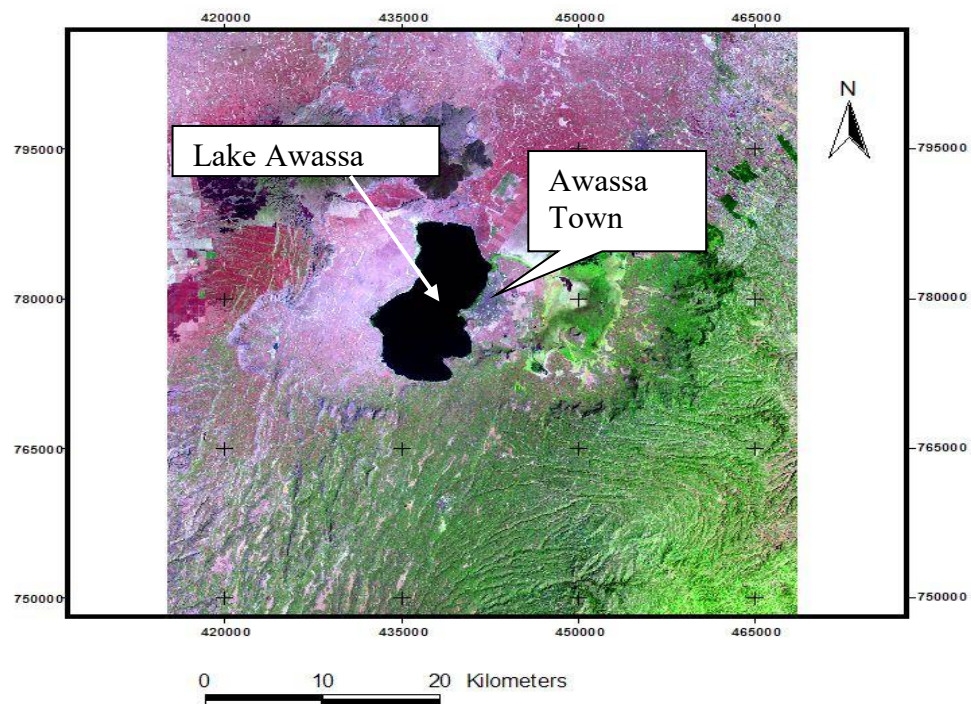




ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF NATURAL SCIENCE
DEPARTMENT OF EARTH SCIENCES

SOIL EROSION MODELING USING REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEM: A CASE STUDY OF
AWASSA AREA.



BY
HAMELMAL HAGOS MESFIN

ADDIS ABABA
JULY 2005

SOIL EROSION MODELING USING REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEM: A CASE STUDY OF
AWASSA AREA.

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

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

BY
HAMELMAL HAGOS MESFIN

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

SOIL EROSION MODELING USING REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEM: A CASE STUDY OF
AWASSA AREA.

BY
HAMELMAL HAGOS MESFIN

APPROVAL BY BOARD OF EXAMINERS

Dr. Dereje Ayalew

Chairman, Department Head

Dr. Tesfaye korme

Advisor

Dr. Syed Ahmed Ali

Examiner

K.V.Suryabhagavan

Examiner

ACKNOWLEDGEMENTS

Above all, I want to thank God for giving me the strength and the courage to continue my studies. This study would never have been completed without the contribution of many people to whom I would like to express my gratitude.

I am greatly indebted to my advisor Dr, Tesfaye Korme for his supervision, valuable guidance, and constructive comments. He was dedicated to help me during my fieldwork and studies in the Addis Ababa University.

My deepest gratitude goes to Dr. Bekele Abebe for his advice and for sharing his invaluable time and ideas and also for critically reading the earlier versions of this manuscript.

I thank Dr Murti for his support in the laboratory work.

My special thanks also goes to the Water Mines and Energy Resource Development Bureaus of SNNPR for collaborating and facilitating the fieldwork.

I am very grateful to Ato Samson, W/t Hiwotie, Ato Anteneh, W/t Yemisirach , W/t Selamawit from GTZ for giving me the chance to print my thesis in their office.

My special thanks goes to Dr. Sonder, Ato Atismachew, from ILRI for all their support and encouragement during my study.

I like to extend my thanks to all library staff members of ILRI, for their assistance during the search of literatures.

Ato Ayenew deserves special thanks for devoting his valuable time in helping me get statistical data.

The assistance of Addisu Derege, my classmate, was so much that without his support this work could have not been completed on time. He devoted much of his invaluable time in helping me finalise this work. He has a special place in my mind for his contributions were so much.

My heartfelt thanks goes to Ato Girmay T/Himanot and his wife Misses Mary, W/o Mihiret T/Himanot without whom this work would not have been completed.

I express my sincere thanks to Ato Mussie W/Micheal, who was encouraging me during my enrolment at Addis Ababa University.

I would like to extend my gratitude to my friends, Yodit, Abiy, Zinash, Tigist, Wubu, Tatek for their encouragement.

I would also like to extend my gratitude to my parents Tiffito and Hagos and my sister Navait and my brothers Abel and Tsuruy who were supporting me during my studies.

My special thanks goes to Girma Habtu for his continues support and encouragement with out whom this work could have not been completed. You have a special place in my heart.

Last but not least, my gratitude goes to Tsehaynesh, Hibron, Haben, Nahom, Natan, Mengesha, Teklay and Shewaynesh with their family for their support meant a lot to me.

TABLE OF CONTENTS

	PAGE
Acknowledgement -----	IV
Table of contents-----	VI
List of Tables-----	IX
List of Figures-----	X
List of Appendices-----	XI
Abstract -----	XII
Chapter One	
1. Introduction -----	1
1.1 Back ground-----	1
1.2 Relevance of the study-----	6
1.3 Objective of the study-----	6
1.4 Materials and Methods-----	6
Chapter Two	
2. Literature Review-----	8
2.1 Land Degradation-----	8
2.2 Forms of Land Degradation-----	9
2.3 Factors Affecting Water Erosion -----	9
2.3.1 Rainfall Intensity and Runoff-----	10
2.3.2 Soil Erodibility-----	10
2.3.3 Slope Gradient and Length-----	10
2.3.4 Vegetation/ Crop Cover -----	11
2.3.5 Conservation Measures-----	11
2.4 Soil Surface Sealing and Crusting-----	11

2.5 Population Increase and Land degradation-----	12
2.6 Crop Production and Land degradation-----	13
2.7 Forest Resources and Land degradation-----	16
2.8 Biodiversity and Land degradation-----	17
2.9 Erosion Modeling-----	18
2.10 Models Review-----	19
2.10.1 Rainfall Erosivity-----	21
2.10.2 Soil Erodibility-----	21
2.10.3 Ls-Factor-----	21
2.10.4 Cover and Management -----	21
2.10.5 Conservation Management Factor-----	22
2.11 Soil Loss Tolerance -----	22

Chapter Three

3.Description of the Study Area-----	24
3.1 Location and Accessibility-----	24
3.2 Climate -----	25
3.3 Physiography and Drainage-----	25
3.4 General Geological Setting-----	26
3.4.1. Tectonics-----	28
3.5 Stratigraphy of the study area-----	30
3.5.1 Basalt and ignimbrites of the plateau trap series (Late Miocene)----	30
3.5.2 Old alkaline and Peralkaline silicic rocks (Late Pliocene- Early Pliocene)-----	30
3.5.3 Recent basaltic lava flows, basaltic hyaloclastites and scoria cone (Recent Pleistocene) -----	30
3.5.4 Recent acidic volcanics -----	31

3.5.5 Volcano-lacustrine deposits -----	31
3.6 Geological Structure-----	32
3.7 Land Use and Land cover-----	34
Chapter Four	
4.1 Analyses and Discussion-----	37
4.2 The Universal Soil Loss Equation (USLE)-----	37
4.3 Determination of various factors of USLE-----	38
4.3.1 Rain fall Erosivity (R Factor)-----	38
4.3.2 Soil Erodibility (K factor)-----	39
4.3.3 Slope Gradient Factor (S factor)-----	41
4.3.4 Slope length factor, L-----	43
4.3.5 Cover and management factor-----	44
4.3.6 Conservation Practice Factor, P-----	47
4.4 Results and Discussion-----	49
4.5 Soil erosion rate in relation to Woredas-----	51
4.6 Impact of Population in the study area-----	53
4.7 Livestock impacts in the study area-----	55
Chapter Five	
5.1 Conclusion and recommendation-----	56
5.1.1 Conclusions-----	56
5.1.2 Recommendation-----	57
Reference -----	59
Appendices-----	69

List of Tables

	PAGES
Table 1. Soil erosion loss on 6 SCRP sites in various parts of Ethiopia.-----	4
Table 2. Estimates of soil erosion from areas with different land cover types.---	14
Table 3. Annual loss of Organic Matter, Nitrogen and Phosphorous associated with the loss of top soil under various land use system.-----	15
Table 4. Mean Annual Rainfall and calculated R factor of the stations.-----	39
Table 5. Showing different soil types and their corresponding K factor.-----	40
Table 6. Slope gradient classes, area in km ² , area covered in percentage, slope gradient factors.-----	42
Table 7. Showing Cover Management Practice.-----	46
Table 8. The Conservation Practice Factor.-----	48
Table 9. Soil Erosion Rate's in the Study Area.-----	49
Table 10. Woredas and Area Coverage in the Study Area.-----	52
Table 11. Soil Erosion Rate with in the Woredas.-----	52
Table 12. Total Area (km ²) and Population of Woredas in the Study Area, CSA(2005)-----	54
Table 13. Livestock Population of Sidama Zone in the Study Area, CSA (2002)-----	55

List of Figures

	PAGES
Figure 1. Causes of soil erosion.-----	4
Figure 2. Flow Chart Showing Steps taken to Assess USLE Model Validation for Erosion Risk Assessment in the Awassa catchment.-----	7
Figure 3. Causes of Nutrient Depletion.-----	16
Figure 4. Location map of the study.-----	24

Figure 5. Drainage system of Lake Awassa Catchments.-----	26
Figure 6. Geological map of the study area.-----	32
Figure 7. Showing the location of Recent Cracks.-----	33
Figure 8. One of the Recent Cracks in Multi area.-----	34
Figure9. Land use map of Lake Awassa catchment-1965-----	35
Figure10. Land use map of Lake Awassa catchment-1998-----	36
Figure 11.Rainfall Erosivity factor, R of the study area.-----	39
Figure 12. Showing Soil type in the study area.-----	40
Figure 13. Showing the Soil Erodibility.-----	41
Figure 14. Sowing the Slope Gradient in (%).-----	42
Figure 15.Showing the Slope Gradient Factor.-----	43
Figure 16.Showing the Slope Length Factor-----	44
Figure 17. Land use/ Land cover of the Study Area from supervised classification.-----	45
Figure 18. Land use/ Land cover of the study area after digitizing the different classes.-----	46
Figure 19. The Cover Management Factor of the study area.-----	47
Figure 20. Conservation Practice Factor of the study area.-----	48
Figure 21. Soil erosion rate (t/ha/yr) of the study area.-----	50
Figure 22. Woredas in the catchment.-----	51
Figure 23. Soil erosion rate (t/ha/yr) with in the Woredas.-----	53

List of Appendices

	Pages
Appendix 1 Erosion Assessment.-----	69
Appendix 2 Land use classes and their corresponding C factor near Lake Tana in the central Ethiopian Highlands.-----	73

ABSTRACT

Land degradation has been a major global issue because of its adverse impact on agronomic productivity, the environment, and its effect on food security and the quality of life. Soil erosion is the major form of land degradation in Ethiopia. This study is done in Awassa Catchment, which is the central part of the Main Ethiopian Rift. Assessment of soil erosion rate in the study area is done using the statistical and relatively simple soil erosion model that is USLE. All factors used in USLE were derived independently, while in reality the factors interact in a dynamic system and several assumptions have to be made to adapt the model to a given set of conditions. Based on the analysis of the data, 97.51% of the study area is characterized by low to moderate soil erosion rate (0-10.09 t/ha/yr) and 2.49% of the study area is characterized by high to extremely high soil erosion rate (10.09-201.79 t/ha/yr). Out of 97.51% of the study area that is characterized by low to moderate soil erosion rate, 88.05% of it is associated with slope gradient factor less than one. 49.32% of areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are associated with slope gradient factor greater than or equal to one. And 6.37% (1.97 km²) of those areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are related to slope length greater than or equal to 4.5. And areas with high to extremely high erosion rates are associated either higher slope gradient factor or with degraded bare land and grassland and shrub land cover. Out of the whole catchment, 30.24 km² lies under high to extremely high soil erosion rate and this requires immediate conservation measures like planting trees which can hold the soil intact. According to the rates of soil tolerance limits that are developed for tropical soils (0.2 and 11 t/ha/yr), 97.51% of the study area is under tolerable soil erosion rate.

But one thing to remember is that the USLE measures only rill and interrill erosion therefore the overall soil erosion rate especially in the Muleti area where ground cracks are observed could be much higher than the predicted by the USLE. Thus, estimation of soil loss from the ground cracks in Muleti area should be assessed by other models.

Therefore the analysis of high-resolution remote sensing data combined with further spatial information in a GIS environment provides an integrated and cheap tool for resource management within the scope of sustainable development.

CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND

Land degradation has been a major global issue during the 20th century and has remained important in the 21st century because of its adverse impact on agronomic productivity, on the environment, on food security and the quality of life, Eswaran et al., (2001). Land degradation reduces the productivity of the land and affects the income and well being of the people Kunaporn et al., (2001) as a result of natural or anthropogenic factors. Land degradation has been defined in several ways. Some of the definitions are very general and address all types of processes leading to a negative change in productivity of land under all types of uses. An example of these types of definitions by Dudal, (1981), describes it as a loss of land productivity, quantitatively or qualitatively, through various processes such as erosion, salinisation, water logging, depletion of nutrients, deterioration of soil structure, and pollution. UNCCD, (1994) defines land degradation as reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodland. Sometimes soil degradation, land degradation, and desertification are used interchangeably. However, soil degradation can be recognized as a major aspect of land degradation. Land refers to an ecosystem comprising land, landscape, terrain, vegetation, water, and climate, which contribute to agricultural production, including livestock production and forestry. Desertification refers to land degradation in arid, semi arid and sub humid areas due to anthropogenic activities, UNEP, (1993), Darkoh, (1995). So, due to the variations in definitions there is a large variation in the available statistics on the extent and rate of land degradation. According to Eswaran et al., (2001), the two principal global sources of land degradation data include the global estimates of desertification by Dregne and Chou,(1994), and land degradation by the International Soil Reference and Information Center, Oldeman et al., (1992), Oldeman,(1994). Current estimates indicate that close to 4 billion hectares of land or 75 percent of the Earth's land mass are affected by some form of degradation. These processes affect more than 15 percent of the world population and are expected to worsen unless effective actions are undertaken, CIESIN, (2002).

The principal process of soil degradation, one of the major aspects of land degradation, has been classified into four types: water erosion, wind erosion, chemical degradation (comprising acidification, salinization, leaching etc,) and physical degradation (comprising crusting, compaction, hard crusting etc), Oldeman, Hakkeling, & W.G.Sombroek, (1991). About 85% of the cause of land degradation worldwide is soil erosion by wind and water. Nearly 1.1 billion hectares of world's soils are affected by water erosion, 0.55 billion hectares by wind erosion, and 0.24 billion hectares by chemical and 83 million hectares by physical degradation, Lal & Steward, (1994). This shows that soil erosion is the prominent form of land degradation. Hence, soil and land degradation are often used interchangeably. Using a combination of on site and off site measurements to assess the extent and impact of soil erosion, it was estimated that world's soils are being depleted at the rate of 0.7% per year, Brown & Wolf, (1984). Soil degradation and siltation of inland water bodies resulting from soil erosion are widely recognized problems in most parts of the world. Therefore, accelerated erosion are an increasing threat to the decline of soil productivity and agricultural production. Soil erosion exacerbates soil degradation, and vice versa. Declining in soil quality, especially weakening of structural units precedes erosion.

Ethiopia with an area of 1,130,000 km² and about 67 million population is the third largest and most populous country in Africa, MoFED, (2002), Kidanu, (2004). The country's altitudinal variation ranges between 110 meters b.s.l to 4620 a.s.l resulting in different agro-ecological conditions. Ethiopia is facing problem of land degradation and unsustainable agriculture due to increase in population and decrease of natural resources. This has become a threat to Ethiopia whose 52% GDP, World Bank, (2002) comes from agriculture. According to Oldeman, (1994), Morgan (1995), the major cause of land degradation is soil erosion, which is also perhaps one of the most serious mechanisms of land degradation and the decline of soil fertility in tropical environments, El-Swaify, (1997), Enters, (1998) in which Ethiopia is no exception. Thus, soil erosion is one of the most serious environmental problems in the world today, because it seriously threatens agriculture and natural environment. The processes and impact of soil erosion are recognized as a threat to farm livelihoods and ecosystem integrity worldwide, Pimentel, (1993), Pimentel et al., (1995), but the threat is particularly acute in the tropics because of the circumstantial convergence of intense climatic inputs, low levels of

fertilizer use and conservation activities, frequently fragile soils, and strong dependence on soil quality for livelihood, Sanchez et al., (2003). Soil degradation can cause in lowering the capacity of land productivity temporarily or permanently. According to FAO, (2000), excessive land degradation, along with other climatic factors such as low and high rainfall intensity are causing reduced average crop yield per unit area. This imposes threat on agricultural production and on the communities who depend on the environment for their livelihood. Consequently, Ethiopia has become one of the largest food aid recipients in the continent. The dominant causes of land degradation in Ethiopia are poor farming practices, population pressure, erratic and erosive rainfall patterns, declining use of fallow, overgrazing, soil erosion, deforestation, salinity and alkalinity problems, pollution, loss of organic matter, fertility and vegetation cover, habitat conversion and aquifer degradation and the use of livestock manure and crop residue for fuel as energy resource of the rural households, Cesen (1986), World Bank, (1984).

