of overland flow.

The model uses six operating equations for which 15 input parameters are required (Appendix II). The model compares predictions of detachment by rain splash and the transport capacity of the run-off and assesses the lower of the two values as the annual rate of soil loss, there by den thong whether detachment or transport is the limiting factors.

### **2.4.3 Physical process-based Model**

Empirical models have constraints of applicability limited to ecological condition similar those from which data were used in their development. Further, USLE cannot deal with deposition; its applicability limits a large areas and watersheds. Based on these considerations, several process-based models have been developed such as WEPP, EUROSEM, LISEM (Lal, 2001).

#### ***Water Erosion prediction Project (WEPP) Model***

WEPP is an example of widely used physically process-based erosion model (Renard et al., 1996). It was developed as a system modeling approach for Predicting and estimating soil loss and selecting catchment management practices for soil conservation. Basic erosion and deposition in WEPP are based on the mass balance formulation that uses rill and inter-rill concept of soil erosion, which is a steady-state sediment continuity equation. The WEPP model computed erosion by rill and inter-rill processes. The sediment delivery to rill from inter-rill is computed by following equation-

$$D_i = k_i \cdot i_e^2 \cdot G_e \cdot C_e \cdot S_f$$

Where,  $D_i$  is the delivery of sediment from inter-rill areas to rill ( $\text{kg}/\text{m}^2/\text{sec}$ );  $K_i$  is the inter-rill erodibility ( $\text{kg}/\text{m}^4/\text{sec}$ );  $I_e$  is the effective rainfall intensity ( $\text{m}/\text{sec}$ );  $G_e$  is the ground cover adjustment factor and  $S_f$  is the slope adjustment factor calculated as per equation given below-

$$S_f = 1.05 - 0.85 \exp(-4 \sin \alpha)$$

Where  $\alpha$  is the slope of the surface towards nearby rill.

## CHAPTER THREE

### THE STUDY AREA

#### 3.1 Location

The Legedadi & Dire reservoir catchment is situated at approximately 20km East of Addis Ababa between 9°02' to 9°22' N latitude and 38°58' to 39°07'E longitude. The total catchment covers an area of 288km<sup>2</sup>.

The study area consists of two adjacent reservoir catchment, namely the Legedadi and Dire catchments. The Legedadi reservoir catchment is located adjacent to the east of Dire catchment area and its total size is 202km<sup>2</sup>. Its maximum extent is north to south, which is 21km, and its east-west stretch is 15km. The Dire catchment area located adjacent to the north west of the Legedadi catchment covers an area 86km<sup>2</sup>. The maximum extent is from east to west of 16km.

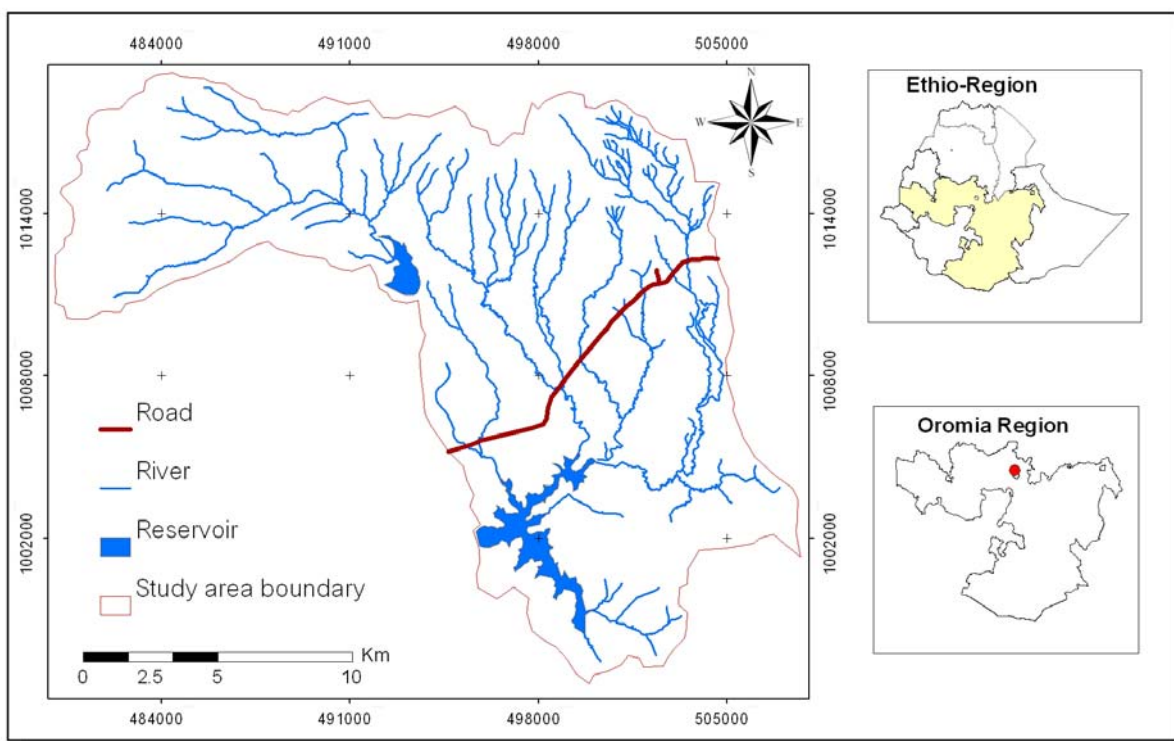


Figure3.1 Location map of the study area

### 3.2 Climate

According to the traditional classification of climatic zone, the Legedadi & Dire catchment is part of the Dege, and Woina-Dega Agro-climatic zone. Average mean annual precipitation (1985 to 2005) in Sendafa station, within the study area, is about 1118mm. For the last 21 years, the highest rainfall of 1405mm was recorded in 1985 and lowest is 856mm in 1994.

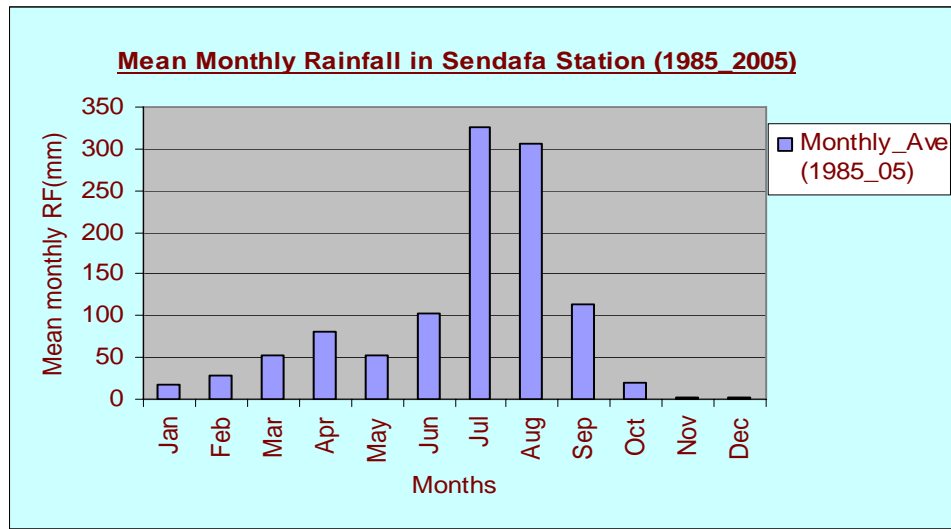


Figure3.2 Mean monthly rainfall distribution in Sendafa station

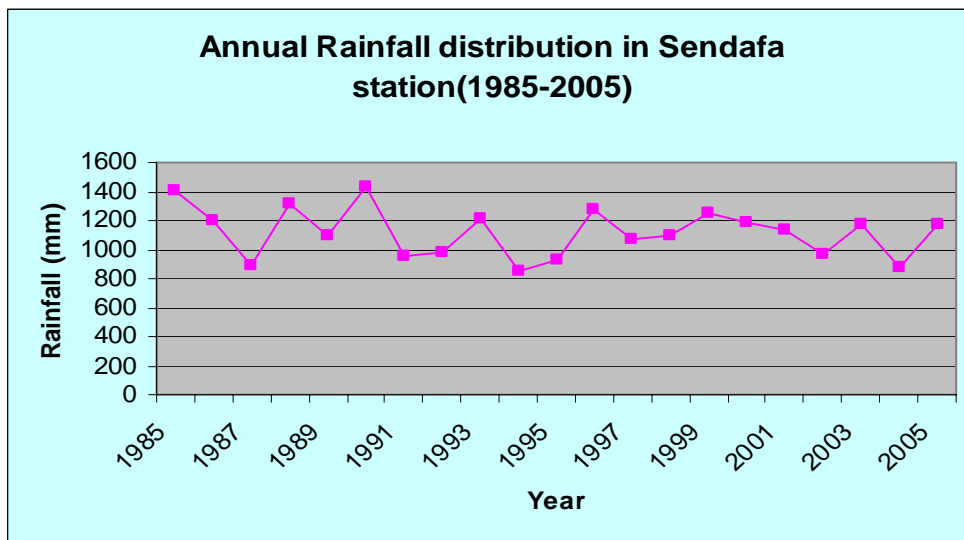


Figure 3.3 Mean annual rainfall distribution

### **3.3 Physiography**

The three major physiographic units of Legedadi catchment include: Bereha Mountain southern slopes, Sendafa hills, and Legedadi plain; while the Dire catchment area consists of two main physiographic units, namely Bereha Bura ridge southern slope, and Haro-Dire Hills. The altitude ranges from 2422 to 3220m.a.m.s.l.