Soil erosion is the major form of land degradation in Ethiopia. The causes of soil erosion are various and interrelated as shown in figure 1. According to FAO, (1986), average annual soil loss all over the country is about 2 billion tones, of which around 10% crosses the national boundary. Taking into consideration the redeposit, soil loss on cropped lands is estimated to be 100 t/ha/yr, on average. Another study conducted by Hurni (1993), shows the national average soil removal to be around 1493 million tones per annum. He subsequently estimated much lower erosion rates from cultivated land (42 t/ha/yr), though still much higher than the rate of soil regeneration (3-7 t/ha/yr), Hurni,(1988). Based on Hurni's erosion estimates, Sutcliffe, (1993) estimated that 0.5 million ha of cropland and 5.7 million ha of pastures would be lost by 2010. Studies conducted by Ethiopian Highland Reclamation Study showed that over 14 million ha in the highland are seriously eroded, some 1900 million tons of soil are annually eroded from the highlands, equivalent to an average net soil loss of 100 tons/ha, with variations between 50 to 170 tons/ha. Berhe (1996), conducted soil erosion assessment in six Soil Conservation Research Project sites in various parts of Ethiopia. The estimated amount of soil loss is given in Table 1.

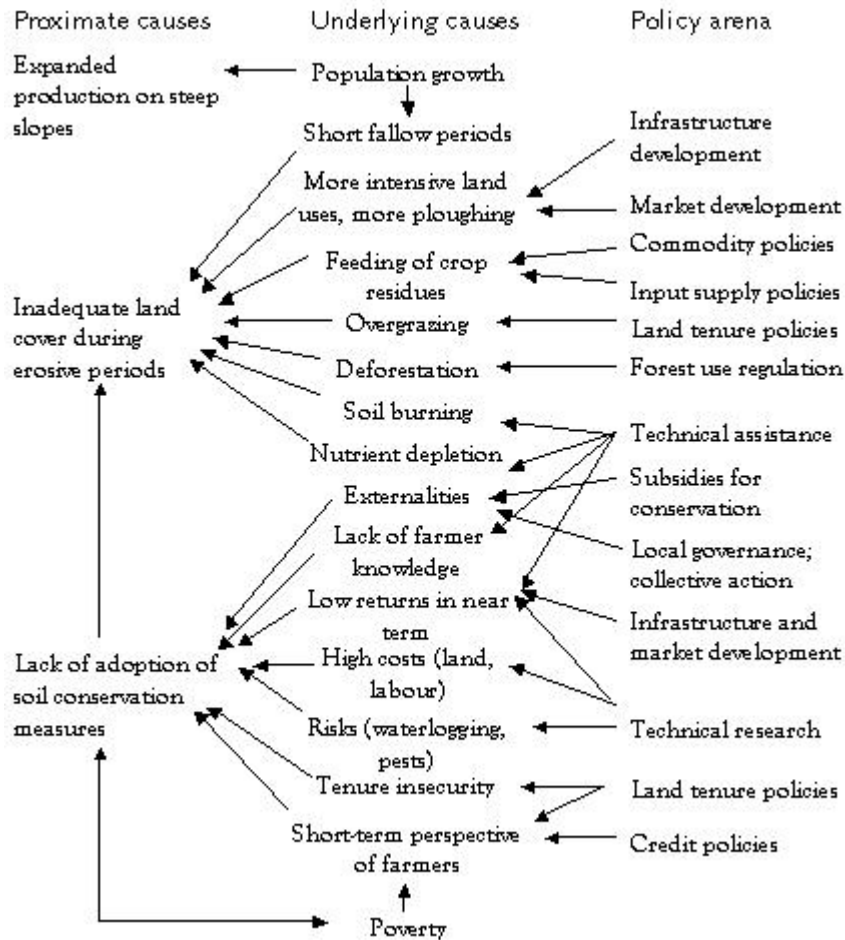


Figure 1. Causes of soil erosion. Source (Fitsum et al., 1999).

Site	Soil loss tons/ha/year
South welo	36.5–53.8
Sidamo	41.2–49.5
Harer	25.5–27.8
North Shewa	152.4–214.8
Gojam	40.2–199.2
Illubabur	18.0–135.3

Table 1. Soil erosion loss on 6 SCRP sites in various parts of Ethiopia. Source Berehe, 1996.

Various studies have been conducted in order to estimate the impact of soil erosion on production and economic activity in the Ethiopian highlands. The Highlands Reclamation

Study estimated that erosion would result in a reduction of crop production of 2.6 million tons by 2010, while Sutcliffe, (1993) estimates are only 13% of this. Studies conducted by Hurni (1993), shows that soil erosion is estimated to lead to productivity loss of 1 to 2% per annum, while use of crop residues and dung for fuel production contributes to biological degradation of the soil, by further increasing the decline of agricultural productivity by 1% per annum.

Estimates of the annual costs of erosion in the Ethiopian highlands range from EB 10 million to EB 135 million per annum (0.05% to 0.7% of the agricultural GDP), while the estimated gross discounted present value of cumulative losses caused by erosion ranges from EB 3 billion to EB 7 billion, Bojo and Cassells, (1995). Despite the debate over these magnitudes, it is clear that soil erosion is causing substantial costs to agriculture in the Ethiopian highlands which comprise more than 90% of the country's population, about 93% of the cultivated land, around 75% of the country's livestock and accounts for over 90% of the country's economic activity.

From the above facts land degradation in the form of soil erosion affects all facets of life. Therefore researches in order to address the problem are needed. Eswaran et al., (2001), proposed three steps in order to address the problem of land degradation: assessment, monitoring, and implementation of mitigating technologies. But effectiveness of any measure taken to prevent land degradation problems is influenced by the type and quality information.

During the last 20 years, *multi-temporal, high-resolution*, remotely sensed data and *Geographic Information Systems (GIS)* have been used extensively to monitor environmental change and to map land cover *changes on the local, regional, and global scales*, Booth, (1989), Lillesand and Kiefer, (1999), *Berberoglu, (2003)*. Such information is essential for land use planning and sustainable management of resources. Sustainable management of natural resources requires that ecological goods and services to be used to meet both current and future generations' need by recognizing and adapting to the

inevitable biophysical limitations and interdependences, Evrendilek and Doygun, (2000), Wali et al., (2002).

Thus, assessment of the extent of land degradation has been cost effective with the advent of Remote Sensing and GIS, since remote sensing provides timely and reasonably reliable information for large area if supported by ground truthing, which otherwise would need considerable amount of human resources and time if it is assessed through field survey.

1.2 Relevance of the study

In the Awassa Catchment, population increase is forcing farmers to expand their land by clearing forests, bushes and scrubs for crop cultivation, construction purposes and for fuel as energy source. Thus, loss of agricultural lands is increasing in the catchment. Therefore estimation of soil erosion in Awassa catchment is very important aspect of study so as to make sound environmental management strategies and land use planning.

1.3 Objective of the Study

The General Objective of the Study is:

- ❖ To produce soil erosion risk map.

The Specific Objectives of the Study are:

- ❖ To determine the amount of soil loss using USLE.
- ❖ To prioritize different areas within the watershed based on soil erosion rate.
- ❖ Conclusions and Recommendations.

1.4 Materials and Methods

Remote Sensing Data

- Land sat Etm+ 2000 image, with path number 168 and row number 55.
Date of acquisition of the image is December 5, 2000.

Ancillary Data

- Topographic maps with 1:50,000 scale from National Mapping Authority.
- Rainfall data from National Meteorological Services.
- Soil map was obtained from Ethio-GIS.
- Population data and livestock data from the Central Statistics Authority.
- Field data.

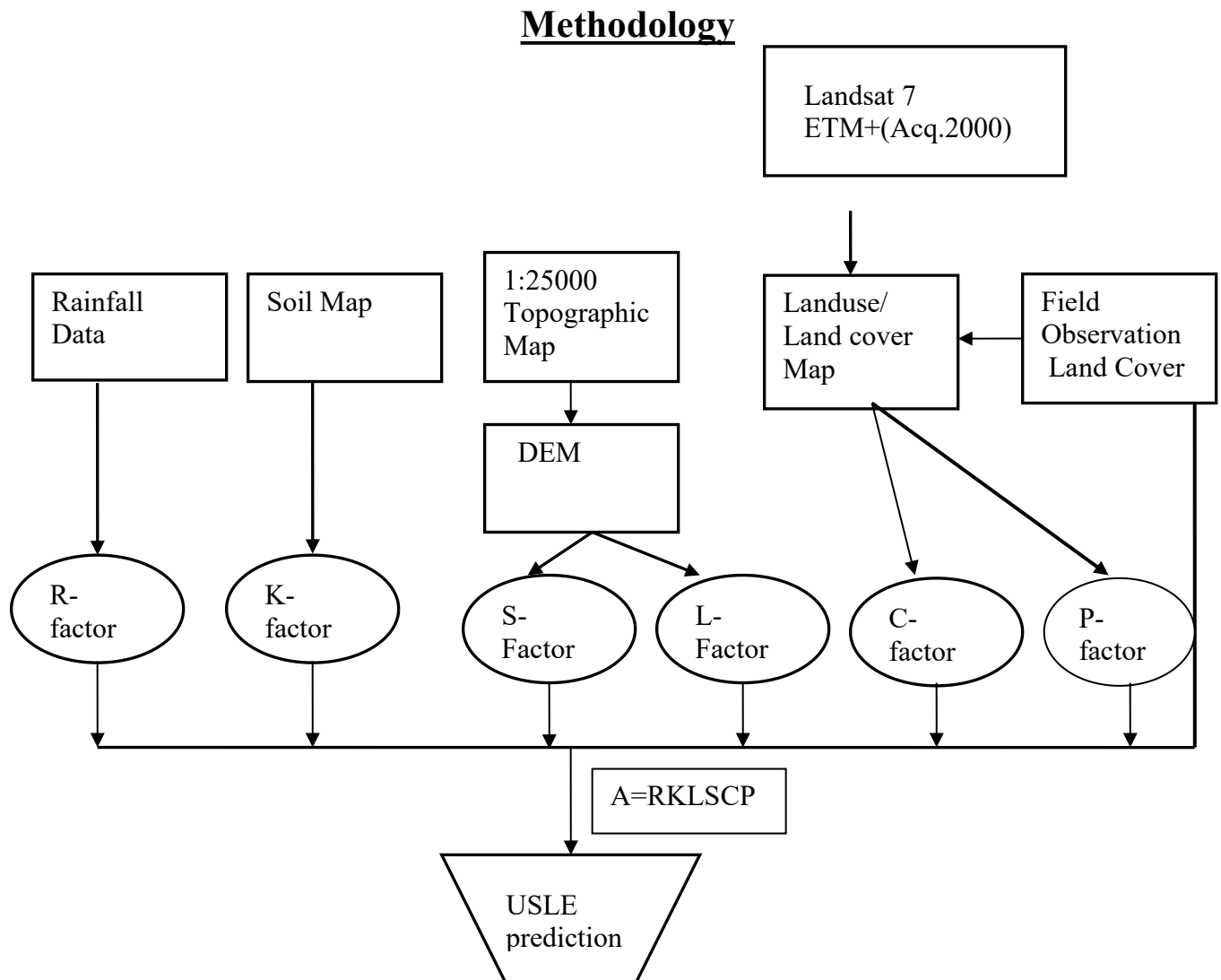
Softwares used: - Erdas Imagine 8.6 for mosaicing and geo-referencing scanned topo maps.

Arcview 3.2 for screen digitizing of the topo maps and for implementing USLE.

Envi 3.5 for image processing.

Vector→ Raster→ USLE→ SOIL EROSION RISK MAP.

The methodology employed in this research is given as flow chart in figure 2.



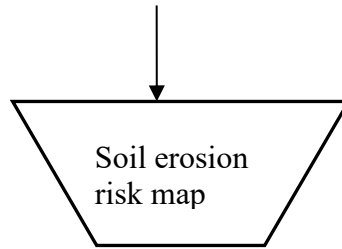


Figure 2. Flow chart showing steps taken to assess USLE model validation for erosion risk assessment in the Awassa catchment.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Land Degradation

As mentioned in the previous chapter, land degradation can be defined in many ways. According to Blaikie and Brookfield, (1987), land degradation is a decline in the productive capacity of the land in relation to its actual or possible uses. It is the decline of land quality or the reduction in its productivity and environmental regulatory capacity. In the context of productivity, land degradation results from a mismatch between land quality and land use, which is a problem for those who use the land. Land degradation can be caused by natural factors (comprising high rainfall intensity, flooding, wild fire) and anthropogenic factors (comprising deforestation, overgrazing, over cultivation and population increase etc.,). Degradation processes that are caused by natural factors are broadly at a rate, which is in balance with the rate of natural rehabilitation. For example, water erosion under natural forest corresponds with the subsoil formation rate. But the most important source of land degradation is human induced. Mechanisms that trigger land degradation can be physical, chemical, and biological processes, Lal,(1994). The most important physical processes are decline in soil structure leading to crusting, compaction, erosion, desertification, anaerobism, environmental pollution, and unsustainable use of natural resources. Significant chemical processes include acidification, leaching, salinization, decrease in cation retention capacity and fertility depletion. Biological processes include reduction in total biomass carbon, and decline in land biodiversity. Soil structure is the important property that affects all three degradation

processes. The agents that cause the degradation determine rate of land degradation. This can be biophysical including land use and land management, including deforestation and tillage methods, socioeconomic (e.g. land tenure, marketing, institutional support, income and human health), and political (e.g. incentives, political stability) forces that influence the effectiveness of processes and factors of land degradation. Thus, land degradation is a biophysical process driven by socioeconomic and political causes.

2.2 Forms of Land Degradation

All processes of land degradation are grouped into seven classes: water erosion, wind erosion, vegetation degradation, soil fertility decline, salinization, water logging and lowering of the water table, soil compaction and crusting as the principal global land degradation processes. Soil erosion by water is the removal of a mass of soil from one part of the earth and its relocation to the other part of the earth, Lal, (1990). Water erosion includes inter-rill and rill erosion, gullying, and land sliding caused by clearing of vegetation and road construction. Wind erosion refers to the loss of soil by wind, occurring primarily in dry regions and usually produces sand dunes. Soil fertility decline refers to deterioration in soil physical, chemical and biological properties that is reduction in soil organic matter status, leading to decline in the structure, aeration, water holding capacity of soil, reduction in the availability major nutrients, initiation of micronutrient deficiencies and development of nutrient imbalances and build up of toxicities. Salinization /sodification (also called alkalinization), which refers to the dominance of the exchange complex by Na^+ , refers to all types of land degradation brought about by increased concentration of salts in the soil. Water logging is caused by over irrigation, and restricted infiltration of water into the soil. This lowers land productivity through rise in ground water close to the soil surface. Pumping of ground water for irrigation, urban and industrial use brings about lowering of the water table, which exceeds the natural recharge capacity. According to Eswaran et.al., (2001) some lands can be affected by numbers of processes so unless a clear distinction is made, there is a considerable chance of overlap and double counting.

2.3 Factors Affecting Water Erosion

Soil erosion by water starts when raindrops strike the bare soil surface. It involves the detachment, transportation and deposition of soil. The most commonly recognized forms of water erosion are splash erosion, sheet erosion, rill erosion, gully erosion and stream bank erosion. Sheet erosion is a uniform removal of soil in a thin layer by the forces of raindrop and overland flow. Rill erosion is the removal of soil by concentrated water running through little streamlets, or head cuts. Gullies are formed when rill development has progressed to the point where the gully is too wide and too deep to be tilled across, Houghton and Charman, (1986). The rate and magnitude of soil erosion by water is controlled by the following factors:

2.3.1 Rainfall Intensity and Runoff

Both rainfall and runoff factors must be considered in assessing water erosion problems. The loss of soil is closely related to the impact of raindrops on the soil surface to separate down soil aggregates and disperse them. The energy of the raindrops influences the kind of soils that are detached. Lighter soil materials can be easily removed by raindrop splash and runoff, but larger and denser materials require raindrops with higher energy. Soil movement is usually high and easily noticeable during short-duration and high-intensity thunderstorms. Less intense, long lasting rainfall should not be misinterpreted as being not capable of moving significant amount of soil when compounded over time. Runoff depends on rainfall intensity and infiltration capacity of soil. It can occur when rainfall intensity exceeds the rate of infiltration, as a result, the excess water cannot be absorbed into the soil so it forms surface runoff. The amount of runoff can increase if infiltration is reduced due to soil compaction, saturation, crusting or freezing.

2.3.2 Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. The physical factors which affect erodibility of soil are aggregate stability, particle size distribution, base minerals, organic carbon content, clay mineralogy, infiltration capacity, pore size, pore stability, moisture holding capacity of soil, topographic features and management of the land, Hudson, (1996), Shetha, (2002). Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have

greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. Tillage and cropping practices that lower soil organic matter levels, cause poor soil structure, and result in increases in soil erodibility.

2.3.3 Slope Gradient and Length

Generally, soil erosion by water increases as the slope of a field increases. Soil erosion by water also increases when the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with high erosion potential, due to increase in the velocity of water, which permits a greater degree of scouring (carrying capacity for sediment).

2.3.4 Vegetation / Crop Cover

Soil erosion potential increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash. Plant and residue cover tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent, and quantity of cover. The effectiveness of any crop, management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. Soil erosion potential is affected by tillage operations, depending on depth, direction, timing of plowing, type of tillage equipment and number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing erosion.

2.3.5 Conservation Measures

Certain conservation measures can reduce soil erosion by both water and wind. Tillage and cropping practices, land management practices, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to

control erosion on a field, a combination of approaches or more extreme measures like contour plowing, strip cropping, or terracing might be necessary.

2.4 Soil surface Sealing and crusting

Surface sealing refers to the reorganization of the surface soil layer during a rainstorm and crusting is the hardening of the surface seal as the soil dries, Morgan, (1995). Crusting is a sign of soil degradation caused by deteriorating conditions of plant cover and soil structure, which are caused by over cropping, overgrazing or over tillage.

The process that surface sealing involve include pore filling due to transport of fine particles into pore space, particle deposition, reorientation and raindrop compaction with consolidation upon subsequent drying, West et al., (1992) cited in Bedadi (2004). Soil sealing is due to the effect of raindrop on bare soil, which decreases infiltration, increases runoff and potential of soil erosion, Houghton and Charman, (1986). Sealing soils often generate more surface runoff, which causes a greater hazard for rill erosion, de Ploey, (1983). Soil conditions which favor sealing are low content in organic matter, a clay fraction with reduced activity, high silt content, dominance of fine and flat particles in the sand fraction, Pla Sentis, (1981), as cited in Ringo, (1999).

2.5 Population Increase and Land Degradation

About two centuries ago, Malthus hypothesized that the population growing exponentially would take over the food production growing linearly, Malthus, (1978). Also some scientists argue that an increase in population poses a severe threat in natural resources, Ehrlich et al., (1993). Others argue that, the mounting demographic pressure often induces the adoption of agricultural practices that raise the output while simultaneously improving the natural resource management Hyden et al., (1993). Hence, growth in agricultural production has exceeded population growth for almost three decades, Squire, (2000) cited in Kahsay B. (2004).

Population growth and changes in the spatial distribution are obviously the key driving forces for change in natural resource management, even though other factors such as human settlement, land tenure policy, Blaikie and Brookfield, (1987), Murphree and Cumming (1993), fiscal policy, Schmink and Wood (1987), Klink et al. (1993), international aid and trade policy, Young,(1993), agricultural policy, Reed,(1996), changes in technology, Grubler,(1994),

culture, Rockwell,(1994), power, Stedman-Edwards,(1998) and political /economic institutions, Sanderson,(1994) play an important role in land use change. In Ethiopia, population growth, in the absence of technologies for agricultural intensification and opportunities for off-farm employment has resulted severe shortage of arable land and continuous expansion of cultivation on to the more fragile environments such as steep slopes, drought prone areas, etc., Messerli and Aerni (1978). Usually, the expansion of agricultural lands is undertaken at the expense of forest clearing which causes land degradation. On the other hand, farmers of Machakos District in Kenya practiced growing of fodder periodically on sloping land in order to feed their domestic animals, which has a positive environmental impact, Tiffen et al., (1994), with increased population. Positive environmental trends are also observed in Ethiopia, in the highly populated sloppy areas of Konso where terracing for soil conservation is practiced, which makes them one of the world's heritage of UNESCO. Therefore, high population density is not necessarily related to land degradation. What the population does to itself and to the land determines the extent of land degradation. People can be a major asset in reversing the degradation trend as those in Machakos district Kenya. So one has to consider the socio economic and biophysical conditions of the study area in order to make the appropriate conclusions and recommendations.

2.6 Crop Production and Land Degradation

The major cause of soil degradation is soil erosion, Oldeman, (1994), Morgan (1995), which is also perhaps one of the most serious mechanisms of land degradation and soil fertility decline in tropical environments, El-Swaify, (1997), Enters, (1998). The processes and impact of soil erosion are more pronounced in tropical regions due to intensive rainfall, highly weathered and erodible soils, poor vegetation cover, and greater potential water flow energy in steeply sloped areas, Lo, (1990), El-Swaify, (1997).

According to El-Swaify and Hurni, (1996), the Ethiopian highlands (> 1500m a.s.l), which account for 44% of the country, are amongst the most degraded lands in Africa. According to FAO (1986), some 50% of the highlands are significantly eroded, of which 25% are seriously eroded, and 4% have reached a point of no return. In order to estimate the quantity soil loss in the Ethiopian highlands, Hurni (1986), used the USLE model. (Table 2) shows the amount of soil erosion lost from different land cover types in the Ethiopian highlands. He estimated that

average erosion rates on currently unproductive cropland are 70 t/ha/yr and the average erosion rate from currently used cropland (planted to annual crops) are 42 t/ha/yr or 4 mm of soil depth, which is sufficient enough to wear away the total soil profile within 100-150 years (assuming average soil depth is 60 cm in the highlands). But it may also reach up to 300 t/ha/yr in individual fields, Hurni, (1993), this by far exceeds the natural rate of regeneration, while erosion averages 8 t/ha/yr on land planted to perennial crops and 5 t/ha/yr or less for all other land cover types, Table 2. In some areas soil loss from newly cleared forest land for crop production purposes was reported to be 130 t/ha/yr, Solomon Abate, (1994). Thus, land cover management practices are important in affecting erosion on cropland, by reducing erosion by as much as 50% or more, Eweg *et al.*, (1997).

Estimated rates of soil loss on slopes in Ethiopia (including Eritrea)

Land cover	Area of Country (%)	Estimated soil loss tons/ha/yr	Total soil loss million tons /year	% Of total
Annual crops	13.1	42	672	45
Perennial crops	1.7	8	17	1
Grazing and brows	51.0	5	312	21
Forests	3.6	1	4	-
Wood and bush land	8.1	5	49	3
Currently unproductive	3.8	70	325	22
Currently uncultivable	18.7	5	114	8
Total	100	141	1,493	100

Source Hurni (1986).

Table 2 estimates of soil erosion from areas with different land cover types.

Nutrient depletion is another principal process of land degradation with severe economic impact at a global scale, especially in sub-Saharan Africa. The causes of nutrient depletion are interrelated with each other as shown in figure 3. There is loss of organic matter, nitrogen, phosphorus, potassium and other essential plant nutrients associated with the soil movement. According to Hawando, (1997), organic matter loss associated with the removal of surface soil ranges from 15–1000 kg/ha/yr, which amounts to 1.17–78 million tons of organic matter lost

per year from 78 million ha of cultivated and grazing lands. The loss of soil nitrogen ranged from 0.39–5.07 million tons per year and that of phosphorus ranged from 1.17–11.7 million tons per year, Hawando, (1997). Taking an average value of nitrogen loss of 30 kg/ha/year, organic matter loss of 200 kg/ha/yr and phosphorus loss of 75 kg/ha/yr the corresponding loss of the three plant nutrients amounts to 15.6, 2.16 and 5.85 million tons per year of organic matter, nitrogen and phosphorus respectively from 780,000 km² of land (Table 3).

Land use type	Land area Million ha	Nutrient documented range of annual loss, kg/ha						
		OM	15	50	100	200	500	1000
		N	5	10	15	30	50	65
		P	15	30	50	75	100	150
		Amount of nutrient loss, million kgs						
Cultivated land	18	OM	270	900	1800	3600	9000	18000
		N	90	1800	270	360	900	1170
		P	270	360	900	1350	1800	2700
Pasture & Range Land	60	OM	900	3000	6000	12000	30000	60000
		N	300	600	900	1800	3000	3900
		P	900	1800	3000	4500	6000	9000
Total	78	OM	1170	3900	7800	15600	39000	78000
		N	90	780	1170	2160	3900	5070
		P	1170	2160	3900	5850	7800	11700

Table 3. Annual loss of Organic Matter, Nitrogen and Phosphorous associated with the loss of top soil under various land use system, (Hawando 1997).

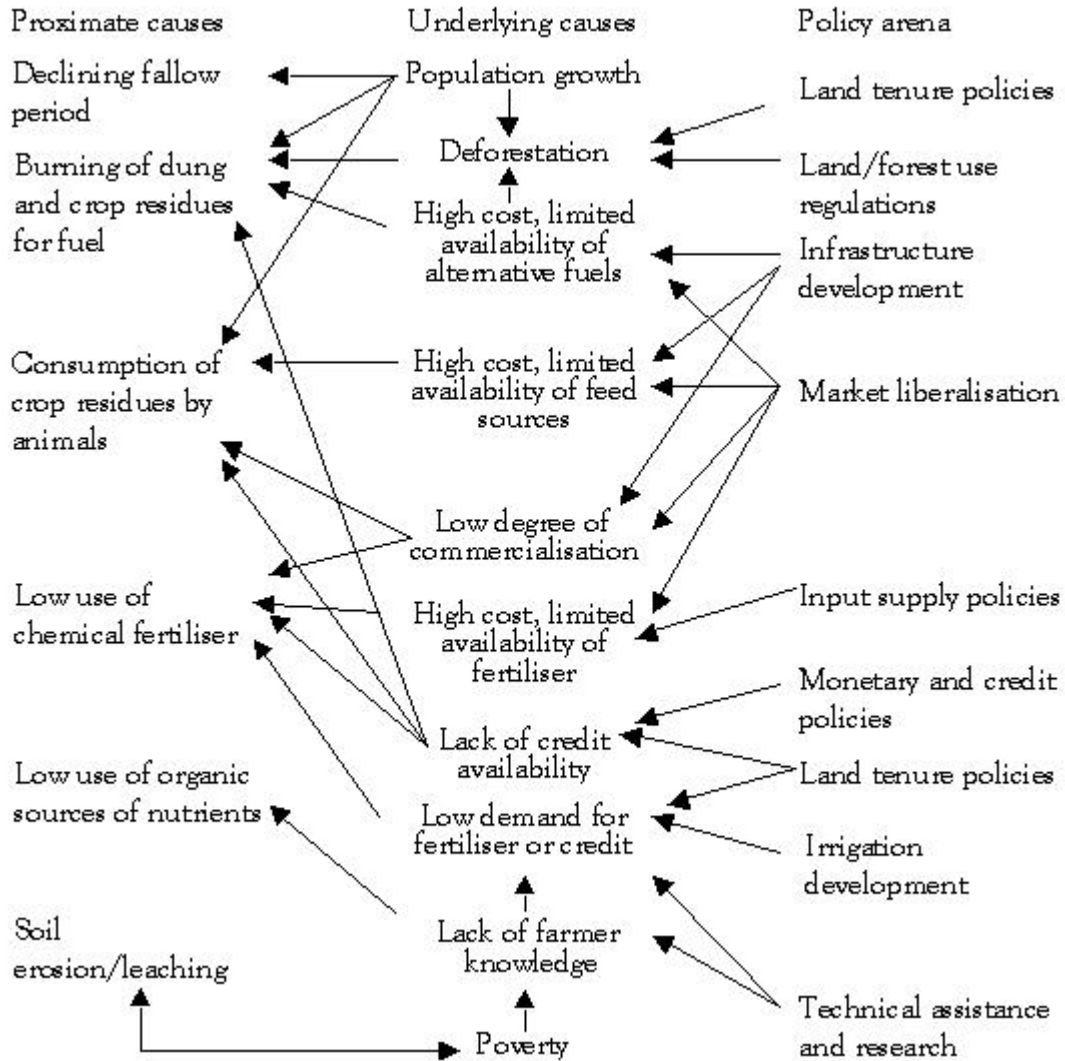


Figure 3. Causes of Nutrient Depletion. Source (Fitsum et al., 1999).

2.7 Forest Resources and Land Degradation

39 million km² (29 percent) of the world's land surface is under forest cover, FAO, (2001) as cited in Kahsay (2004), The World Resources Institute WRI, (1997) estimates that only one-fifth of the world's original forest cover remains, largely in blocks of undisturbed frontier forests in the Brazilian Amazon and boreal areas of Canada and Russia. In the same way, Ethiopia's forest resources have been disappearing at an alarming rate. Almost all the forests in Ethiopia have been destroyed in the last 40 years, and only less than 3 percent, MNRDEP, (1992), of the entire country is now covered with trees, prompting fears of environmental disaster if the problem is going to get worse. The forest cover affects the rate of runoff,

infiltration, evaporation and soil erosion. Though, effects of forest vary depending on the size of the watershed, increase in forest should increase transpiration rates, reduce soil erosion, flood and, by reducing sediment loads, it improves water quality, Kramer et al., (1997), Ammer et al., (1995). Therefore, areas with undisturbed forest cover show the lowest erosion rate, which ranges from 0.004 to 0.5 t/ha/yr, Pimentel *et al.*, (1998) as cited in Bezuayehu *et al.*, (2002). However, deforestation is continuing due to rapid population growth, extensive forest clearing for cultivation and over-grazing, movement of political centers, exploitation of forests for fuel wood, and construction materials without replanting which has reduced the forest area of the country to 16 percent in the 1950's and 3.1 percent in early 1980's. Further estimates of the distribution of forest and woodland areas made on the basis of information revealed that only 2.8 percent of the land surface is under forest and woodland. At present, larger forest stands are only found in the remote southern and southwestern parts of the country and in some remote areas of the country. The current rate of deforestation is estimated to be 150,000 to 200,000 ha/yr, EFAP, (1994), which exceeds the rate of afforestation by up to 15 times. As a result large areas of the country are now exposed to heavy soil erosion. The Soil Conservation Research Project (SCRCP) has estimated an annual soil loss of about 1.5 billion tons from the highlands, resulting in a massive environmental degradation and serious threat to sustainable agriculture and forestry. Studies indicate that clearing of forests for agriculture without adequate erosion prevention measures in the past many years have been the main causes of soil degradation in the densely populated highlands of Ethiopia, Feoli *et al.*, (2002). Therefore the impact of deforestation is felt by many people living in developing countries who obtain 90% of their daily needs directly from the biological resources, Kumar, (1999), and over 80% of the people in the developing countries depend on traditional herbal medicines obtained from the forests for primary health care, Farnsworth and Soejarto, (1991).

2.8 Biodiversity and Land Degradation

Ethiopia is an important regional center of biological diversity, and the flora and fauna have a rich endemic element, Sayer et al., (1992), WCMC, (1992). The country has the fifth largest flora in tropical Africa. The flora of Ethiopia is very heterogeneous and is estimated to include between 6,500 and 7,000 species of higher plants, and about 12% of these are endemic, Tewelde Berhan Gebre Egziabher, (1989). The existence of different agro-ecological zones

made Ethiopia to be in rich floral and faunal diversity. However, deforestation and conversion of natural forest to agricultural land that promote soil erosion are increasing loss in biodiversity that are accelerated by anthropogenic activities that degrade the self-repairing capacity of an ecosystem such as soil seed banks, soil fertility, etc., Garwood, (1989), Brown and Lugo, (1990), (1994), Teketay, (1996), as cited in Mulugeta (2004). Thus, the depletion of biodiversity as a result of soil erosion will certainly slow down sustainable development and endanger human life in the future, Mugabe, (1998), cited in Mulugeta (2004).

2.9 Erosion Modeling

Extent of soil loss is hard to quantify because, field measurements of erosion are rare, time consuming, and are usually only acquired over restricted temporal and spatial scales. To day global mapping of erosion has involved looking at sediment yield or questionnaire surveys. Willing and Webb (1983) as cited in Ulanbek Turdukulov,(2000), generated global maps of sediment yield data, however, problems associated with coupling and the variable sediment dynamics of fluvial system means that these data are not directly comparable to hill slope erosion. While, Middleton and Thomas (1997), used questionnaire surveys to gain an insight erosion severity but this approach only provides qualitative information and suffers from bias on the part of the people being questioned.

One way to provide a quantitative and consistent approach is to model erosion over large areas. Our ability to do this is restricted by parameter using models because data requirements are large, including information on vegetation, soil, topography and climate. Remote sensing and GIS hold great promise in this regard as they allow distributed models above do, erosion model predictions can be updated on a monthly or even daily basis. However, the modeling of soil erosion at regional and global scales may be problematic because soil erosion models have generally been built and calibrated only at the field or catchment scale and may not be directly applicable at the regional or global scale, Nick A. Drake,et al.,(1999) as cited in Ulanbek Turdukulov,(2000).

Modeling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. There are at least three reasons for modeling erosion.

- a) Erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories and for formulation regulations.
- b) Physically based mathematical models can predict where and when erosion is occurring, thus helping the conservation planner target to reduce erosion.
- c) Models can be used as a tool for understanding processes and their interactions and for setting research priorities.

2.10 Models Review

Models are the simplest form of representation of reality. There are basically three types of models: physically based models (white box), conceptual (gray box), and empirical (black box), Dangnachw et al., (2003).

Physically based models are those models that explicitly consider the spatial variability of some factors if not most. Most of them use particular differential equations and generally required more inputs parameters than empirical models. Many physical-based erosion models have been developed last two decades: CREAMS (Chemical, Runoff and Erosion from Agricultural Management system, USA), WEPP (Water Erosion Prediction Project, USA), EUROSEM (European Soil Erosion Model) etc. The power of physically based erosion models is that they represent a synthesis of the individual components, which affect erosion, including the complex interactions between various factors and temporal variabilitys.

Conceptual models lie somewhere between physical-based models and empirical models. Conceptual models are based on spatially lumped variables.

Empirical models are those models that do not explicitly consider the governing physical laws of the process involved, but only relate inputs to output through some transform function, Leavesley, (1994) cited in Dangnachw et al., (2003).