### **3.4 Land use / Land cover**

The Land use/Land cover types mapped in the study area consist of cultivated land, grassland, Eucalyptus plantation, water body, barren land and built up areas. The eucalyptus woodland of the Addis Bah Fuel wood project covers most of the mountain summits of the Dire catchment, which are currently owned and maintained by the Oromia Natural Resources and Environmental protection office. The steep sides of the streams and mountain sides below the eucalyptus plantation have been left for grazing lands for livestock. Shrubs with grasses and scattered trees have naturally covered these units. Grasses covering the undulating valley and plains provides grazing land for livestock. The cultivated land, which predominates the land uses, are scattered all over the catchment area of including the steep mountain slopes, undulating valley, foot hills and plains. In general, about 53% of the catchment area is partially covered by natural and planted vegetation.

### **3.5 Population and Agriculture**

During the 1994 census the total population in the study area is 26,000 with a total population density of 92 person/km<sup>2</sup>. The population projection is based on a natural growth rate of 3% take into account the anticipated influx of people attracted by the proximity to the city, assuming no steps are taken to restrict migration to the area.

Table 3.1 Population data of the study area

Catchment	Area	1994 Census		1999 projection		2010 projection	
		Pop <sup>n*</sup>	Density p/km <sup>2</sup>	Pop <sup>n*</sup>	Density p/km <sup>2</sup>	Pop <sup>n*</sup>	Density p/km <sup>2</sup>
Legedadi	205	20000	98	23,000	112	32,000	156
Dire	78	6000	77	7,000	90	9,000	116
Total	283	26000	92	30,000	106	41,000	145

Source: AAWSA, 2000

\* population figure rounded to 1,000 persons

Most of the populations in the catchment areas are small-scale farmers engaged in mixed farming, i.e. crop cultivation and livestock production. The crop production practice is mainly dependent on a traditional rain fed agriculture in which all cultivation is done by traditional methods and practically no modern agricultural production inputs are applied. Similarly the livestock's are fed entirely on natural grasslands and overgrazing is common, one major factor conducive to soil erosion.

# CHAPTER FOUR

## DATA ANALYSIS

### 4.1 Data Preparation

#### 4.1.1 Digital Elevation Model

DEM is an ordered array of numbers that represents the spatial distribution of elevation of the surface in digital format. DEM has become vital input for automated generation of terrain and hydrologic features. It is basic source for generation of such terrain features like slope, aspect, hill shade, and other relief features. DEM has also some hydrologic application for watersheds such as determining flow direction, flow accumulation, stream-order, stream length, watersheds, Basins etc. DEM is also vital input for soil erosion modeling. For the study, the modified LS-factor map was generated from the slope and flow accumulation map derived from the DEM.

To create DEM of the study area contour map was digitized from the topographic maps of 1:50,000 scale with contour interval of 20m.

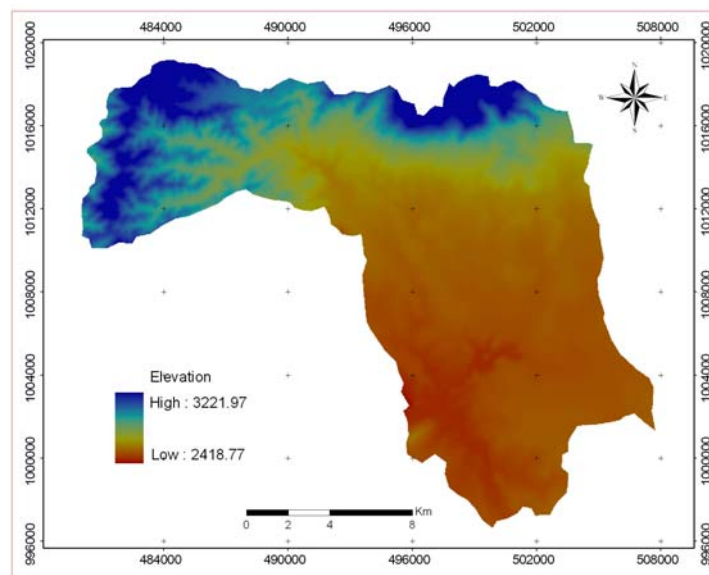


Figure4.1 DEM of the study area

#### **4.1.2 Land use/ land cover classification**

Digital image processing techniques try to improve the interpretability of images by highlighting different features of interest in the data. The ultimate goal of digital image processing is, therefore, to classify (group) images into various categories or thematic classes. The procedure followed during the land use land cover classification phase of Landsat ETM+ involved three steps:

- Image enhancement
- Image classification
- Accuracy assessment

##### **4.1.2. 1 Image Enhancement**

Image enhancement is to improve the visual interpretation of satellite image by increasing the visual distinction between the features in a scene (Lillesand and Kiefer, 1994). To improve the apparent spatial resolution and to enhance the landsat ETM+ image was merged with the Landsat Panchromatic band (15m) for the study.

The 15-m resolution, multi-spectral image was produced through merging that contains the high-resolution information of the respective panchromatic images while maintaining the basic color content of the original multi-spectral data. Among several processing techniques, the resolution merge technique was used to integrate low and high resolution images of the study area.

##### **4.1.2. 2 Image classification**

The image classification procedure mainly involved unsupervised and supervised classifications. Unsupervised classification has been done prior to the field survey using visual interpretation method for differentiating various land-use/land-covers in the study area. After field survey the various land use/land cover was delimited using supervised

image classification method. In the supervised classification the maximum likelihood method was used since the method quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel.

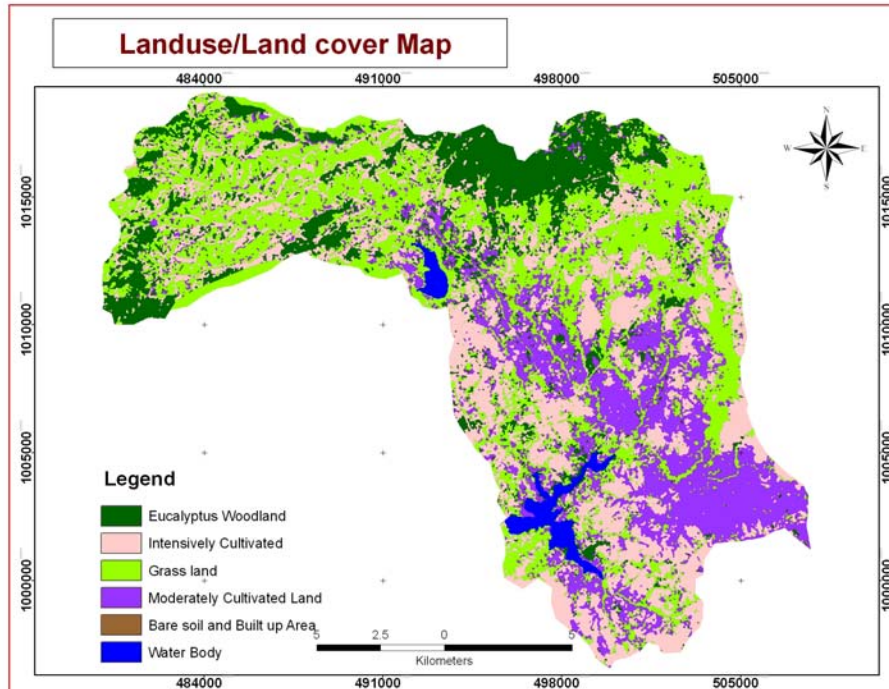


Figure 4.2 Land use /Land cover map

#### 4.1.2. 3 Accuracy Assessment

Because of its empirical approach, the results of spectral classification need to be assessed for accuracy. One such method is a contingency table (confusion matrix) which is produced from a random sample of individual pixels or clusters compared to "known" cover conditions over the same pixel areas. Therefore, the confusion matrix method was used to calculate the accuracy of the spectral supervised classification of Landsat ETM+ image of the study area. Accordingly, the eucalyptus woodland, intensively cultivated lands, and water bodies were mapped with very good accuracy (> 93%). Other land use/land-cover classes, such as moderately cultivated land, grassland and built up areas were mapped with moderate accuracy i.e. 80%.