USLE: The USLE is an empirical erosion model, Wischmeier and Smith, (1978), used to assess soil erosion. The equation was designed for interrill and rill erosion, Wischmeier and Smith (1978). Although, the equation is described as universal and its database is extensive, it is restricted to slopes normally 0 to 17⁰, and to soils with a low content of montmorillonite. It is also deficient in information on erodibility of sandy soils. In addition to the limitation of its database, there are theoretical problems with the equation.

The universal soil loss equation (USLE) is widely used to estimate the soil loss and/or to estimate the numerical values of the different components of the erosive process. USLE allows prediction of annual soil loss based on the product of six factors.

It is represented by

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

Where,

A= Computed spatial average soil loss and temporal average soil loss per unit area, expressed in the units selected for k and for the period selected for R. Usually expressed in tons ha⁻¹ y⁻¹.

R= Rainfall-runoff erosivity factor is the rainfall erosion index plus a factor for any significant runoff from snowmelt. Expressed in joules m⁻².

K= Soil erodibility factor is the soil loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6 ft (22.1m) length of uniform 9% slope in continuous clean tilled fallow. Expressed in t-s m⁻².

L = Slope Length factor is the ratio of the soil loss from the field slope length to soil loss from a 72.6ft length under identical conditions.

S = Slope gradient factor is the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = Cover management factor is the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = Support practice factor is the ratio of soil loss with a support practice like contouring, stripping, or terracing to soil loss with straight-row farming up and down the slope. The last four factors are dimensionless, Wischmeier and Smith, (1978)

To predict the mean annual soil loss A in tones per hectare and year [t ha⁻¹ y⁻¹] of a certain area, all erosion factors have to be surveyed before their calculated numerical values are multiplied.

2.10.1 Rainfall Erosivity (R factor)

Typically, rainfall erosivity (R) is a product of the kinetic energy of the falling raindrops and its maximum 30 minute intensity. This factor is directly related to the rainfall characteristics found in a particular geographic location. In general, the greater the intensity and duration of the rain storm, the higher the erosion potential, thus, higher R-Factor is expected.

2.10.2 Soil Erodibility (K factor)

The soil erodibility Factor (K) reflects the characteristics of the soil. Soil erodibility is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. It is a quantitative value that is experimentally determined by taking into account the soil texture, the structure, the organic matter content, and the permeability, Wischmeier and Smith, (1978). Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.

2.10.3 LS-Factor

The length and the gradient of the slope can have a major influence on the amount of soil erosion that can potentially occur. Soil loss increases with increasing slope due to the greater volume of runoff accumulating on the longer slope lengths from larger areas and result in higher flow velocities. Steeper slopes produce high runoff velocities. Thus, Steeper and longer slopes result the water to travel at a higher rate of speed, therefore, it increases its shear stress on the surface and its capability to transport more sediment. Often the L and S factors are combined into a single topographic factor, LS.

2.10.4 Cover and Management (C factor)

The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. This factor is very complicated and takes several factors into consideration, including the seasonal erosivity index distribution, crop characteristics, cropping history (rotation), and crop yield level (organic matter production potential), tillage management (dates and types) and land use.

The land cover factor C measures the combined effect of all the interrelated cover and management variables, Wischmeier and Smith, (1978).

2.10.5 Conservation Management Practice (P-Factor)

P factor demonstrates the effects of practice that will reduce the amount and the rate of water runoff that causes the amount of erosion to reduce. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross slope cultivation, contour farming and strip cropping.

2.11 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 these 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), and for temperate regions 13.7 t/ha/yr, Thomson, (1957), as cited in Ringo, (1999). A common used soil loss tolerance rate is 5-12 t/ha/yr for shallow to deep soil, Crosson, (1983) and Lal, (1983), as cited in Ringo, (1999). However the current used rates for tolerable soil loss are far too high for fragile tropical soils with low levels of fertility, Lal, (1983), as cited in Ringo, (1999). It is also indicated that tolerance value for tropical soils have not yet been formulated at international level, Nill et. al., (1996), as cited in Ringo, (1999). Nevertheless, 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.

CHAPTER THREE

3. Description of the study area

3.1 Location and Accessibility

The study area is found in the main Ethiopian rift in the lakes region. It is located in southern Ethiopia, in and around the capital town of SNNPR, Awassa town, which is 275 Km south of Addis Ababa figure 4. It lies between 6⁰49’N-7⁰15’N latitude and 38⁰17’E-38⁰44’E longitude. The area is accessible through the asphalt road, which goes from Addis Ababa to Moyale, and the surrounding area is accessible by all weather road and seasonal gravel roads.

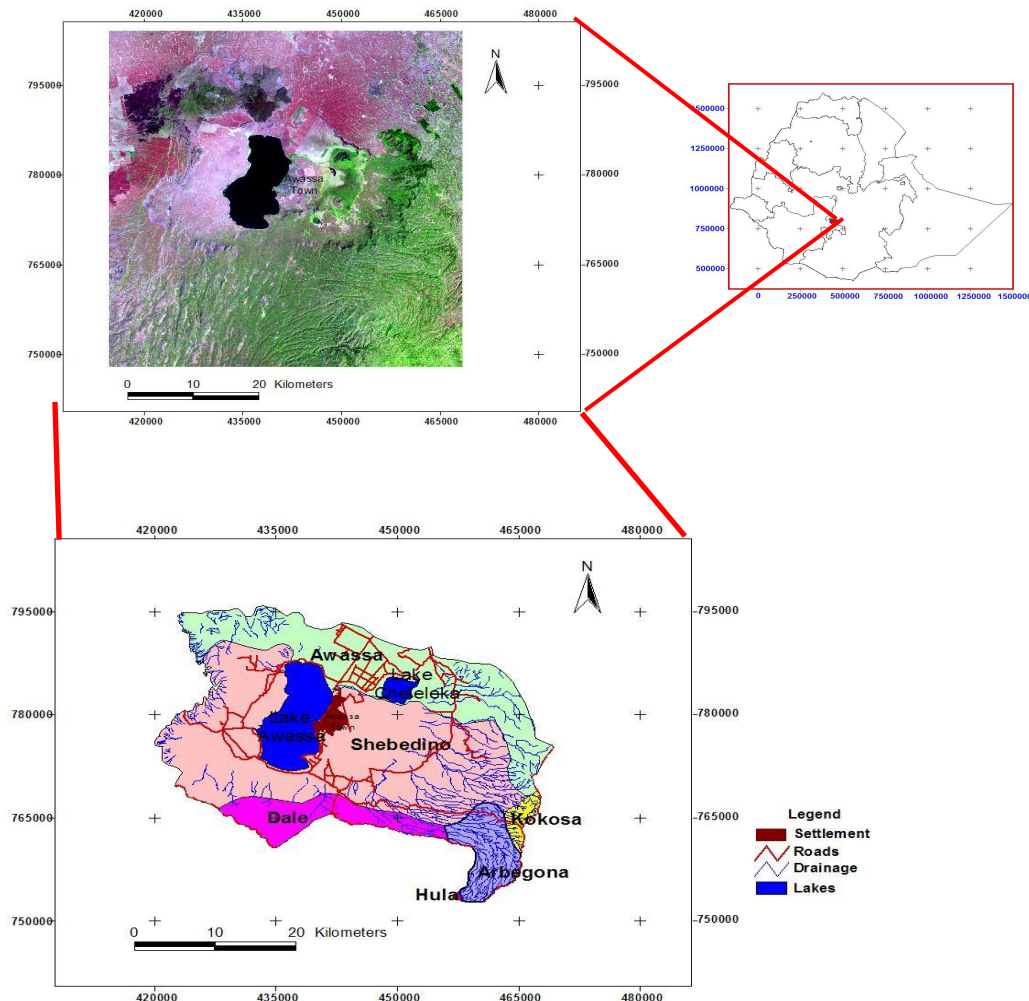


Figure 4. Location Map of the Study Area.

3.2 Climate

The Awassa catchment is affected by the north-south movement of ITCZ (Inter Tropical Convergence Zone) almost through out the year, MoWR, (2000). The Awassa area has a sub-humid climate, FAO, (1984) with mean annual precipitation of about 963 mm. The mean minimum precipitation is 17.8 mm in December during the dry season and the mean maximum precipitation is 119.8mm in August, during the rainy season. Temperatures vary between 12⁰C in rainy season and 27⁰C during the dry season. The daily sunshine hours ranges between 4 hours during the rainy season and 9 hours during the dry season and the relative humidity varies between 48% and 73% over the year at 1800 local station. The average wind speed recorded is between 0.7 and 1.3m/second at 2m elevation with dominant direction from northeast to southwest.

3.3 Physiography and Drainage

The study area, Awassa town and its surrounding is situated in a large volcano-tectonic collapse (Awassa caldera) at the eastern margin of the MER, having a diameter of 40-50Km, Woldegabriel et al., (1986). The catchment is characterized by flat lying topography with some scattered hills, like Mount Tabor (1800m), Mount Alamura (2019m). The depression is bounded by remnants of the caldera wall and some regional and local faults. The eastern scarp forms the edge of the rift whose average throw is about 500 m, whereas the southern and western scarps of the caldera which roughly form an arc of a circle, are relatively lower with a 250 m elevation difference from the floor.

Lake Awassa is a closed catchment with no surface water out flow. It is fed by some ephemeral streams from the west and northwest and by Tikurwuha River from the east, which is the only perennial river that flows to the lake. The former Lake Cheleleka is converted to swamp since sediments that are coming from the eastern side of the scarp are partly deposited in this area.

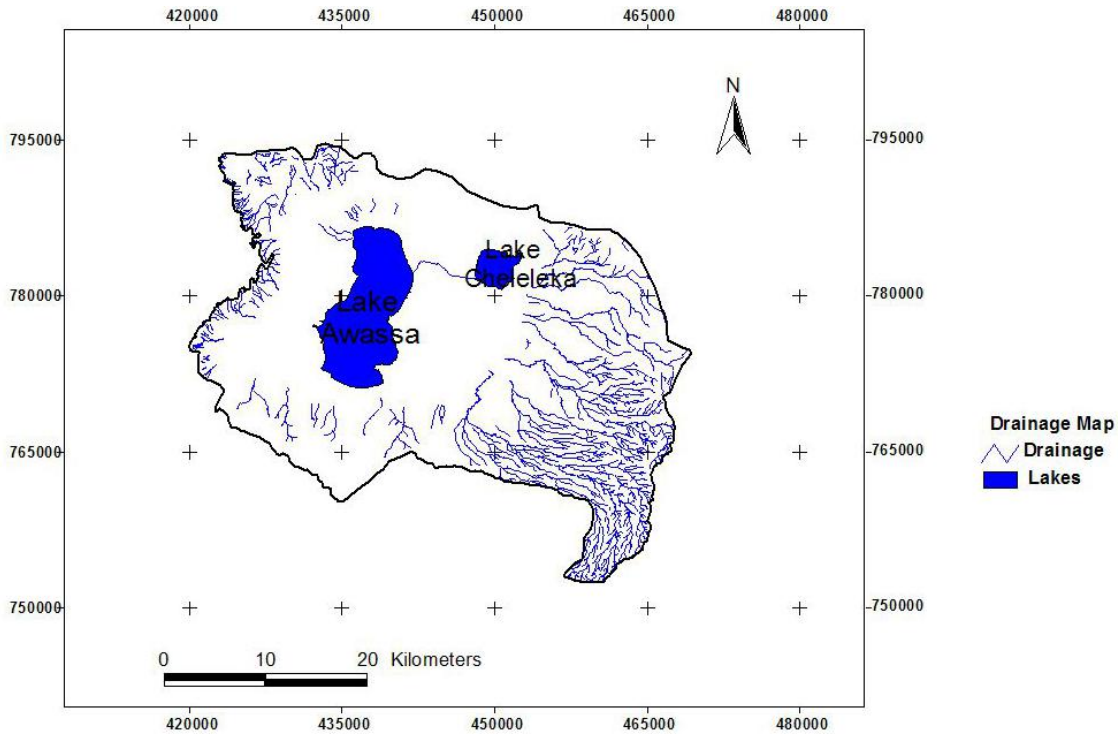


Figure 5. Drainage System of Lake Awassa Catchment.

According to Dessie Nedaw (1997), the Awassa catchment is poorly drained surficially, figure 5. Unwelded pumicious pyroclastic rocks with no significant drainage system cover the western boundaries of the catchment. The western upland shows triangular facets, which are remnants of erosion indicating that the rain that falls on the upland topography goes down the slope to the closed sub-catchment of Muleti area. There are big ground fractures that are formed in this sub-catchment, but these does not have any surface relationship with the lake, so there is no risk of lake sedimentation. The eastern side is covered by fractured ignimbrites and tuffs. Rivers from the eastern side drain in radial pattern to cheleleka swamp which serves as a regulator of sediment and water flow to the lake.

3.4 General Geological Setting

Volcanic and tectonic events in the study area constitute an essential part of the volcano-tectonic history of the Main Ethiopian Rift (MER). The MER is the northern segment of the east African Continental Rift system separating the 1000km wide uplift Ethiopian volcanic province asymmetrically into the north-west and south-east plateau, Zemenu, (2000). MER is

a graben, about 800Km long and up to 60-80Km wide, having a mean elevation of 1600m Mohr, (1967). The MER is characterized by a great number of step faults, which produced a total altitude difference of more than 1500m, Di paola, (1972), between the top of the plateau and the floor of the rift. According to Mohr, (1967), Di paola (1972), all these normal step faults of various dimensions and throws, are commonly arranged in an en echelon style and trending mainly along NNE-SSW and rarely along NE-SW, N-S and NW-SE directions. The youngest structural deformation of the Ethiopian Rift Valley is the Wonji Fault Belt (WFB), which is characterized by the prominent N-S to NNE-SSW trending rift floor normal and occasionally dilatation faults, Mohr, (1962). According to, Woldegebriel, et al., (in press), the WFB has been forced into en echelon transpositions in order to remain with in the rift margin envelop. These sites of transposition is characterized by very recent and closely spaced normal faults, extensional fractures, Chorowicz et al., (1994) and other fault oriented open structures with significant volumes of fissural basalts and related differentiation products of very recent age and even historical, Di paola (1976). According to Mohr & Wood (1978), the rift floor comprises calderas that are generally elliptical in plan view with the long axes with length between 2 and 17 km.

The Awassa catchment lies in the central part of Main Ethiopian Rift (MER). The Main Ethiopian Rift is divided based on structural features into three geographic areas; represented by the northern (Fentale-Nazeret), Central (Nazeret-Awassa) and southern (Awassa-Konso) sectors, Woldegebriel et al., (1990). The central sector, to which the Awassa lake basin belongs, is a symmetric rift basin where both sides of the rift margins are fully defined except in the region between Guraghe and Sodo of the western escarpment and in the Shashemene area of the eastern margin, Woldegebriel et al., (in press. According to Woldegebriel (1990), most of the geological sections exposed along the rift margins are dominated by Tertiary volcanic rocks except for few locations where crystalline basement is unconformably overlain by Mesozoic marine sedimentary and /or Tertiary volcanic rocks.

The formation of MER is attributed to extensional tectonics, Mohr (1967), Kazmin & Berhe (1978), though the direction of relative motion between blocks (extension direction) is still controversial. From fault slip analysis two different directions have been proposed, northwest-

southeast, Chorowicz et al., (1994) and northeast-southwest, Boccaletti et al., (1994). Moreover, there is no universal agreement as to when the rift system began to develop. Many authors relate the development of the East African Rift to the Afro-Arabian doming in lower Tertiary times. On the other hand, Mohr (1967), described the Afro –Arabian rift system as an expression of a tectonic zone of weakness in the lithosphere which dates back to the Precambrian. According to Woldegebriel et al., (1990), the development of the rift has been episodic rather than continuous, and a two-stage rift development is proposed based on structural and stratigraphic relationships from the central sector of the MER. The initial stage was characterized by the development of a series of half grabens along the rift with alternating polarity (in late Oligocene or Miocene) and a second phase of symmetrical rifts that evolved from these half grabens in late Miocene and early Pliocene times. According to the same author, the present symmetrical rift is fully formed by 3.5 Ma. The evolution of the central sector of the MER is characterized by widespread and voluminous mafic eruption in the oligocene that were repeated during the Miocene times.

3.4.1 Tectonics

The tectonic history of the present study area shares the tectonic activity and history of the MER. Batur et al., attributed the major uplift and graben faulting in the central sector of the MER to the early Pleistocene, however, Woldegebriel et al., (1987), has presented abundant evidence signifying that faulting coincident or nearly coincident with the present margin has had longer episodic history. According to Woldegebriel et al., (1987), faulting started approximately in the early Miocene (as evidenced by the intercalated fluvial sediments with Oligocene lavas at Hegre Selam) and there were major episodes in the late Miocene (topographic confinement of the 8.3 ignimbrite to the present main Guraghe escarpment), the Pliocene (the containment of the 3.6 Ma crystal rich tuff of the Butajira Ignimbrite with the rift margin) and the late Quaternary. The eastern rift margin of the MER is fully developed along its length except in the northeastern part of the Awassa caldera area. According to Woldegebriel, (1987), the age of the rocks exposed on the rift wall varies from upper Pliocene to Miocene in the middle section and Oligocene to Pliocene in the southern part of the central sector. The same author states, the total composite scarp height increases from the NE (Chilalo area), where the scarp rarely exceeds 100m exposing Quaternary rocks, to the SW (Heger

Selam), where fault scarps of 500-800m are associated with Pliocene and other lavas. This disparity has been caused by in filling of both lavas from the shield volcanoes at the rift shoulder flowing towards the rift and by ignimbrite from the rift floor where volcanism exceeded the rate of subsidence, Woldegebriel, (1987).

The Pliocene age Awassa Caldera, Mohr, (1983), Woldegebriel, (1987), Woldegebriel et al.,(1990), underlain by ignimbrite, Di Paola, (1972), is by far the largest in the east African rift system, spanning half the breadth of the rift floor, approximately 50x40 km, Woldegebriel, (1987). According to Zemenu, (2000), the Awassa caldera contains a younger 15km diameter Corbetti caldera nested within it near the northern margin. It is located at the intersection of the rift axis by a major north-westerly lineaments on the western plateau marked by strato volcanoes and three other small calderas, the Wagbeta caldera complex, extending 400km from Awassa, Woldegebriel et al, (1986).

According to Zemenu, (2000), the main Awassa caldera is asymmetrically overlapped and displaced against the eastern rift escarpment while Corbetti is along the rift axis. These calderas are younger features that are slightly eroded along the eastern marginal graben of the rift. More than 500m of mostly air fall ash and ignimbrite are exposed in the caldera wall against the eastern escarpment, Woldegebriel, (1987). However, the northern and southern walls of the main caldera are subdued perhaps due to rifting and burial along the MER, Zemenu, (2000). According to the same author, the northeastern wall of the Awassa caldera is poorly defined, though a NW-SE Werencha fault shows some of the stratigraphic successions. This fault scarp exposes crystal rich sediment, columnar jointed light gray ignimbrite and young pyroclastic on the west of Shashemene and the western wall of the Awassa caldera, Abaya ridge, which is well preserved and affected by NNE-SSW regional fault, the WFB.

The floor of the caldera is highly dissected by NNE-SSW normal faults cutting the young pyroclastic and lacustrine deposits especially, in southern and western side of the caldera and some transverse escarpment with a northerly down throw is evident in the southern side of lake Awassa which has limited the size that the lake had, Zemenu, (2000). Korme et al., (1997), reported the presence of deep-seated extension fractures in the study area, they also reported the occurrence of short and steep hills of trachyte and /or rhyolite lava necks, commonly associated with calderas.

3.5 Stratigraphy of the study area

(Zemenu, 2000), subdivided the main formations in the area into five lithologic units, figure 6, based on previous works and field investigations as follows:

3.5.1 Basalt and Ignimbrites of the Plateau Trap Series (Late Miocene)

Basalt and ignimbrites are exposed at quarry site close to the base of the eastern caldera wall where the caldera wall is asymmetrically overlapped against the eastern rift escarpment. According to Woldegebriel et al., (1990), these rocks are geochronologically grouped under the Guraghe basalts and consist of fine-grained mugearite overlain by 30 to 50m thick welded tuff dominated by collapsed pumice clasts and sparse feldspar phenocryst. The Mega Awassa caldera is thought to be constructed on these rocks, Woldegebriel (1987), Woldegebriel et al., (1990).

3.5.2 Old Alkaline and Peralkaline Silicic Rocks (Late Pliocene- Early Pliocene)

Rift pyroclastics and old rhyolite lava formations cover large part of the caldera. Eastern wall of the caldera overlying the late Miocene formations is covered by pumiceous deposits, laminated surge deposits which show cross bedding, a perlitic crystal rich tuff characterized by strongly welded shards, pumice fragments and few lithics having a total thickness of about 200m. The age of these deposits range from 3.7 to 1.6 Ma, Woldegebriel (1987). Rocks of these groups are also exposed on the western side of lake Awassa, making 200m thick unwelded pumice out crop. Rhyolite ridges at Wondogenet (Mt Abaro), at southwestern edge of the Awassa caldera which has an age of 2.45 Ma, Woldegebriel (1987), and probably the rhyolite necks at the south eastern side of Awassa town are also included in this group.

3.5.3 Recent Basaltic Lava Flows, Basaltic Hyaloclastites and Scoria Cone (Recent Pleistocene)

It is represented by small monogenic cones that are sprinkled forming the only relief in the floor of the caldera. The scoria is usually found associated with scoracious basalt flows having

a color ranging from dark brown to reddish brown and with grain size ranging from lapilli to bomb size. Flat-topped hyaloclastites having a color ranging from yellowish to brown consisting of fine glassy material containing large blocks of basaltic, rhyolitic and ignimbritic materials of ages 0.5 ± 0.06 Ma (Mohr et al., (1980),) are exposed in the eastern side of the Awassa Lake.

3.5.4 Recent Acidic Volcanics

These are the youngest volcanic products that are exposed in the north, east and northwestern part of the lake catchment. Most of these rocks are composed of pyroclastics, such as unwedded pumice flows, pumice falls, ashes and rhyolites associated with obsidian flows. The products of Chibbi volcano, the rhyolite beds exposed on the NW-SE transfer fault east of Chibbi, the pyroclastic deposits overlying the Pliocene deposits on the eastern and western caldera wall belong to this unit.

3.5.5 Volcano-Lacustrine Deposits

The volcano lacustrine deposits, which cover mostly the floor of the caldera, are the only non-volcanic formations in the area. These lacustrine deposits are the result of the recession of lake Awassa, which occupied larger part of the caldera in the past. According to Telford (1998), most of the lake sediments are intercalated with recent volcanic materials, which are evidenced in borehole logs and sediment cores drilled on the lake floor.

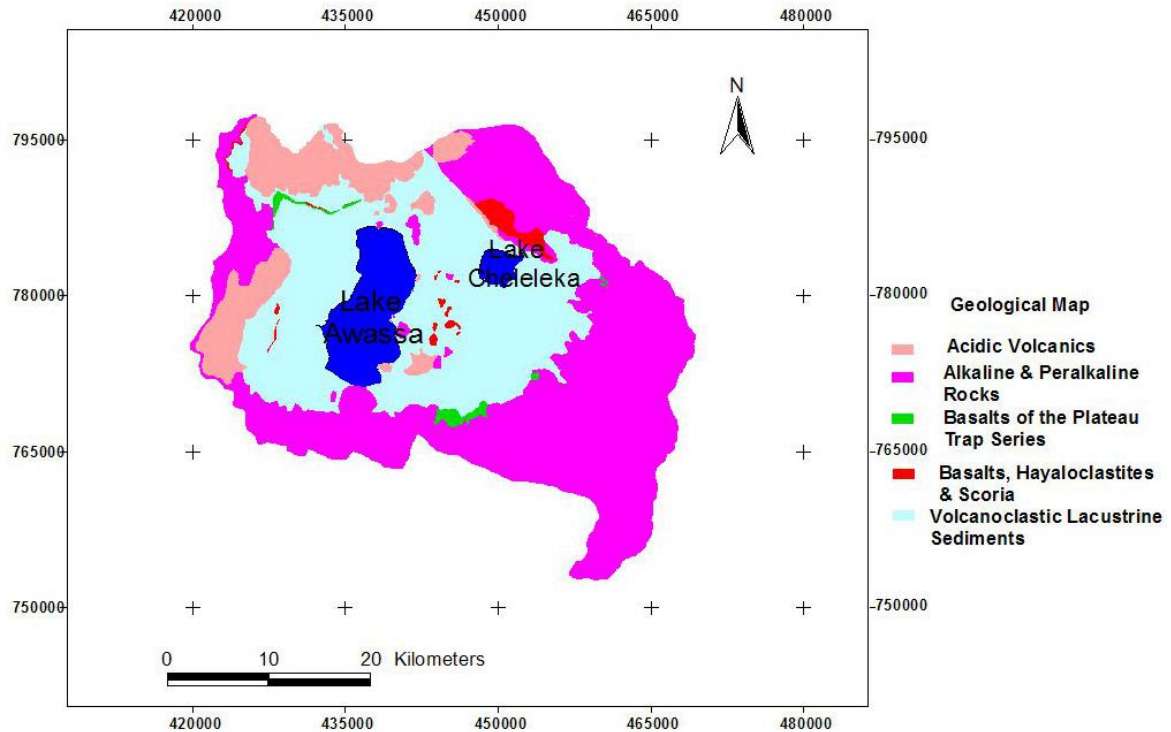


Figure 6. Geological Map of the Study Area.

3.6 Geological Structure

The main Ethiopian Rift Valley is affected by NE–SW- or NNE– SSW-trending normal faults, Mohr, (1967), Di Paola, (1972). There are also suggestions for the presence of E–W direction of extensions which can be related to an oblique system of rifting, Boccaletti et al., (1998). According to Ayalew et.al., (2004), the ground cracks are lined semi-parallel to each other figure 7, and to the distant fault scarp and mountain ridges showing similar trend to the main Ethiopian rift. The ground cracks show no vertical displacement or horizontal offset. Field survey and geophysical investigations were conducted in order to figure out the cause and the mechanism of ground crack formation in the Ethiopian rift. Crack one having a length 150m and depth 3m was first reported in April 1996 when a massive flood following an above normal precipitation inundated the region. Crack two developed in April (1997), Yirgu et al., (1997), with a grand reactivation in March 1998, Muleta and Welde Aregay, (1998). The total length of this crack was a little higher than 800 m and its visible depths were in the range of 3–8 m. Crack 3 was formed in April 1996, almost at the same time as Crack one, and also

widened again in April 1997, Yirgu et al., (1997), with reactivation in March 1998, Muleta and Welde Aregay, (1998). The length of crack 3 is 2.4 Km and 8-12m deep.

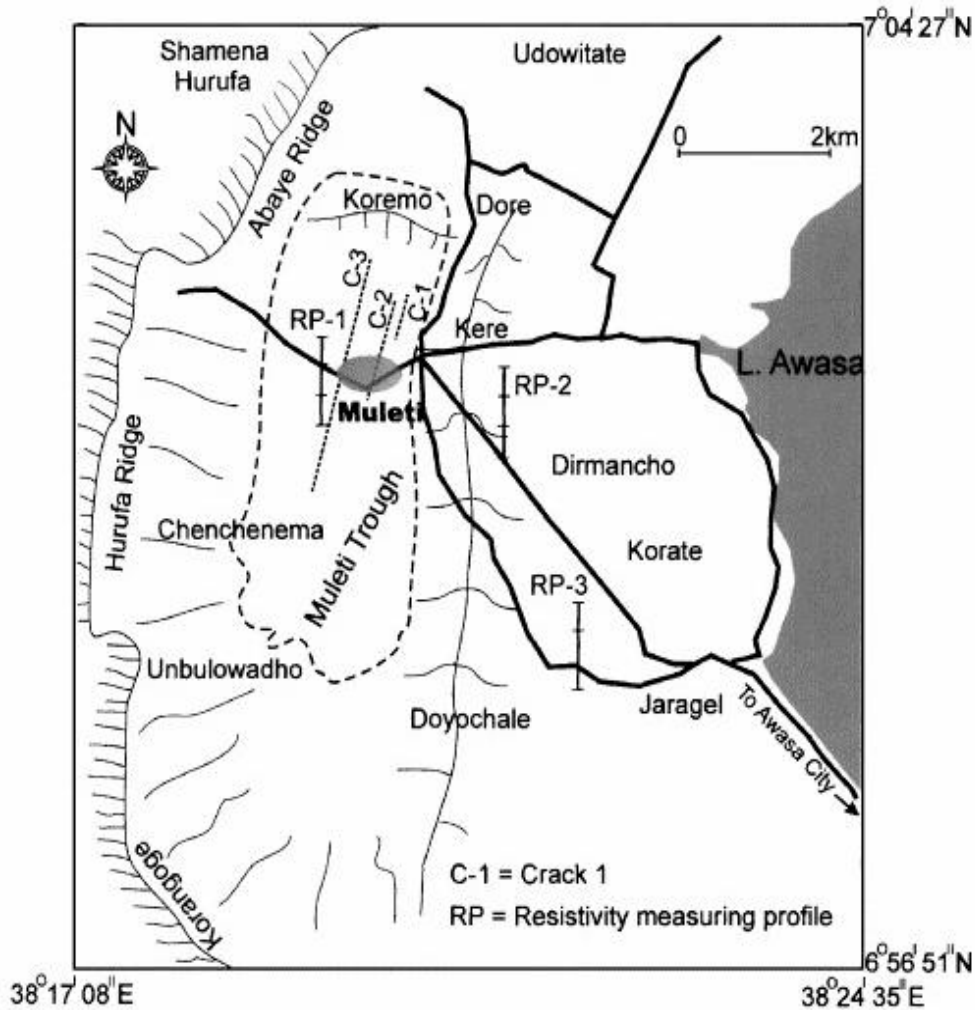


Figure 7. Showing the Location of Recent Cracks (After Ayalew et al 2004)



Figure 8. One of the Recent Cracks in Muleti area.

As discussed by Ayalew et.al.,(2004) , the cause of ground crack in Muleti area has no relation with deep mechanisms such as aquifer system compactions and increased horizontal seepage stresses. The possible causes of ground cracks in Muleti area can be an upward propagating aseismic elastic strain which originates at depth without the formation of bedrock faults, which favors the formation of cracks by piping and hydro compaction.

3.7 Land use and Land cover

The eastern escarpment of the catchment is covered by vegetation and the lowlands close to the foot of the escarpment are covered with mixed type vegetation, while the poorly drained western part of the catchment has no vegetation cover. The North West mountainous area formed of obsidian rock formation is covered scrub and bush.

The Water works construction supervision enterprise has prepared a land cover map of 1965 based on 1965 and 1975 areal photograph interpretations and ground survey figure 9. According to the maps of 1965 and 1998 the catchment has revealed considerable land use

change. The land use in 1998, figure 10, has shown that dense wood land and bushy wood land have been changed to open bush land, open grass land, and cultivated land by about 70% as compared to the situation of the lake watershed in 1965. This condition is believed to have come due to increase in population and demand for firewood and construction materials, household furniture, according to the report of W.W.D.S.E, (2001). As a result degradation of natural vegetation cover and continuous process of erosion are becoming evident in the catchment. Land use land cover of the current situation is discussed in chapter four.

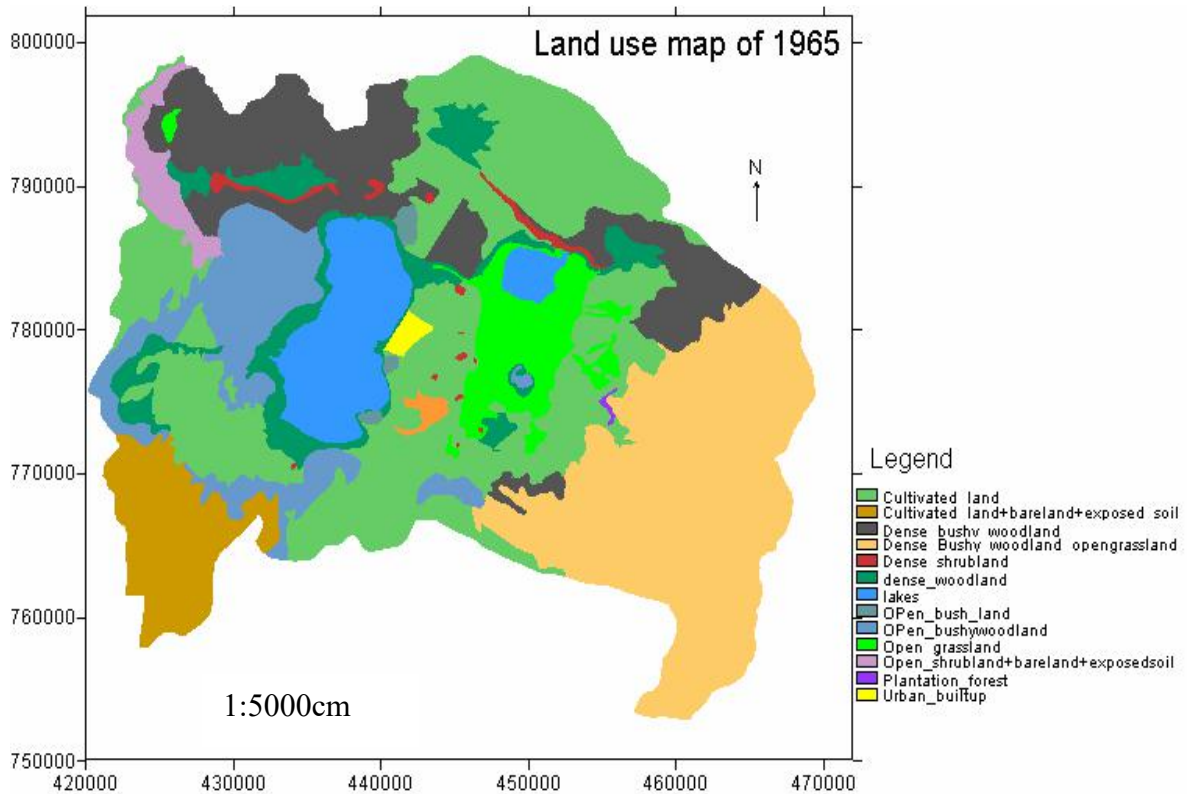


Figure 9.Land Use Map of Lake Awassa Catchment-1965 (adopted from W.W.D.S.E, 2001)