## **4.2 Erosion Modeling**

### **4.2.1 Description of the USLE Model**

The Universal Soil Loss Equation (USLE) is one of the most widely used empirical overland flow or sheet rill erosion equation. USLE is an erosion prediction model designed to predict the long-term average annual soil loss from specific field slopes in specified land-uses and management System. It computes soil loss as a product of six major factors, representing rainfall-runoff erosivity, soil erodibility, slope-length, slope-steepness, cover and management practices, and supporting conservation practices (Morgan, 1986). The equation is represented by:

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

Where, A is the amount of soil erosion that is eroded with in the unit area during the corresponding period of rainfall runoff erodibility factor; R is rainfall runoff erosivity factor; K is a soil erodibility factor; L is the length of erosion slope; S is the gradient of erosion slope; C is a cover management factor; P-is a support practice factor.

Based up on soil and water conservation research plots data, a modified USLE was adopted to Ethiopian condition by Hurni (1985). The six parameters of the USLE are estimated for each land mapping unit using the land resources data as an input. The equation was validated by comparison with the plot measurement in Ethiopia and showed a high correlation of 0.90, explaining 80% of the measured sample (Hurni, 1986).

For this study, USLE model as modified and adopted to Ethiopian conditions by Hurni was used to compute annual soil loss from sheet and rill erosion within the study area.

## 4.2.2 Derivation of USLE Parameters

### 4.2.2.1 Rainfall Erosivity factor (R factor)

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to run-off. Rainfall erosivity index is a factor established by blowing energy from rain drop per storm event, kinetic energy of rainfall, and maximum 30 minute rainfall intensity. Although there are many methods of calculating rainfall erosivity, the values for the R factor was estimated according to the equation proposed by Hurni (1985) (Appendix I)

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

Where, R= Rainfall erosivity

P= mean annual precipitation (mm/yr)

The mean annual rainfall data of 21 years (1985 to 2005) derived from six rainfall stations of Aleltu, Chefe-Donsa, Addis Ababa observatory, Gurandameta, Sholla gebeya and Sendafa were considered to estimate R-factor using the above formula. The calculated R factor for each station was converted to raster surface with 30m grid cell using IWD interpolation techniques. (Table 4.1)

Table 4.1 R factor values of rainfall stations

Stations	Location		Elevation (m)	Mean annual RF (1985–2005)	R Factor
	Lat.	Long.			
Addis Ababa Obs.	9° 02'	38°45'	2354	1215.29	674.90
Aleltu	9°12'	39°09'	2550	1069.39	592.88
Chefe-Donsa	8° 9'	39°08'	2380	882.88	488.06
Gurandameta	8° 9'	38°46'	2246	957.68	530.10
Sendafa	9°09'	39°01'	2560	1102.00	611.20
Shola-Gebeya	9°03'	38°46'	2500	980.29	542.80

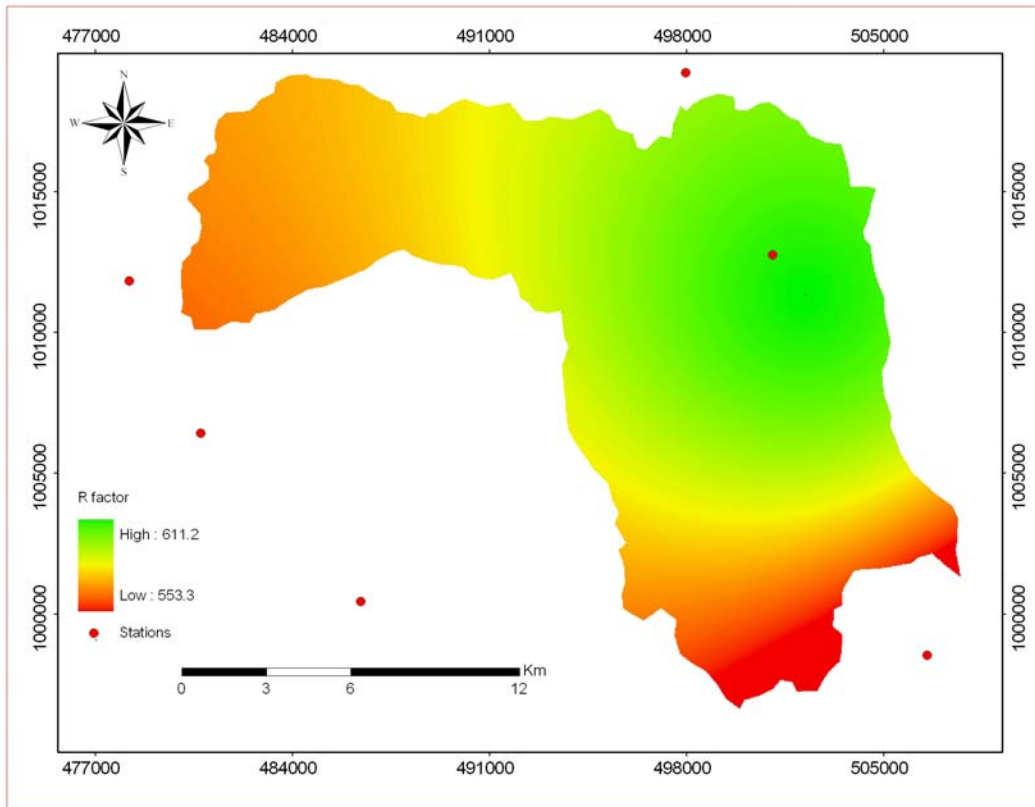


Figure4.3 Rainfall erosivity (R factor) map

#### 4.2.2.2 Soil Erodibility Factor (K Factor)

Soil erodibility defines the inherent resistance of the soil to both detachment and transport. The soil erodibility factor is a measure of the susceptibility of soil particles to detachment and transport of rainfall and runoff. Texture is the principal factor affecting soil erodibility, but structure, organic matter and permeability also contribute.

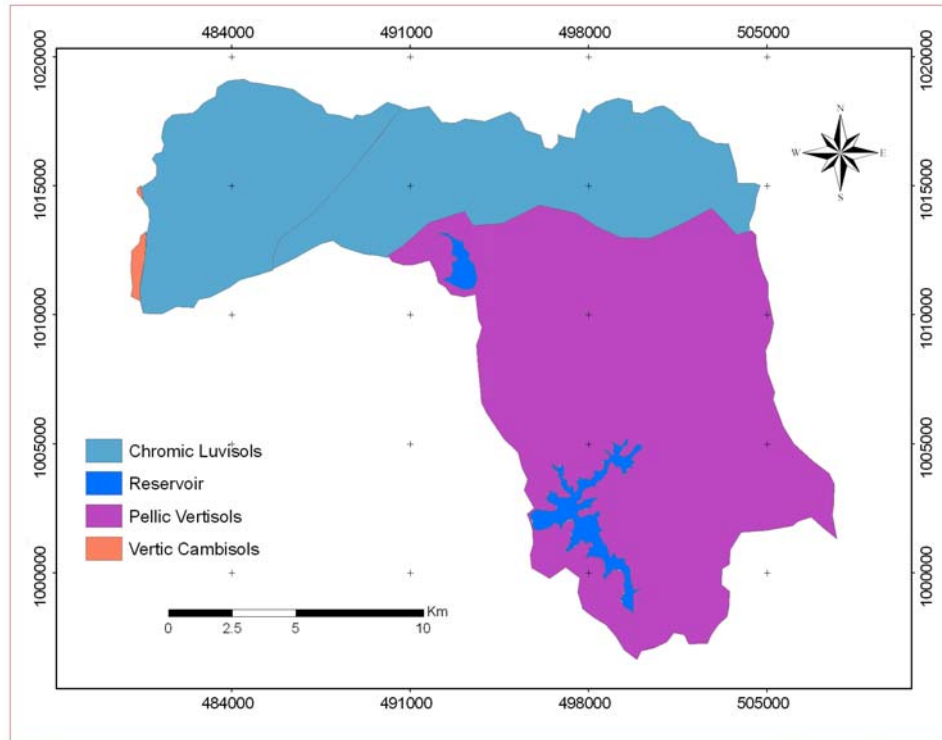


Figure 4.4 soil map of the study area

In this study, a digital FAO/UNESCO soil classification map was obtained from ministry of Agriculture and Rural development, soil and water conservation department. Three major soil categories were identified in the study area. After assigning values for each soil types the soil map was reclassified using adopted K values by Hurni (1985) with a grid map of 30m-cell size.