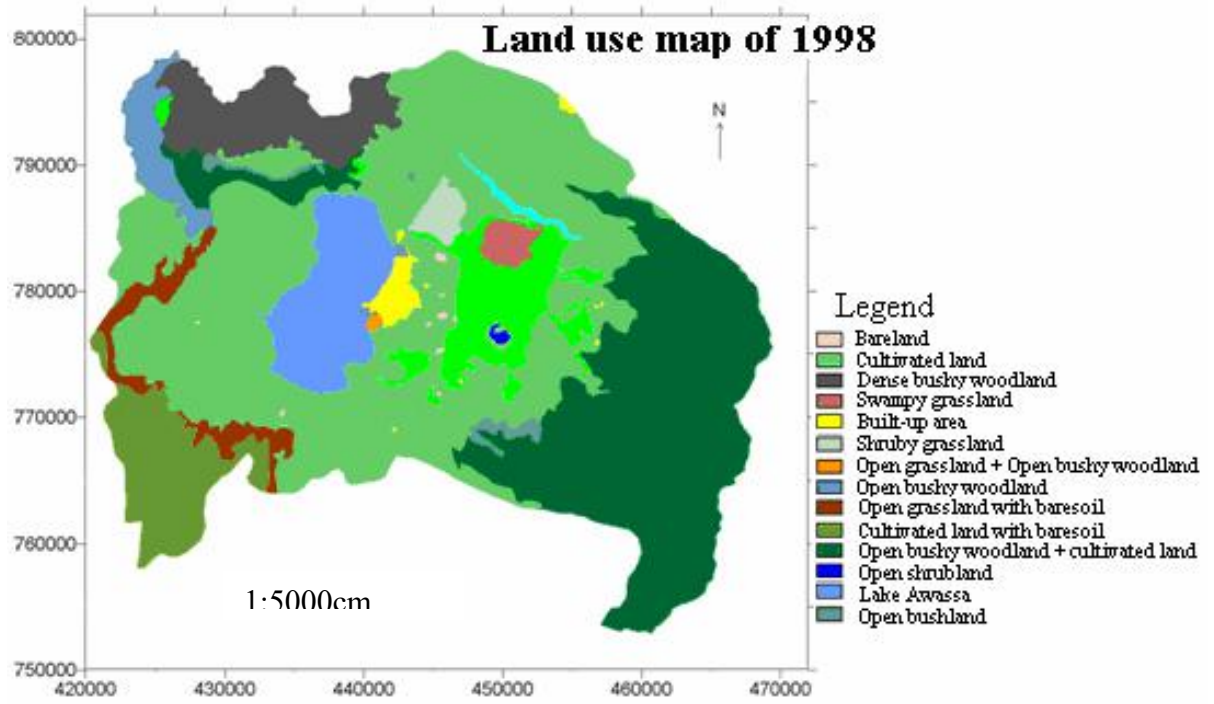


Figure 10 Land Use Map of Lake Awassa Catchment-1998 (adopted from W.W.D.S.E, 2001)

4. CHAPTER FOUR

4.1 Analyses and Discussion

Soil erosion assessment has gained attention because it can be used as a base for developing effective soil and water conservation plans to reduce soil erosion. In this regard, there has not been a locally developed soil erosion model for erosion risk assessment. Therefore, scientists have been relying on models developed in USA and European countries, which are then adapted to local conditions. One such empirical model is the Universal Soil Loss Equation (USLE) that was designed for the USA east of the Rocky Mountains. As discussed in previous chapters Ethiopia is among the most degraded lands in Africa, El-Swaify and Hurni, (1996). The Awassa catchment is being affected by soil erosion due to deforestation, overgrazing. Therefore, assessment of soil erosion rate is important in order to quantify the amount of soil loss and to propose conservation measures.

When assessing erosion risk at a district or regional level, the use of Geographical Information systems (GIS) becomes an important and powerful tool. According to Mati et al., (2001), the application of GIS has increased in the last decade with the availability of digital data, cheaper and more user-friendly software and the need to handle large spatially oriented database.

4.2 The Universal Soil Loss Equation (USLE)

Though, USLE was developed for USA, its simplicity and black-box characteristics make it easily adaptable to other environments, Mati et al., (2001). Therefore, according to, Dissmeyer & Foster, (1980), it has become one of the most widely used models for predicting soil loss in many countries.

The equation was designed for interrill and rill erosion (Wischmeier and Smith 1978) assessment. The equation considers Rainfall erosivity (R), Soil erodibility (K), Slope length (L), Slope gradient (S), Land cover (C), Land management (P). The USLE model was modified and adapted to Ethiopian conditions based on recommendations of the Soil Conservation Research Project (SCRCP) by Hurni (1985).

4.3 Determination of various factors of USLE

4.3.1 Rain fall Erosivity (R Factor)

The concept of rainfall erosivity presented by Hudson (1971), Wischmeier and Smith (1978), describes the erosivity as an interaction between kinetic energy of raindrops and the soil surface. This can result in a greater or lower degree of detachment and down slope transport of soil particles according to the amount of energy and intensity of rain by considering the same soil type, the same topographic conditions, soil cover, and management. Typically, rainfall erosivity (R) is computed as total storm energy multiplied by the maximum 30min intensity, Renard et al., (1997).

$$R = EI_{30}$$

Where;

R = Rainfall erosivity factor in metric unit

E = Rainfall Kinetic Energy in Jm^{-2}

I₃₀ = 30 minutes rainfall intensity, $mmhr^{-1}$

But the application of the above formula for calculating the rainfall erosivity is limited in Ethiopia due to the absence of data on rainfall kinetic energy and rainfall intensity. So calculation of the rainfall erosivity factor is done using the formula that was modified and adapted to Ethiopian condition by based on recommendations of the Soil Conservation Research Project (SCRCP) by Hurni (1985) (Appendix 1).

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

P is mean annual precipitation (mm)

R is Rainfall erosivity factor.

Rainfall data of five stations Awassa, Wondogenet, Shashemene, Yirba Dibancho, Haisa Witto were used for this study. Mean annual rainfall data of ten years (1993-2002G.C) were used because these data were more or less complete. And stations with incomplete data for some months were filled by nearest neighborhood interpolation technique. The R factor was calculated using the above formula, table 4 and these data's were converted to surface with 100m grid cell using Arcview 3.2, figure 11.

Station Name	Mean Annual Rainfall (mm)	Rainfall erosivity factor, R
AWASSA	956.74	529.57
WONDGENET	1158.93	643.20
SHASHEMENE	892.765	493.61
YIRBA DIBANCHO	1070.695	593.61
HAISA WITTO	958.06	530.31

Table 4. Mean Annual Rainfall and Calculated R factor of the Stations.

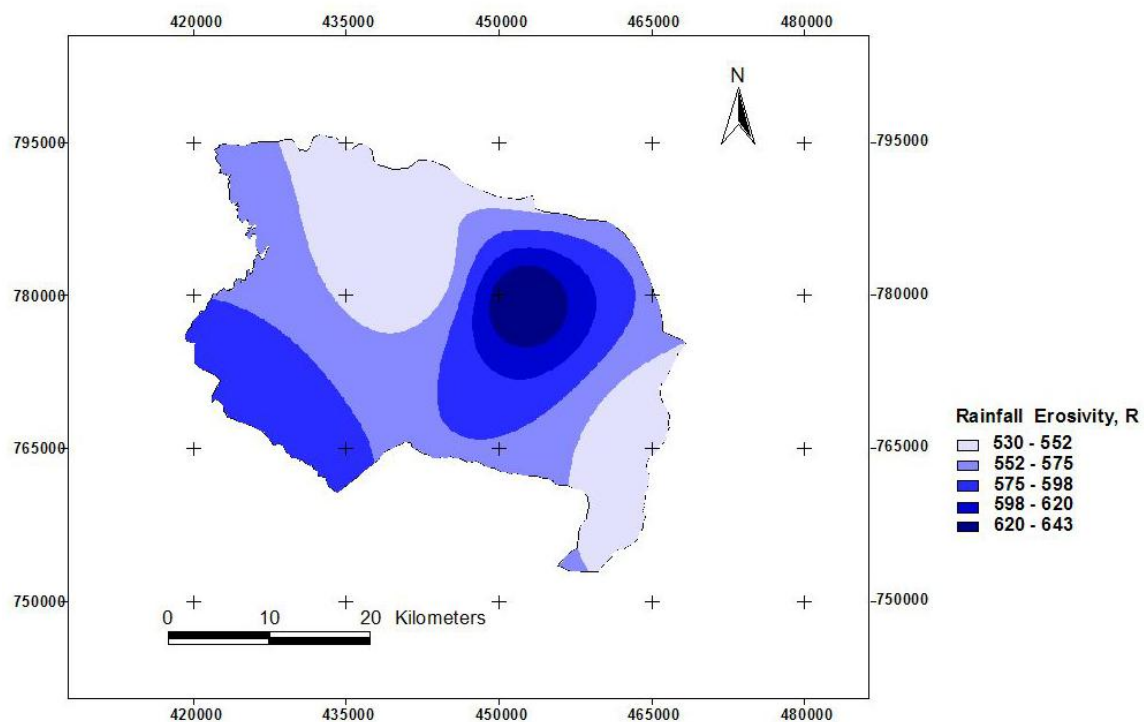


Figure 11. Rainfall Erosivity Factor, R of the Study Area.

4.3.2 Soil Erodibility (K factor)

The soil erodibility (K factor) is a quantitative value, which is experimentally determined taking into consideration the soil texture and structure, the organic matter content and the permeability, Wischmeier and Smith, (1978). Soil erodibility is a measure of the susceptibility of a given soil to erosion by rainfall and runoff. Eleven different soil categories, table 5, were identified in the study area after clipping the ETHIO-GIS soil map with the boundary, figure

12. Finally the soil types were reclassified to K factor values that were adapted to Ethiopia by Hurni (1985) (Appendix 1) based on the FAO Soil classification.

Soil type	Soil erodibility factor, K
Calcic xerosols	0.20
Chromic luvisols	0.15
Chromic vertisols	0.20
Eutric fluvisols	0.15
Eutric nitisols	0.10
Eutric regosols	0.15
Eutric vertisols	0.20
Mollic andosols	0.10
Orthic luvisols	0.15
Pellic vertisols	0.20
Vitric andosols	0.15
No soil	0.00

Table 5. Showing Different Soil types and their corresponding K factor.

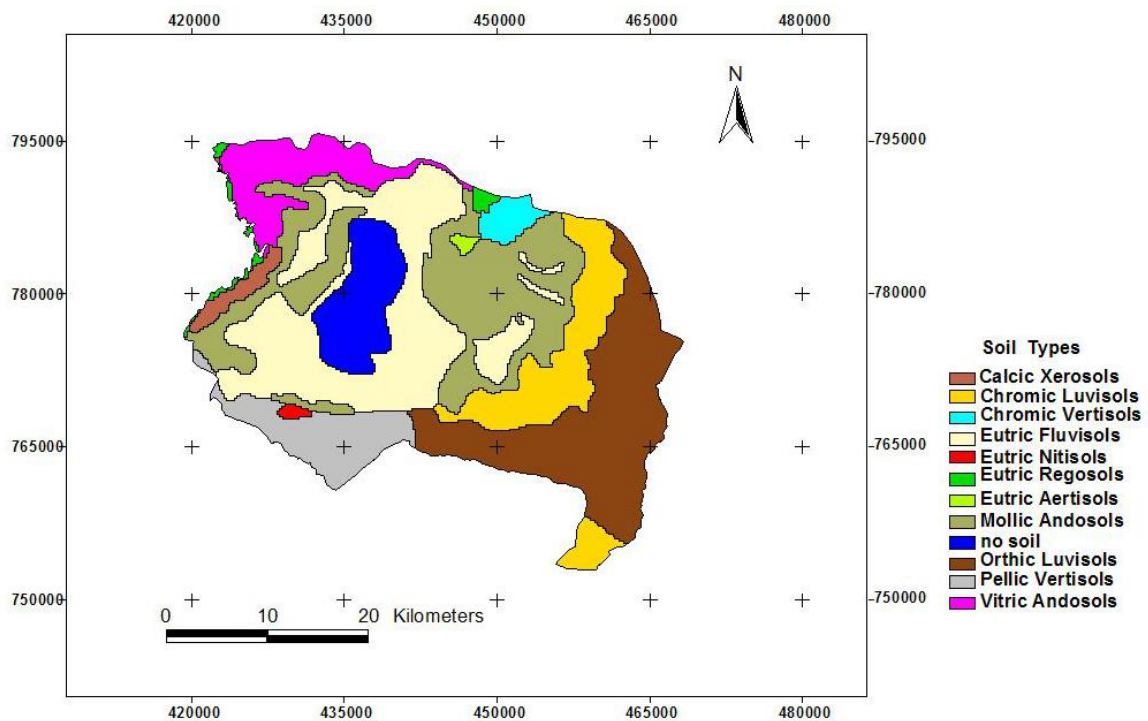


Figure 12. Showing Soil type in the Study Area.

After assigning K factors for the different soil types in the area, the resulting map was converted to a grid map of 100m cell size taking the k factors as values for the cells, figure 13.

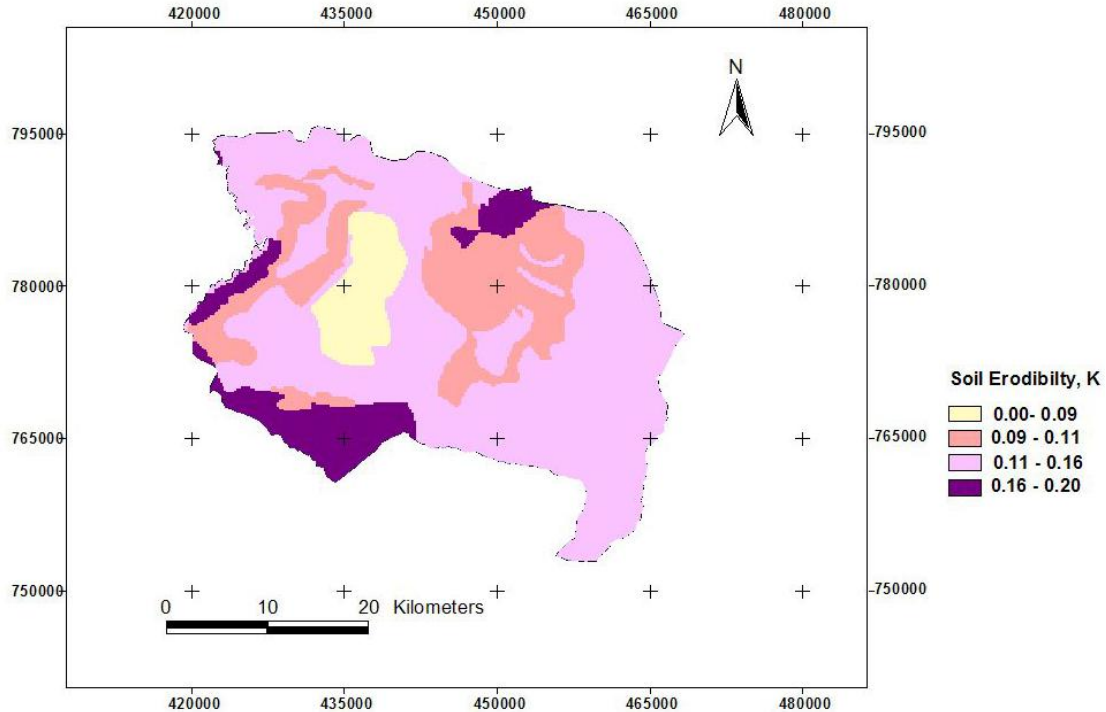


Figure 13. Showing the Soil Erodibility.

4.3.3 Slope Gradient Factor (S factor)

Slope steepness factor is the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions, Wischmeier and Smith, (1978).

The topographic factor S is used to adjust the erosion rate based upon the steepness of the slope. The erosivity of runoff increases with the velocity of the runoff water and steep slopes produce high runoff velocities thus, soil loss increases with increasing slope due to the greater volume of runoff accumulating on the longer slope lengths.

DEM was developed for the study area using 1:50,000 scale topographic maps of Awassa, Wijjira, Shashemene, and Leku with contour intervals of 20m after on screen digitizing of the topographic maps on Arcview 3.2. From the DEM a slope map of 100m grid cell size was generated, reclassification was performed and slope gradient factors, S values were assigned to each slope gradient class according to Hurni, (1985) (Appendix 1).

Eight different slope gradient classes were obtained from the slope map. About half of the study area have a slope gradient of 0-1% and rest of the study area is covered by different slope gradient classes, table 6. Figure 14 and figure 15 shows the slope gradient in % and the slope gradient factors respectively.

Class	Slope gradient (%)	Area (Km ²)	Area covered in percent (%)	Slope gradient factor, S
1	0-1	637.29	51.22	0.10
2	1-2	119.18	9.58	0.10
3	2-4	162.35	13.05	0.20
4	4-6	112.83	9.07	0.35
5	6-8	82.47	6.63	0.60
6	8-13	98.09	7.88	1.00
7	13-25	29.64	2.38	2.00
8	25-40	2.38	0.19	3.20
Total		1244.23		

Table 6. Slope gradient classes, area in km², area covered in percentage, slope gradient factors.

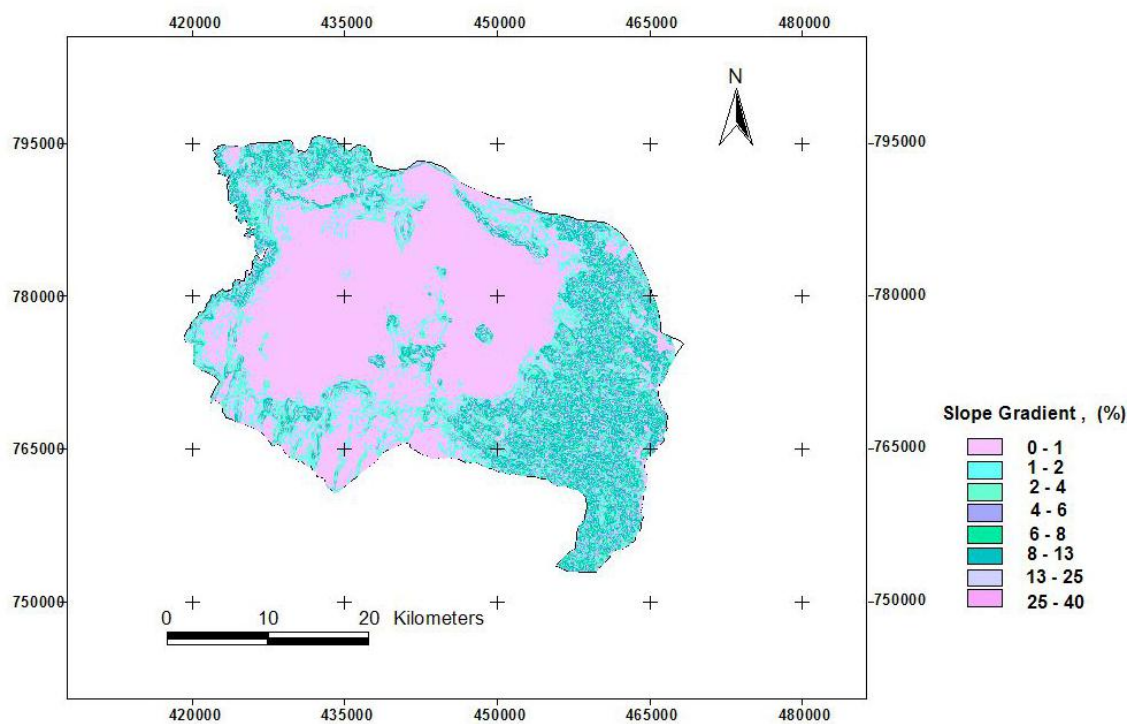


Figure 14. Showing the Slope Gradient in (%).

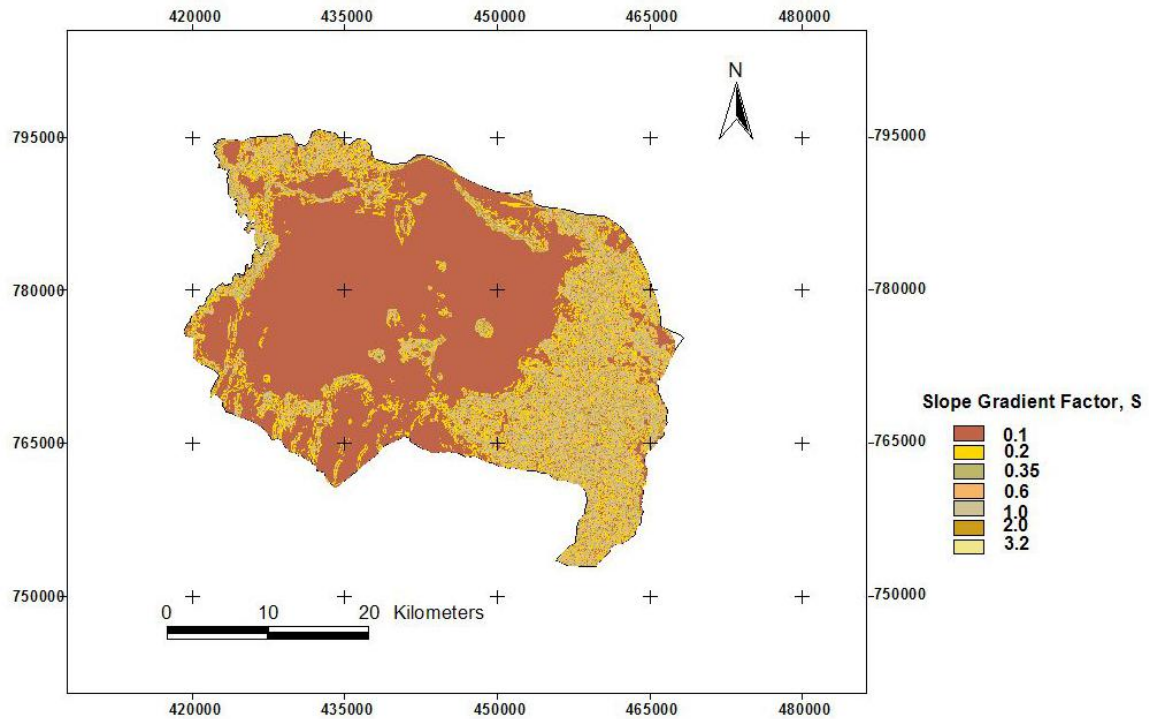


Figure 15. Showing the Slope Gradient Factor.

4.3.4 Slope Length Factor, L

Slope length factor is the ratio of soil loss from the field slope length to soil loss from a 22.1 m length under identical conditions, Wischmeier and Smith, (1978). The slope length is the distance from the point of origin of the runoff to the point where the slope steepness decreases sufficiently to cause deposition or to the point where runoff enters a well-defined channel. The slope length was derived from Digital Elevation Model (DEM) using Arcview 3.2, figure 16.

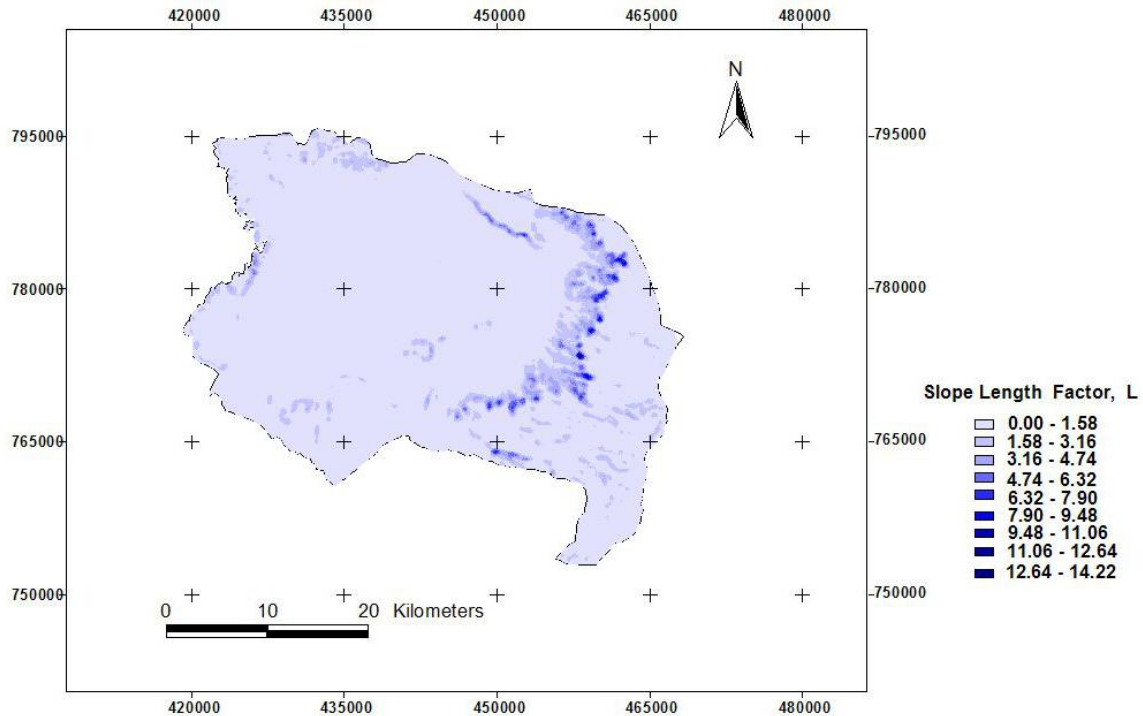


Figure 16. Showing the Slope Length Factor.

4.3.5 Cover and Management Factor

The cover and management factor, C , is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land. The USLE was originally developed for use on agricultural fields. But, it is adapted to use in nonagricultural conditions by appropriate selection of the C factor, this is often done by relating the land use conditions to some agricultural situation. The land cover factor C measures the combined effect of all the interrelated cover and management variables, Wischmeier and Smith, (1978). In this study supervised maximum likelihood classification of land sat ETM + (Dec.5, 2000) data has been carried out to prepare the land use/land cover map of the study area. Using this method the Awassa catchment has been classified into the following land use/ land cover classes, figure 17.

- Water body
- Swampy grassland
- Settlement
- Scrub and bush land

- Open bush land and wood land
- Degraded grazing land
- Degraded bare land
- Cultivated land

Fieldwork was undertaken to collect ground truth information. Initially, reconnaissance survey of the study area was carried out in order to fix up training sites. After the laboratory work is done fieldwork was carried out to confirm the relationship between the interpreted land cover and the actual land cover.

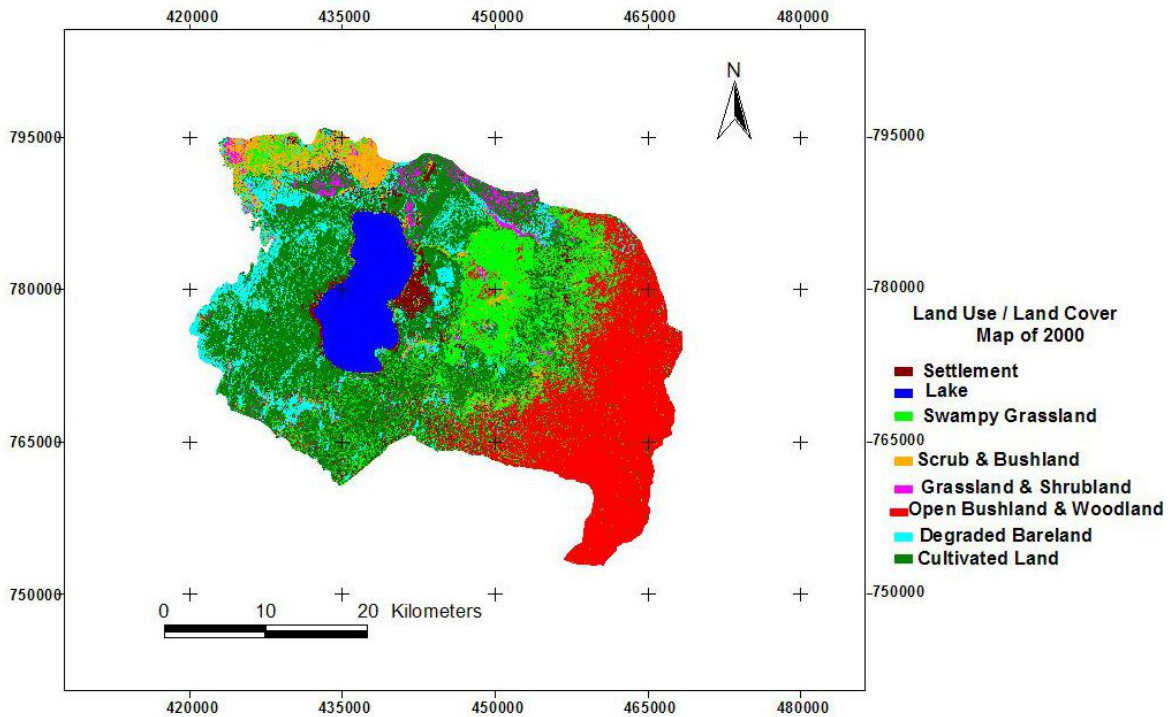


Figure 17. Land use/ Land cover of the Study Area from supervised classification.

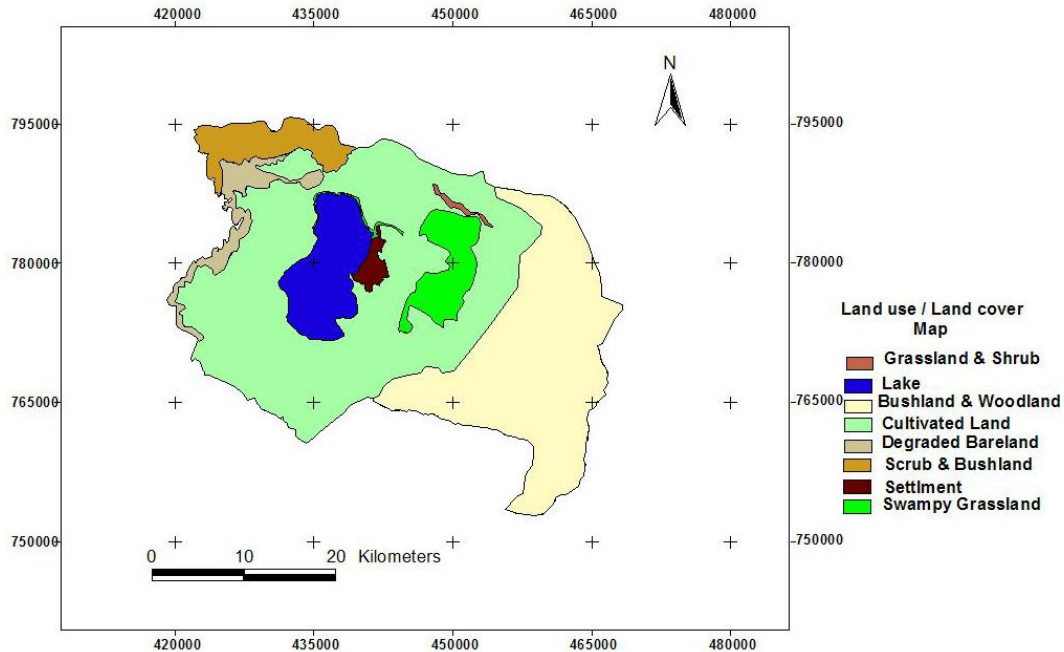


Figure 18. Land use/ Land cover of the Study Area after digitizing the different classes.

After classifying, each land cover was assigned with its corresponding C factor based on Hurni (1985) (Appendix 1) and Reusing et al., (2000) (Appendix 2), table 7. After assigning C factors for the land uses in the area, the resulting map was converted to a grid map of 100m cell size taking C factors as values for the cells, figure 19.

Land use/ land cover	C Factor
Cultivated land	0.01
Grassland & shrub	0.05
Degraded bare land	0.05
Scrub &bush land	0.01
Settlement	0.15
Lake	0.00
Swampy grassland	0.01
Bush land & woodland	0.001

Table 7. Showing Cover Management Practice.

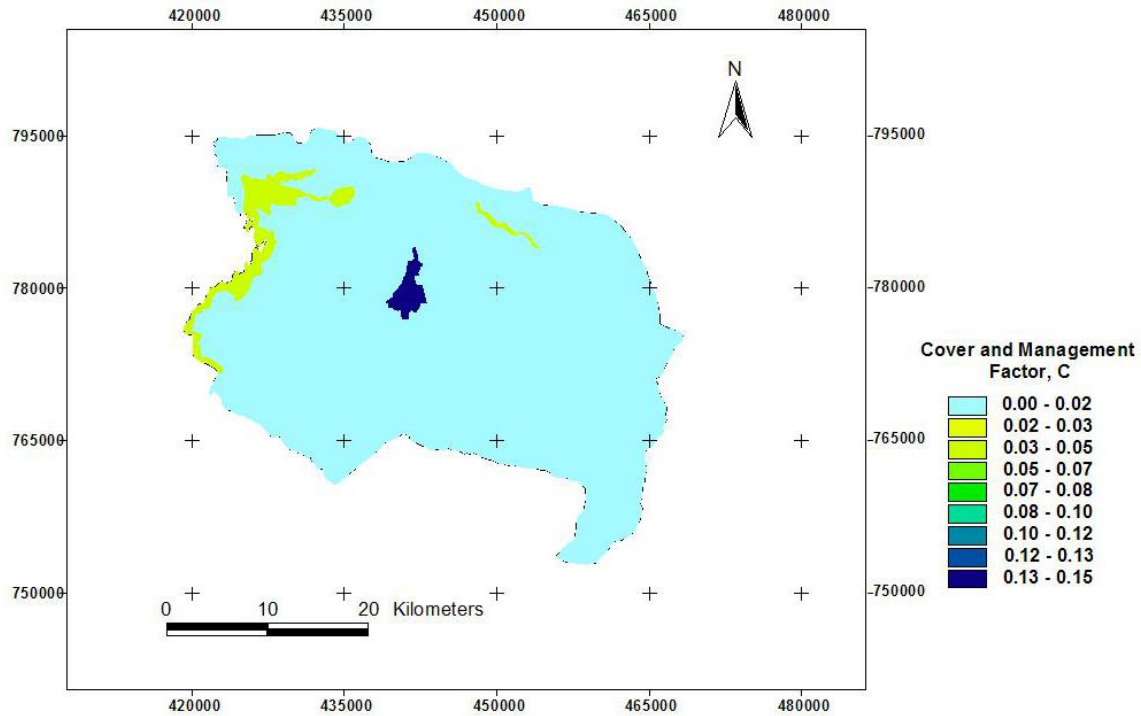


Figure 19. The Cover Management Factor of the Study Area.

4.3.6 Conservation Practice Factor, P

Conservation practice factor (P 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. P factor represents the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. Values for P-factor range from about 0.2 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices, Wischmeier and Smith, (1978). The people in the study area practice no management means in order to reduce soil erosion. The cultivation method they practice is counter plowing. The P factor was assigned to the study area based on the management practice that was adopted for Ethiopia by Hurni (1985) (Appendix 1). Accordingly, 0.9 P factor was assigned to cultivated land and the rest land cover is assigned with 0.8 P factor, table 8.

Land use/ land cover	P factor
Cultivated land	0.9
Grassland & shrub	0.8
Degraded bare land	0.8
Scrub & bush land	0.8
Settlement	0.8
Lake	0.8
Swampy grassland	0.8
Bush land & woodland	0.8

Table 8. The Conservation Practice Factor.