Table 4.2 Soil types with their corresponding K factor

Soil Type	Area (km <sup>2</sup> )	K factor
Vertic Cambisol	1.67	0.20
Chromic Luvisol	117.85	0.15
Pellic vertisol	161.87	0.20

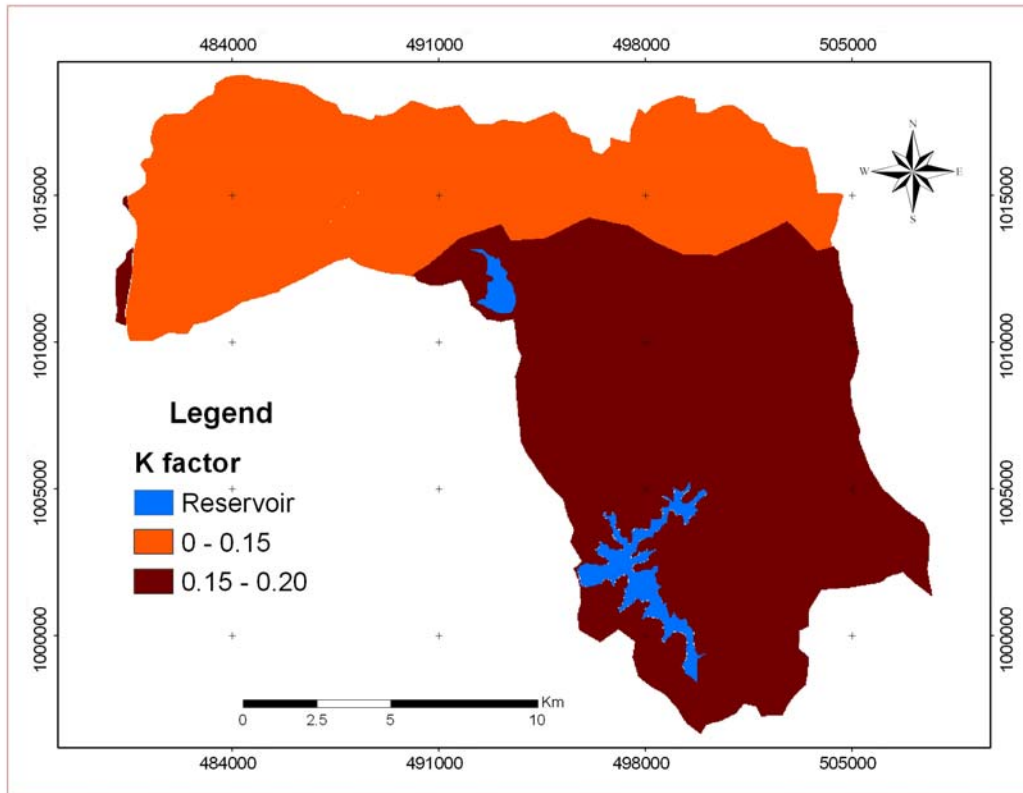
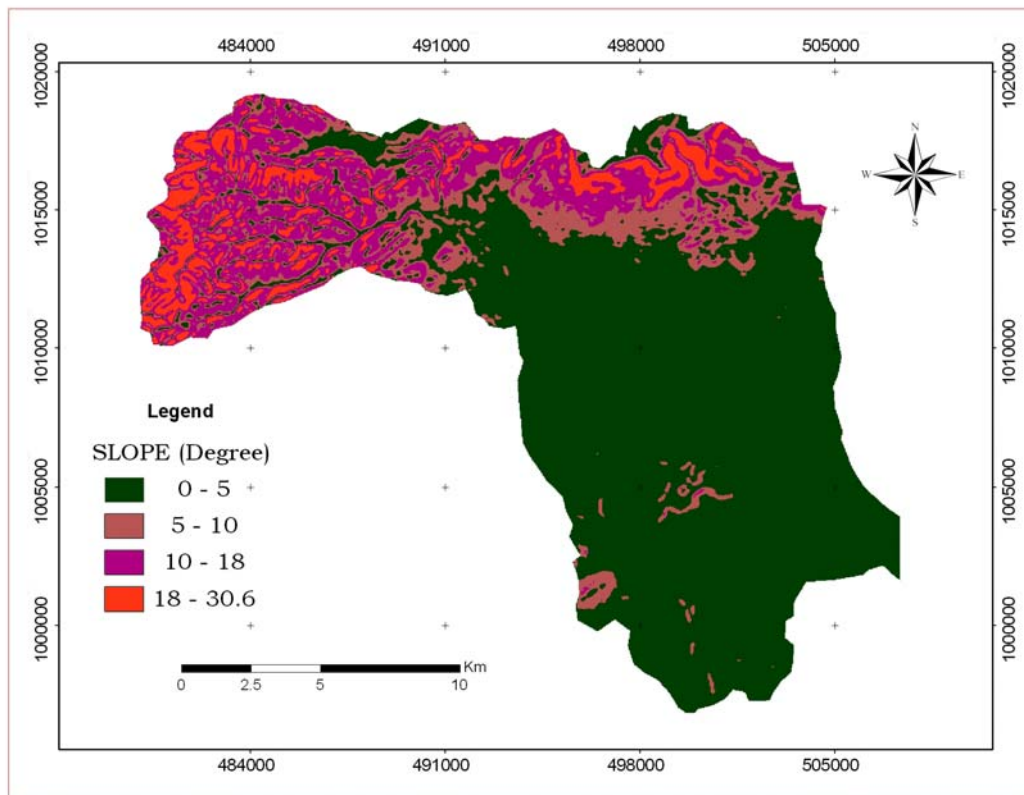


Figure4.5 Soil erodibility (K factor) map

#### 4.2.23 Topographic factor (LS Factor)

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network. Soil erosion increases with increases in slope gradient and slope length resulting from respective increases in velocity and volume of surface run-off water. The modified equation for computation of the topographic factor (LS factor) in GIS environment is employed by the formula recommended by Griffin et.al (1988):

$$LS = \text{Pow}[(\text{Flow Accumulation}) * \text{Resolution} / 22.1, 0.6] * \text{pow}[\sin(\text{slope}) * 0.01745] / 0.09, 1.3]$$



*Figure 4.6 slope map of the study area*

Flow accumulation refers to the number of cells contributing to flow in to a given cell. The DEM, which was created by digitizing contour lines from scanned and geo-referenced topographic map at a scale of 1:50,000 with contour interval of 20m, was used to calculate slope, flow direction and flow accumulation maps. Finally, the LS factor map was generated using the above formula in ArcGIS spatial analysis raster calculator function.

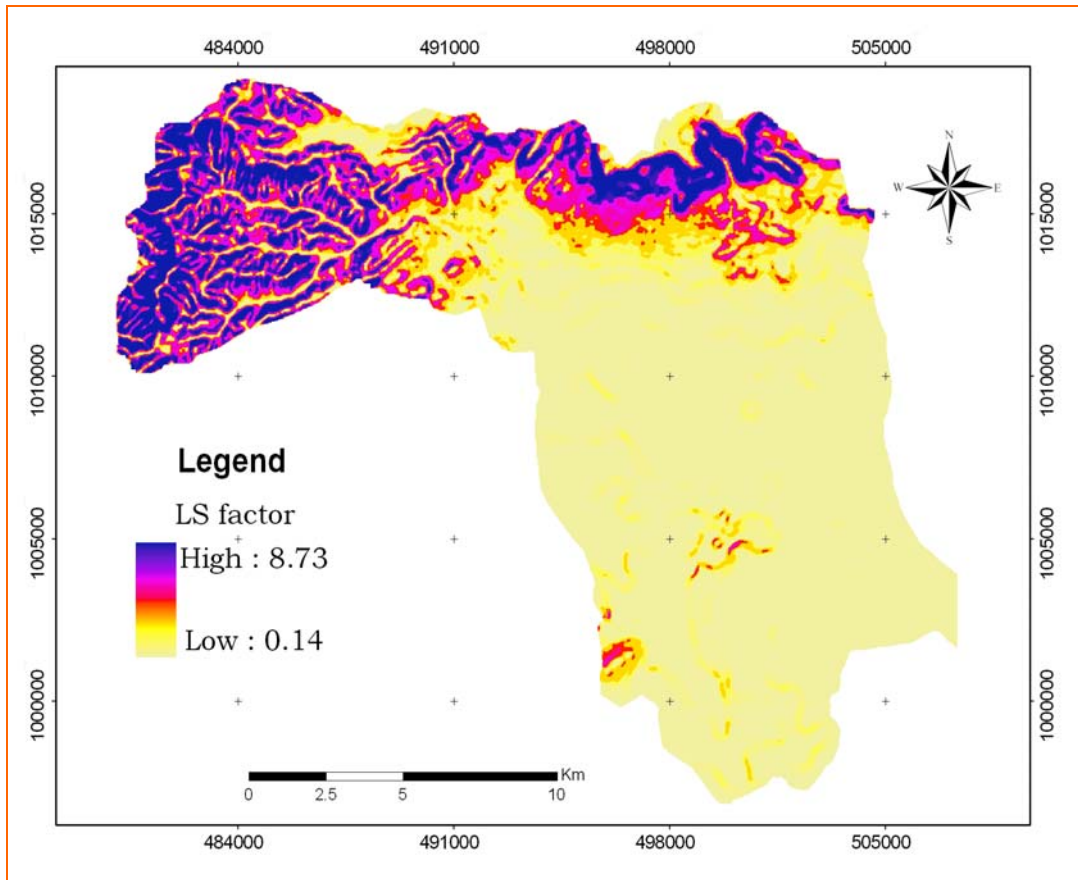


Figure 4.7 Topographic factor (LS factor) map

#### 4.2.2.4 Cover management factor (C Factor)

The cover management factor represents the ratio of soil loss under a given cover type to that from a bare soil. The factor indicates the level of protection of a soil under a certain land cover. At first, supervised classification of Landsat ETM+ image was carried out to generate the land use/land cover map. This layer was converted to vector format and c-factor value was attributed to each land-use classes. Finally the land use land cover map was converted to C factor raster layer using vector to raster conversion command and through reclassification of each cover type in to its corresponding C factor.

Table4.3 C factor of each land use / land cover type

Land use/ Land cover type	C factor
Eucalyptus woodland	0.01
Grassland	0.01
Moderately cultivated land	0.1
Intensively cultivated land	0.15
Bare soil and Built up area	0.05

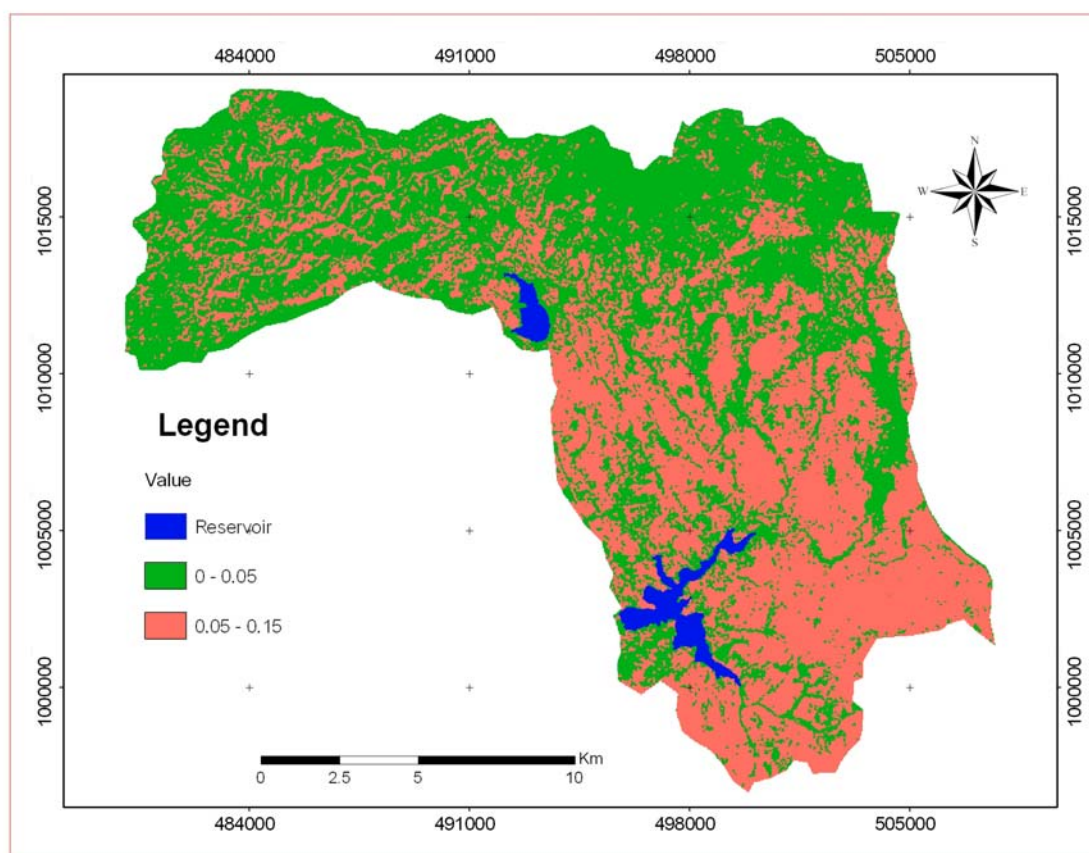


Figure4.8 Cover management factor (C factor) map

#### 4.2.2.5 Conservation Practice factor (P factor)

The conservation practice factor is the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation, which has a value of one. The conservation practices principally affect erosion by modifying the flow pattern or direction of surface run-off.

As described by Schwab et.al (1993), P is calculated for agricultural land only and for all other lands it is assumed as one because there is no any control practice measures. For cultivated land the conservation practices generally includes contouring, strip cropping, terracing and subsurface drainage.

Estimation of the P factor, for the study area, was carried out taking in account the local management practices which was located during the field survey. In agricultural lands of the study area, particularly in the highland parts of the catchment, farmers plough their farmlands in all directions, i.e. both along the contour or perpendicular to the slope with ox drawn ploughs. They construct drainage ditches in crop fields along slopes to reduce run-off. The value of P factor was assigned to cultivated lands based on the adopted P-value by Hurni (1985).

Table4.4 Conservation practice factor

<b>Land use/ Land cover</b>	<b>P factor</b>
Eucalyptus woodland	0.8
Grassland	0.8
Moderately cultivated land	0.95
Intensively cultivated land	0.95
Bare soil and Built up area	1.0

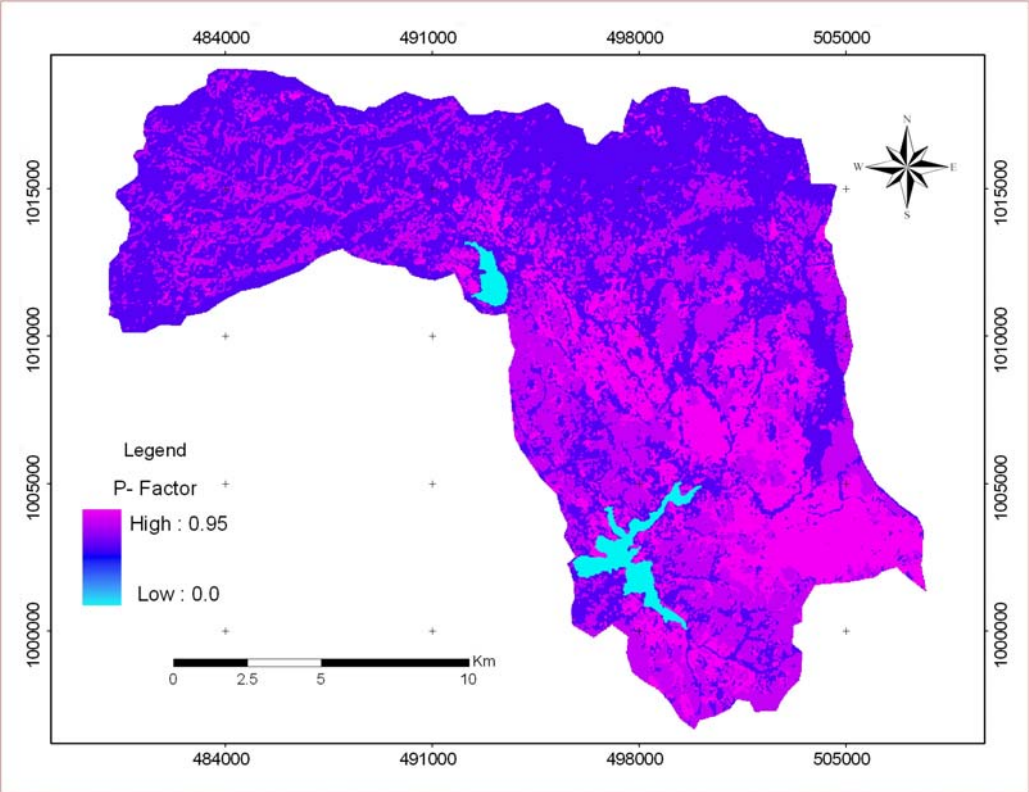


Figure: 4.9 Conservation practice (P factor) map

# **CHAPTER FIVE**

## **RESULT AND DISCUSSION**

### **5.1 Application of USLE model**

In the study, the annual soil erosion estimation was carried out based upon the principles and parameters defined in the USLE model. The derived spatial model input parameters were compiled into one coherent raster database for modeling and annual soil loss prediction. The computation of model input parameters as well as model output is based on raster data formats with grid resolution of 30 meters.

The approach used for erosion modeling involved two aspects: estimation of potential erosion and estimation of actual soil loss. The equation can be expressed as follows:

- Potential erosion,  $A = R * K * LS$
- Actual erosion,  $A = R * K * LS * C * P$

Potential soil erosion expresses the inherent susceptibility of bare soil to erosion as it would be without any protective covers. This way it provides information on the worst possible situation that might occur. Actual soil erosion refers to present endangerment, taking in to account contemporary land cover and management practices that that modifies the potential erosion.

#### **5.1.1 Assessment of Potential Erosion**

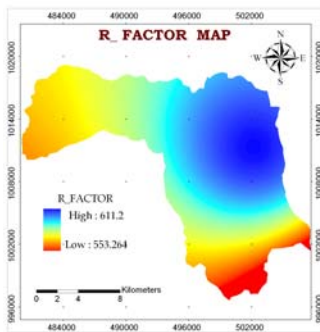
The rainfall erosivity (R factor), soil erodibility (K factor), slope gradient (S factor) and slope length are (L factor) as elements of USLE equation are considered as naturally occurring factors determining the sheet and rill-erosion process. Together, they are considered as the erosion susceptibility or potential erosion or soil loss for the area.

The R factor, K factor and LS factors are multiplied to get the potential soil loss from the catchment by ArcGIS software spatial analysis raster calculator function using the following syntax:

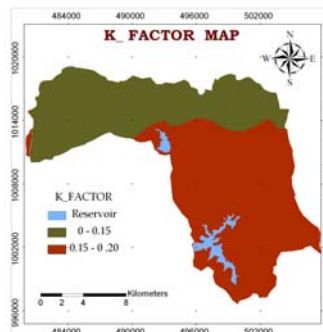
*Raster calculator> potential erosion = R factor \* K factor \* LS factor*

## POTENTIAL EROSION ASSESSMENT

**R Factor**



**K Factor**



**LS Factor**

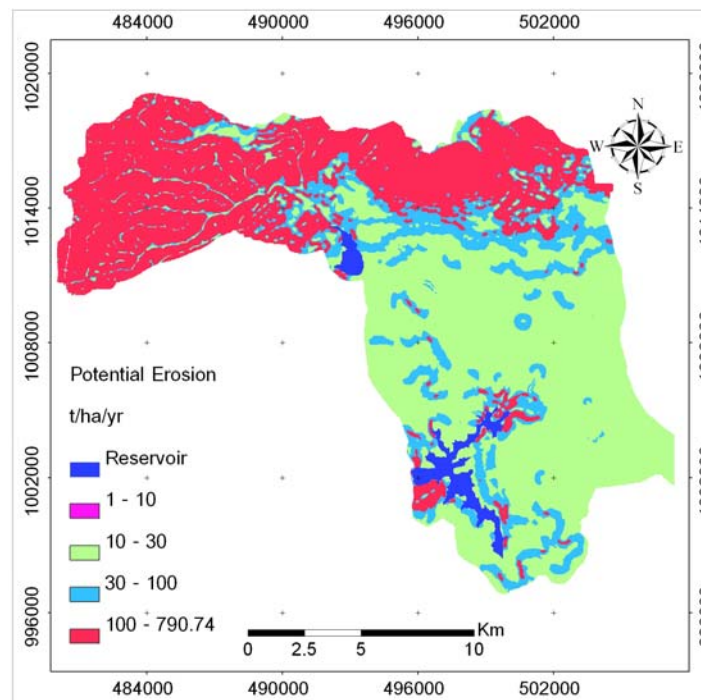
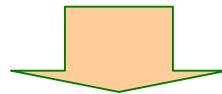
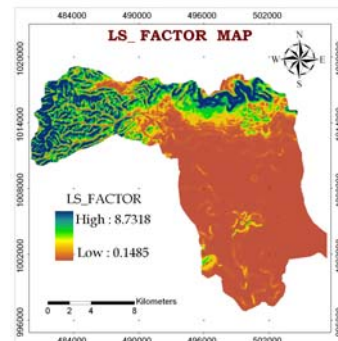


Figure5.1 Potential erosion hazard map

The quantitative output of estimated soil loss varied from 0 to 790.7 t/ha/yr. The mean annual potential soil loss from the entire catchment was found to be 120 t/ha/yr. The spatial pattern of potential erosion indicated that 51% of the catchment is potentially endangered by erosions of various intensity. The highest potential endangerment is strongly associated to mountains and hills. The estimated soil loss is reclassified and presented in to five ordinal classes as shown in Table 5.1

Table5.1 Estimated areas of potential erosion

<b>Erosion Class</b>	<b>Numeric range (t/ha/yr)</b>	<b>Area (km<sup>2</sup>)</b>	<b>Area %</b>	<b>Erosion potential</b>
1	0-10	7.6	2.64	Low
2	10-30	131.4	45.62	Moderate
3	30-100	45.3	15.73	High
4	>100	103.1	36.0	Very High

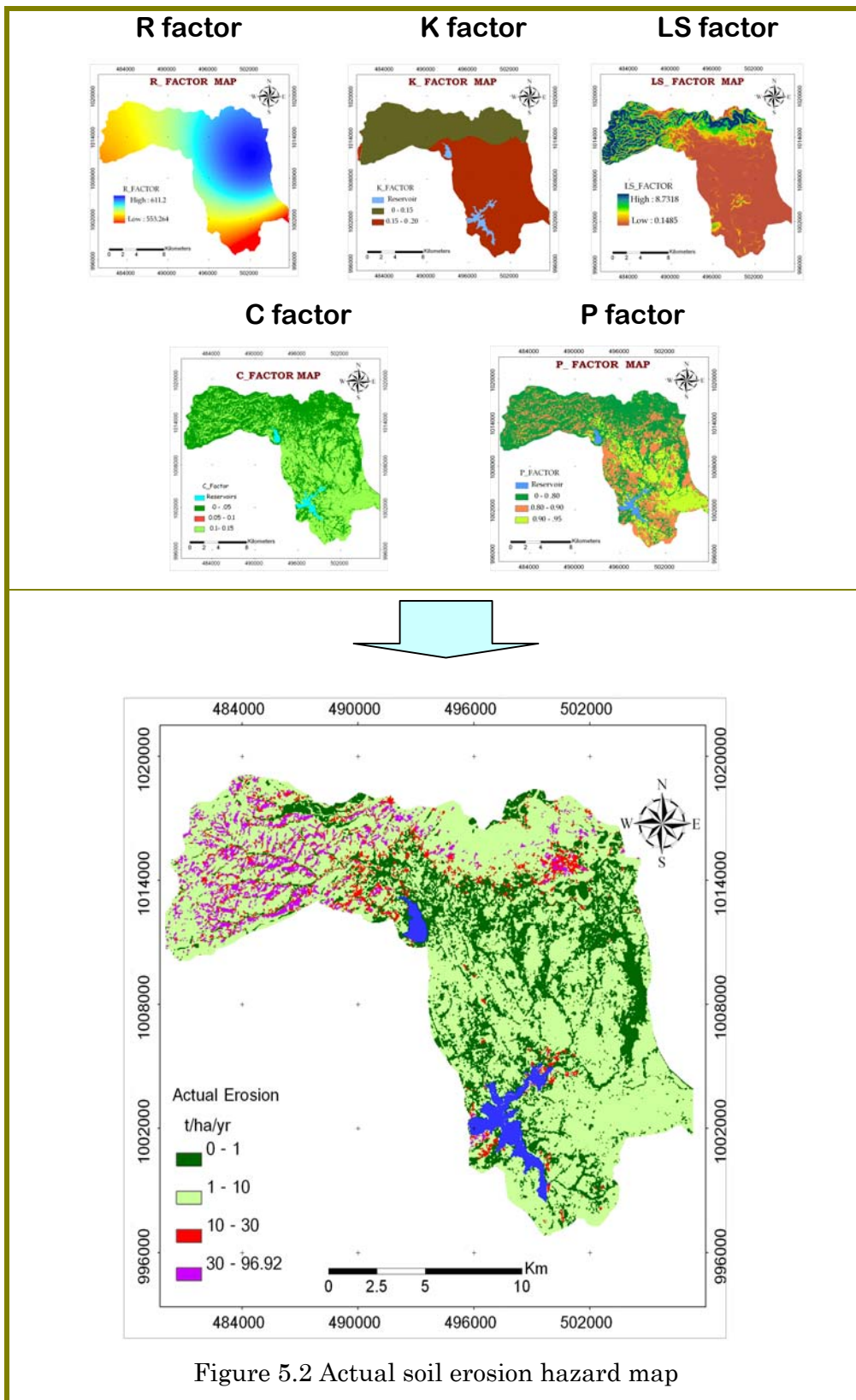
### 5.1.2 Actual Erosion Assessment

The actual erosion assessment is based on the principles of USLE model, which multiplies the six parameters\_ rainfall erosivity, soil erodibility, slope gradient and length, land cover, and soil conservation practices (Fig5.2)

The application of model was by using raster calculator method of ArcGIS spatial analysis function, which enables the multiplication of the parameters cell by cell. The syntax given as follow:

*Raster Calculator>*

*Actual soil loss, A = R factor\*K factor\*LS factor\* C factor \*P factor*



The quantitative out put of predicted soil was then collapsed in to four classes as shown in Table 5.2. The value range of actual annual erosion in the out put raster soil map was 0 to 96.92 t/ha/yr. The mean annual soil loss is about 4.81 t/ha/yr. Accordingly, the gross total estimated soil loss from the entire catchment is 28,800 ton/year. More than 9% of the catchment area is with in high and very high erosion hazard zones.

Table5.2 Area of different erosion classes in the catchment

<b>Erosion class</b>	<b>Numeric Range (t/ha/yr)</b>	<b>Area (km<sup>2</sup>)</b>	<b>Area %</b>	<b>Erosion potential</b>
1	0-1	63.4	23	Very low
2	1-10	188.3	67.6	Low
3	10-30	11.9	4.3	Moderate
4	30-96.92	14.2	5	High

## **5.2 Soil Loss Tolerance**

Soil loss tolerance refers to the maximum rate of soil loss that can be tolerated without decline in economic productivity. However the question of what level is tolerable depends on the local situation and in particular the type and depth of soil, rate of formation of soil, land use, topography and so on. Rose (1994) established annual soil loss tolerable limits to 10t/ha/yr for tropical region. Hurni (1986) estimated the soil loss tolerance level for the different agro ecological zones of Ethiopia to be in the range 1- 16 t/ha/yr.

Therefore, from the level of soil tolerance limits recommended by Rose and Hurni, the mean annual soil loss of the study area i.e. 4.81t/ha/yr as estimated by the model is tolerable.

### 5.3 Soil Loss Distribution

Soil erosion is a function of the spatial and temporal variation and interaction of all factors, natural to human, controlling rate of erosion. Thus, to identify the existing relationship between the factors and rate of soil loss some of the parameters have been examined.

#### 5.3.1 Soil loss by erosivity

For assessing soil erosion, rainfall intensity is very important since splash detachment is a function of rainfall energy, soil detachability and rainfall interception by vegetation covers. The rainfall energy is directly related to rain intensity. However, not all rainfall events are erosive (Wischmeier and Smith, 1978). In order to see the existing correlation between erosivity and rate of soil loss, an isoerodant map was prepared from interpolated rainfall erosivity map and has been overlain on top of the estimated soil loss map (figure 5.3). Statistical out put of cross tabulation between erosivity and rate of soil loss resulted that 52% of the high soil degradation zone located with in erosivity range of 580 – 595.

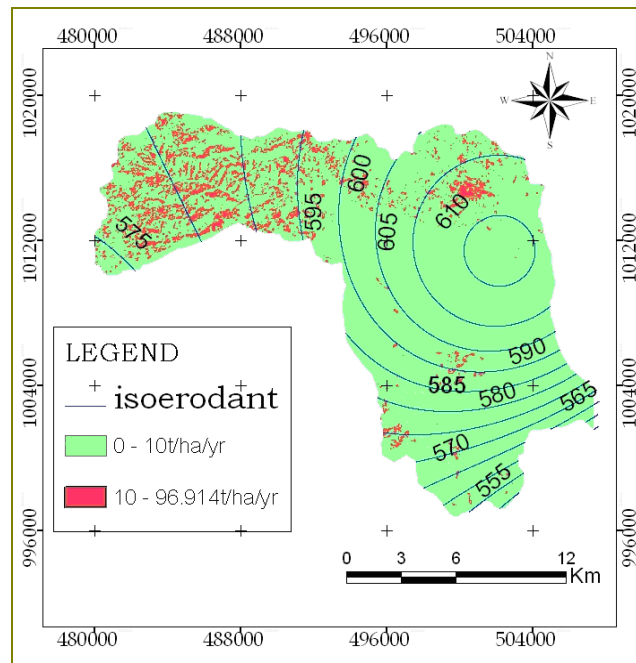


Figure 5.3 soil loss by rainfall erosivity

### 5.3.2 Soil loss by slope gradient

Soil erosion hazard map was cross tabulated with slope gradient map to estimate the amount of soil loss from different slope classes (Table5.4). Slope classes in degree and soil loss > 10t/h/yr were cross tabulated to estimate area of soil loss. From the result, 44% of the soil degradation occurred within the slope range of 10 – 18° or moderately steep slope classes.

Table5.4 soil loss by slope group

Slope class	Slope Description	Area(km <sup>2</sup> )	Area%
< 5 <sup>0</sup>	Gentle	2.56	9.6
5-10 <sup>0</sup>	Moderate	9.34	35.0
10-18 <sup>0</sup>	Moderately steep	11.74	44.0
18-31 <sup>0</sup>	Steep	3.06	11.4

### 5.3.3 Soil loss by land-use/land-cover type

The soil loss map was correlated with the land-use map to get the amount of soil loss from different land-use/land-cover classes and presented in table5.5. The table shows that the soil loss degradation in intensively cultivated land is highest i.e. 40% Of soil degradation of >10t/ha/yr, followed by grassland (30%).

Table5. 5 Soil losses by land use/land cover

Land use/ Land cover type	Degraded Area (km <sup>2</sup> ) > 10t/ha/yr	Area %
Bare soil & Built up area	1.86	5.1
Eucalyptus woodland	5.22	14.4
Moderately cultivated land	3.67	10.2

Intensively cultivated land	14.53	40.1
Grassland	10.92	30.2

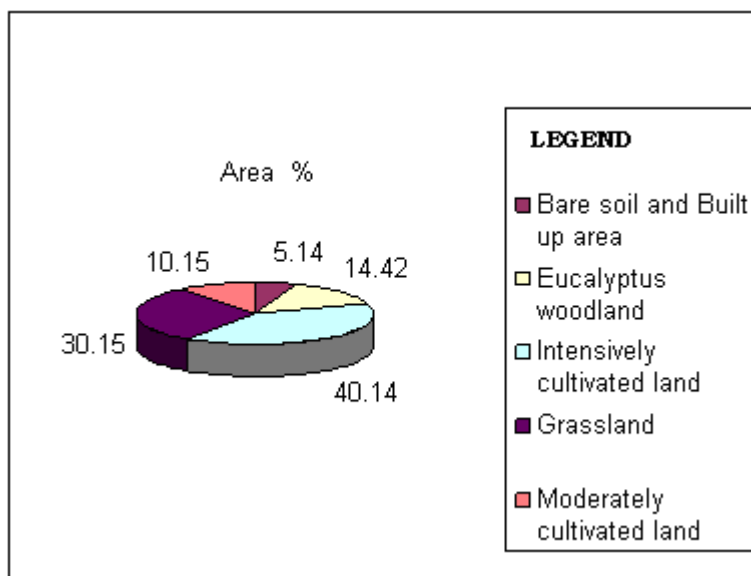


Figure 5.4 Soil degradation by land-uses

### 5.3.4 Soil degradation by major soil type

To assess soil loss by major soil types of the study area, the soil degradation map was cross tabulated to soil types and the out put result presented in Table5. Accordingly, the most degraded soil in the study area is chromic Luvisols. 20% of its total cover in the catchment was highly prone to high rate of soil degradation. Chromic Luvisols consists of nearly 87% of high soil erosion from the entire catchment.

Table5.6 Area of soil erosion by soil type

Major soil types	Degraded Area (km <sup>2</sup> ) > 10 t/ha/yr	Area %
Vertic Cambisol	0.15	0.7
Chromic Luvisol	23.31	88.6
Pellic vertisol	2.66	10.11

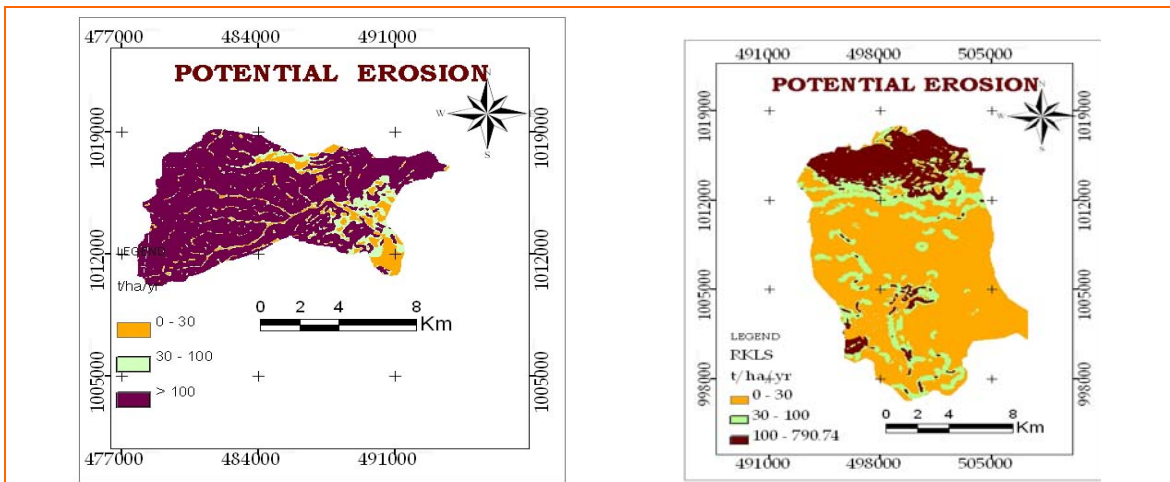
## 5.4 Comparison of soil erosion hazard in the two reservoir catchment.

A comparative analysis of erosion hazard between Legedadi & Dire catchment was made so as to identify the magnitude of erosion hazards between the two catchment. Comparison was made by potential and actual erosion risks of the catchment

### 5.4.1 Comparison by potential erosion hazards

Assessment of potential erosion risk provides information on the erosion susceptibility of the catchment without land cover and management practices. As stated earlier, the rainfall erosivity, soil erodibility, slope steepness and slope length factor as inputs of USLE model are considered as naturally occurring factor determining the potential erosion processes.

For the sake of visual comparison, the potential soil loss estimated map was reclassified in to three classes and presented in figure 5. 6



(a)

(b)

Figure 5.5 potential erosion in Dire (a) and Legedadi (b)

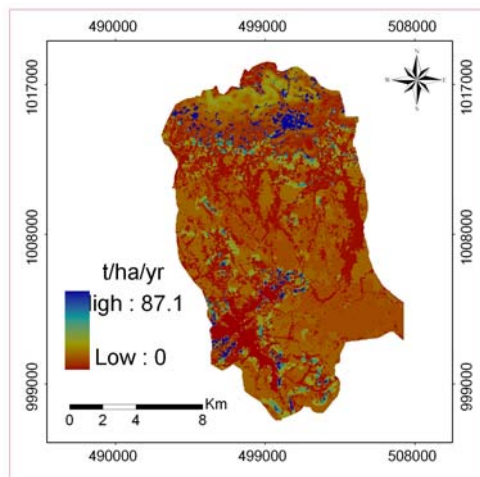
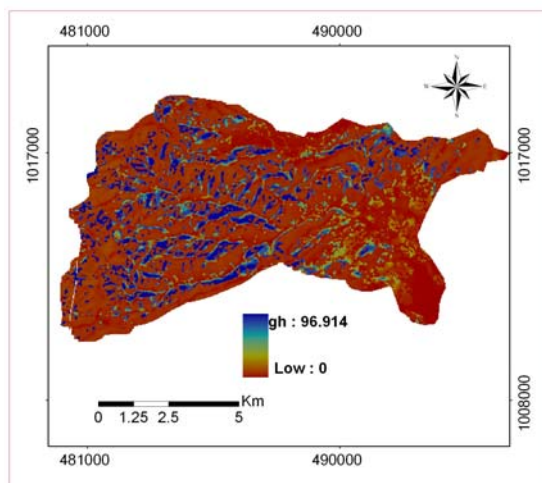
Table 5.7 shows that the mean annual potential soil loss in the Dire catchment was found to be highest (255.7t/ha/yr), which is more than four times that of the Legedadi catchment (62.4t/ha/yr). In general the Dire catchment has high potential erosion risk compared to Legedadi catchment.

Table 5.7 Area of potential soil loss in Legedadi &amp; Dire catchment

Catchment	Area	Erosion Class (t/ha/yr)			Mean annual Soil loss
		Low (0-30)	Moderate (30 - 100)	High > 100	
Legedadi	Km <sup>2</sup>	132	36	34	62.4
	%	65.4	17.8	16.8	
Dire	Km <sup>2</sup>	7	10	69	255.7
	%	8.2	1.6	80.2	

#### 5.4.2 Comparison by Actual erosion Hazards

Estimation of actual erosion rate considers all the six parameters of USLE model. For visual comparison purpose the actual erosion hazard map was presented in figure 5.7



(a)

(b)

Figure 5.6 Actual erosions in Dire (a) and Legedadi (b)

Table 5.8 presents estimated rate of actual soil erosion for the two reservoir catchment. It shows that 14.5% of dire catchment highly prone to high erosion hazards. The area of erosion hazards account 14.5 % and 121.2% of Dire and Legedadi catchment, respectively. The mean annual erosion in Dire catchment is highest (10.2 t/ha/yr), however, legedadi has lowest mean annual soil loss (2.5 t/ha/yr). According to Hurni (1986), the soil loss in both reservoir catchment is with in the ranges of tolerable limits. However, according to Rose (1994), who set tolerance limits to 10t/ha/yr for tropical zones, the soil loss in Dire catchment is intolerable and hence conservation measures are required.

Table5. 8 Area of actual soil loss in Legedadi &amp; Dire catchment

Catchment	Area	Erosion Class (t/ha/yr)			Mean annual Soil loss
		Low (0-30)	Moderate (30 - 100)	High > 100	
Legedadi	Km <sup>2</sup>	194.8	4.7	2.5	2.5
	%	96.5	2.3	1.2	
Dire	Km <sup>2</sup>	66.3	7.2	12.5	10.2
	%	77.1	8.4	14.5	

#### 5.4.3 Comparison by slope gradient

Slope steepness is one of the most important factors determining soil erosion. In the study, a soil erosion rate comparison by slope gradient classes between the two catchment was carried out by cross tabulating a slope class map with the estimated soil map. According to the result, more than half of the high erosion rate (> 10t/ha/yr), in both catchment, has occurred with in a slope class range of 5 -10 degrees.

Table5.9 comparison of soil loss by slope gradient

ID	Slope class (dgree)	Description	Slope class (degree)	Dire Catchment Soil loss > 10t/ha/yr		Legedadi catchments Soil loss> 10t/ha/yr	
				Area (km <sup>2</sup> )	%	Area (km <sup>2</sup> )	%
2	< 5	Gentle	< 5	6.88	34.8	1.46	23
3	5 - 10	Moderate	5 - 10	10.07	51	3.54	55.4
4	10 -18	Moderately steep	10 -18	2.78	14.1	1.10	17.2
5	18 - 31	Steep	18 - 31	-	-	0.28	4.4
	Total		Total	19.74		6.39	

# **CHAPTER SIX**

## **CONCLUSION AND RECOMMENDATION**

### **6.1 Conclusion**

The study area, Legedadi and dire catchment, situated 20km east of the city of Addis Ababa is characterized by various topographic features, soil types and land covers. In recent years, there has been an increasing concern with respect to land and soil degradation of the reservoir catchment. According to the survey report on reservoirs (AAWSA, 2000), the storage capacity of the two reservoirs, Legedadi and Dire, are constantly and rapidly decreasing due to Siltation of eroded materials. A considerable part of the sediment load is due to present agricultural practices in the area with no soil conservation measures. The report also stated that many of the upstream watersheds are in a state of physical and biological deterioration due to over exploitation of lands by the inhabitants. Assessment of soil erosion is required for mitigating on-site and off-site impacts of erosion.

This thesis aimed at estimating soil losses using USLE model and GIS techniques. The soil loss estimation was carried out based on the principles of the Universal soil loss Equation (USLE). Generally, the USLE model defines annual soil loss as a product of six main factors: rainfall Erosivity (R factor), soil erodibility (K factor), slope length and gradient (LS factor), land cover (C factor) and conservation practices (P factor).

In the first stage a GIS database of the relevant primary dataset and derived model input parameters was compiled. The input parameters were derived from primary data of various sources and data formats. The spatial thematic map of the respective factors of USLE with grid resolution of 30 meters was created as follows: R factor was interpolated from station point data; K factor for soil erodibility by using FAO/UNESCO soil map; LS factor that is related with the slope length and gradient by using DEM; C and P factor map that are the factors in respect to surfaces vegetation cover and soil conservation by using land use /land cover map of Landsat ETM+. In the second stage the derived parameters were used for modeling and assessment of erosion.

Finally, the application of USLE model in assessment of soil erosion has resulted the following findings:

- In the study area, estimated potential erosion varied from 0 to 790.74 t/ha/yr. The mean annual potential soil loss from the entire catchment was found to be 120t/ha/yr. The highest potential erosion is strongly bound to mountain and hill areas.
- Estimated actual soil was found to vary from 0 to 96.9 t/ha/yr. The actual mean annual soil loss is about 4.81t/ha/yr. More than 9% of the catchment area is prone to high soil degradation
- From the level of soil loss tolerance limits recommended by Rose (1994) and Hurni(1986), the mean annual soil loss of the study area (i.e. 4.81t/ha/yr) as estimated by the model is tolerable.
- Among the major soil types in the study area chromic Luvisols soils were found to be highly degraded soil. Nearly 44% of moderate and high soil degradation areas are bound to moderately steep slope class (10 – 18<sup>0</sup>).
- From analysis of soil loss by land use/land cover classes, intensively cultivated land was found to be erosion hot spot, which calls for immediate conservation practices.
- A comparative analysis of erosion hazards between Legedadi and Dire catchment has resulted more vulnerability of Dire catchment to erosion than the Legedadi catchment. According to Rose (1994), the soil loss in Dire catchment is intolerable and hence conservation measure is urgently needed.

## **6.2 Recommendation**

Upgrading of present agricultural and livestock management practices and introduction of appropriate soil conservation measure are essential for mitigating erosion and reservoir sedimentation on one hand, and for improving the welfare of the inhabitants of the catchment on the other hand. The cultivation practice, in the study area, is mainly

dependent on a traditional rain fed agriculture, and the livestock are fed entirely on natural grassland and over grazing is common, a major factor conducive to erosion.

Intensively cultivated lands and grassland areas, which contributed too much soil erosion of the catchment, should be treated as erosion hazard zone and the watershed management practices should be adopted in this area.

Although, the USLE model is a valuable tool in characterizing annual soil erosion from field survey and laboratory analysis, detail assessment of erosion is recommended so as to come up with a comprehensive solution for mitigating the existing problem, in the study area.

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