After assigning P factors for the land uses in the area, the resulting map was converted to a grid map of 100m cell size taking the P factors as values for the cells, figure 20.

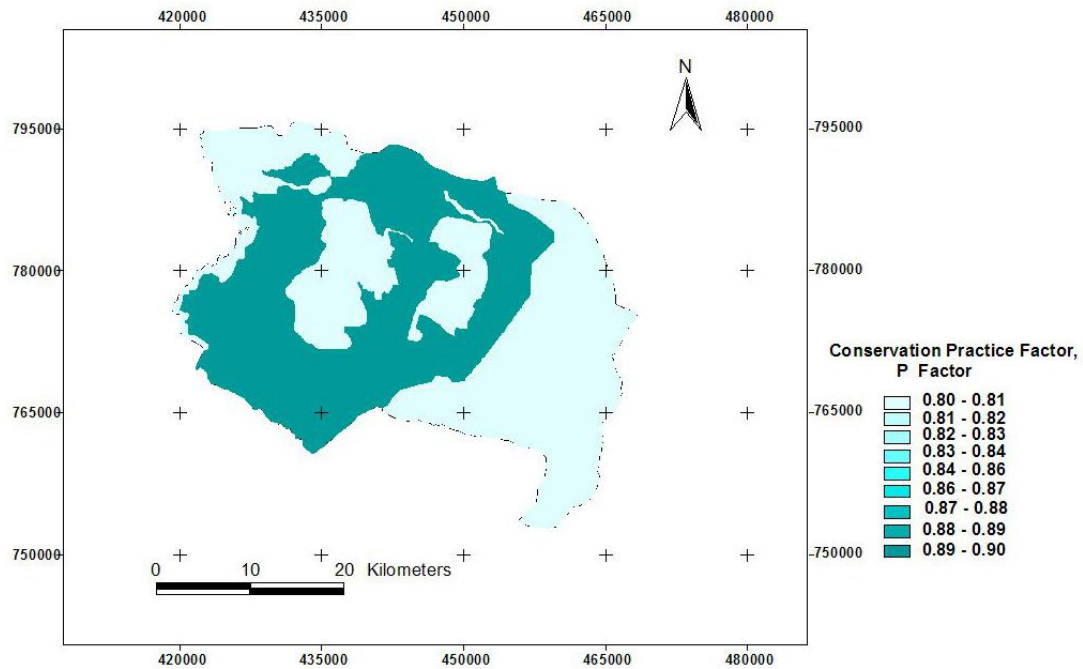


Figure 20. Conservation Practice Factor of the study area.

4.4 Results and Discussion

In this study soil erosion rate is calculated using USLE, which considers the six parameters. The actual estimation of soil loss for this study was carried out by simple map overlays, pixel by pixel, which enabled the multiplication of USLE parameters. The different ranges of soil erosion rate are given in table 9.

Soil Erosion Rate (t/ha/yr)	Erosion Potential	Area in (km²)	Area in (%)
0-5.04	Low	1179.99	94.83
5.04-10.09	Moderate	33.34	2.68
10.09-30.27	High	20.21	1.62
30.27-55.49	Very high	5.34	0.43
55.49-90.81	Extreme	3.18	0.26
90.81-201.79	Extremely high	2.19	0.18

Table 9. Soil Erosion Rates in the Study Area.

As we can see from table 9, 97.51% of the study area is characterized by low to moderate soil erosion rate (0-10.09 t/ha/yr) and 2.49% of the study area is characterized by high to extremely high soil erosion rate (10.09-201.79 t/ha/yr). Out of 97.51% of the study area that is characterized by low to moderate soil erosion rate, 88.05% of it is associated with slope gradient factor less than one. 49.32% of areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are associated with slope gradient factor greater than or equal to one. And 6.37% (1.97 km²) of those areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are related to slope length greater than or equal to 4.5. As we can see from figure 21, high to extremely high erosion rates are associated either with higher slope gradient factor or with degraded bareland, grassland and shrub land cover. Most areas with in the watershed that are covered by cultivation, scrub and bush land, swampy grassland, bush land and wood land are characterized by low to moderate soil erosion rate. While areas that are degraded bare land and

those covered by degraded grassland and shrub are characterized by high to extremely high soil erosion rate and these areas need immediate conservation measures.

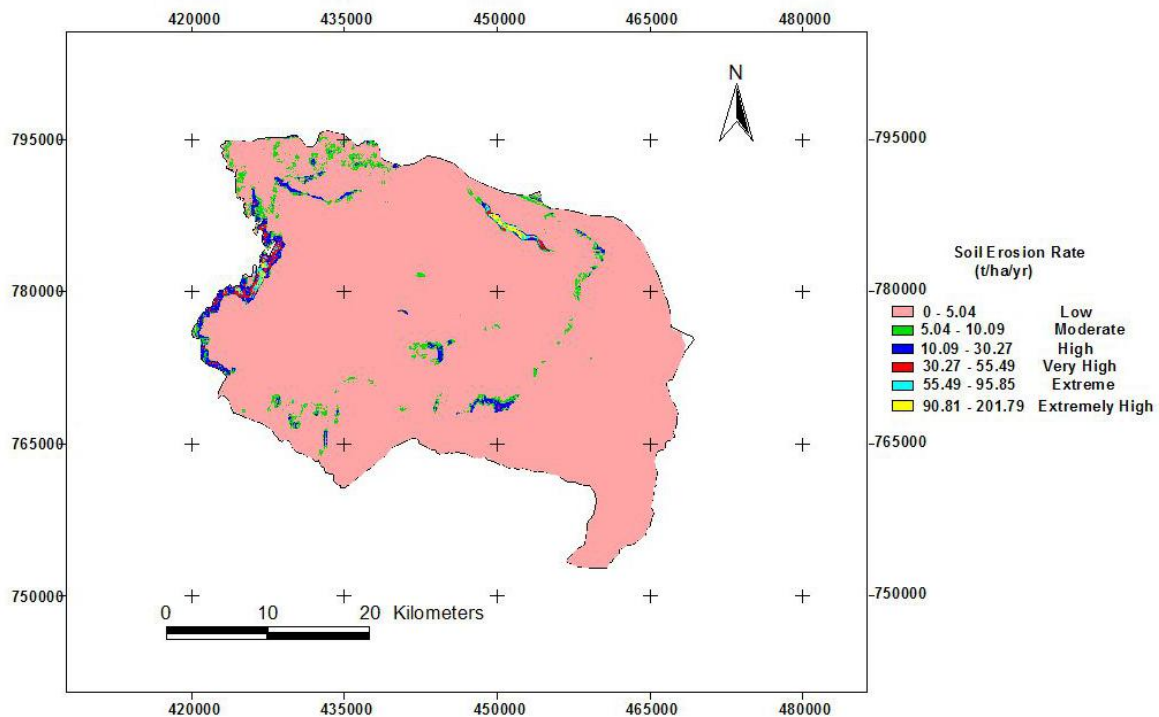


Figure 21. Soil Erosion Rate (t/ha/yr) of the Study Area.

Previous studies conducted on soil erosion assessment in Ethiopia shows different rate of soil erosion. For example, Hellden (1987), calculated a mean soil loss for Ethiopia of 150 t/ha/yr in Mertule Mariam, and studies conducted by FAO, (1986), in the Ethiopian highlands shows 100 t/ha/yr soil loss from cropped lands taking into consideration the redeposit. Another study conducted by Reusing et al., (2000), near lake Tana revealed the annual soil loss rate to be higher than of 256 t/ha and some extreme soil loss of more than 1000 t/ha/yr is expected on cultivated land with slope gradient more than 100% in the same study area. Another study by Solomon Abate, (1994), shows, soil loss from newly cleared forestland for crop production purposes to be 130 t/ha/yr. According to Hurni, (1985), a soil loss rate of 282 t/ha/yr is estimated in the Ethiopian Highlands on areas with 22 percent slope and Nitosol soil type cropped with tef. Hurni (1986), estimated that average erosion rates on currently unproductive cropland to be 70 t/ha/yr and the average erosion rate from currently used cropland are 42

t/ha/yr. Pilesjö (1992), estimated a mean soil loss rates of 88 t/ha/yr close to Wilbareg/South Shewa.

As previously mentioned, soil tolerance refers to the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically. Though there is no international soil tolerance level for tropical soils Nill et. al., (1996), 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. Thus, from the level of soil tolerance limits that are developed by the same authors we can say the amount of soil loss in the study area is tolerable at its current situation.

4.5 Soil Erosion Rate in Relation to Woredas

The woredas that are included in the Awassa catchment are Awassa, Shebedino, Arbegona, Dale, Kokosa, Hula, figure 22. The areas of the woredas with in the study area are given in table 10.

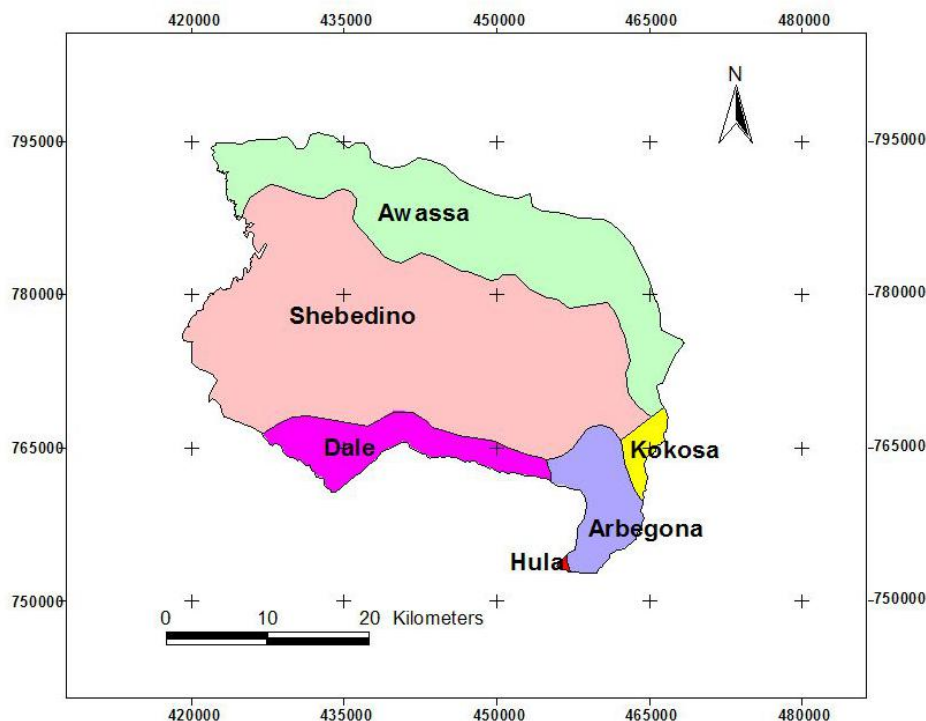


Figure 22. Woredas in the Cacthment.

Woredas	Area in (km²)	Area covered in %
Awassa	349.37	28.07
Shebedino	703.57	56.54
Dale	94.89	7.62
Arbegona	76.52	6.14
Kokosa	18.87	1.51
Hula	1.01	0.08

Table 10. Woredas and Area Coverage in the Study Area.

81.7% of the study area is under low soil erosion loss rate (less than 5.04 t/ha/yr), table 11 and figure 23, which is tolerable according to the limits set by many researchers. 99.01% of the areas that are mainly affected by moderate to extremely high soil erosion loss rate are concentrated in Awassa and Shebedino Woreda in areas with higher slope gradient factor, degraded bareland, and degraded grassland and Shrub land. So in order to keep the current trend of soil erosion in most part of the study area and to minimize the high erosion rate in some part of the study area some conservation means and rehabilitation of the degraded land should be implemented.

Soil Erosion Rate (t/ha/yr)	Awassa (km²)	Shebedino (km²)	Arbegona (km²)	Dale (km²)	Hula (km²)	Kokosa (km²)
< 5.04	325.93	664.30	76.52	92.50	1.01	18.87
5.04-10.09	15.89	15.67	0	1.78	0	0
≥ 10.09	7.55	22.07	0	0.61	0	0
Total Area in (km²)	349.37	703.57	76.52	94.89	1.01	18.87

Table 11. Soil Erosion Rate with in the Woredas.

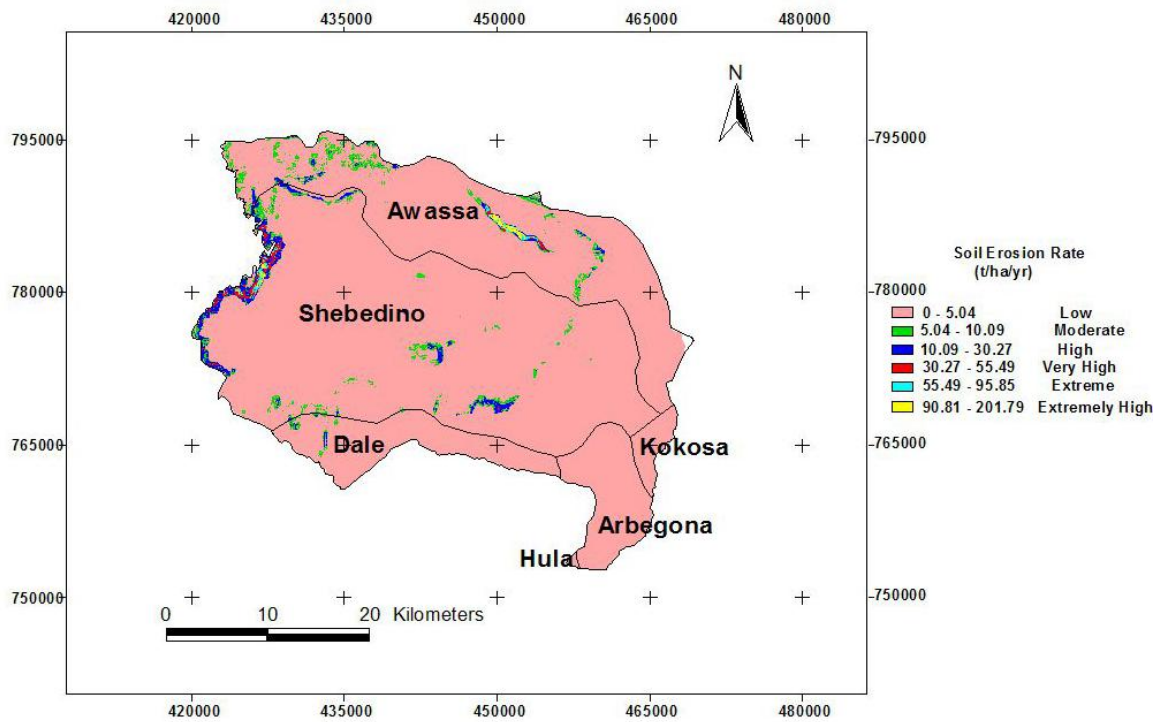


Figure 23. Soil Erosion Rate (t/ha/yr) with in the Woredas.

4.6 Impact of Population in the Study Area

Population datas of five years (2001-2005) of each woreda's were considered in this study, see table 12. The population growth shows 12.11%, 12.17%, 10.59%, 11.05%, 10.89%, and 10.05% of increment in Awassa, Arbegona, Shebedino, Dale, Hula, and Kokosa woreda's respectively. The population data was taken for the whole woreda but the data for the part of the woreda that is with in the cacthment cannot be obtained.

Woreda	Area (km ²)	2001G.C	2002G.C	2003G.C	2004G.C	2005G.C
Awassa	942.35	439,417	454,078	469,049	484,337	499,944
Arbegona	474.07	167,189	172,069	176,962	181,918	186,936
Shebedino	1,035.47	519,849	535,057	550,310	565,764	581,418
Dale	1,326.41	381,563	393,194	404,925	416,842	428,945
Hula	583.76	220,636	227,094	233,574	240,138	246,788
Kokosa	636.88	107,654	110,609	113,593	116,610	119,684

Table 12. Total Area (km²) and Population of Woredas in the Study Area, CSA (2005)

According to, Messerli and Aerni (1978), in Ethiopia, population growth, in the absence of technologies, for agricultural intensification and opportunities for off-farm employment, has resulted in a severe shortage of arable land and continuous expansion of cultivation on to the more fragile environments such as steep slopes, drought prone areas, etc. As mentioned in previous chapters, increase in population can have both positive impact and negative impact on the environment depending on how the people use the land. That is, increase in population can be a major asset in reversing land degradation trend as those in Machakos district Kenya and Konso, as mentioned in previous chapter. But, as it is stated above, increase in population in Ethiopia is usually related to land degradation. From this research most part of study area is under tolerable soil loss rate (0 - 5.04 t/ha/yr) but expansion of agricultural land to more fragile areas in order to feed the rapidly growing population may lead to high soil erosion in the future. Informal interviews made with the farmers indicate that there is a decrease in the land productivity year after year which is a manifestation of land degradation.

Therefore, in order to feed the rapidly growing population with the limited arable land, the government should make policies related to conservation means of the land and the farmers should implement the policies. And the government should also facilitate the supply of improved agricultural inputs with low cost so as to reduce land degradation with increase population.

4.7 Livestock Impacts in the Study Area

Ethiopia, which is considered to have the largest livestock population in Africa, has an estimated livestock population about 32.8 million, FAO (2002). According to Degafe and Nega, (2000), the livestock contributes the about 30-35% of agricultural gross domestic product (GDP), about 13-16% of total GDP. In the study area, livestock population is increasing over time, table 13. The livestock are usually left in open grazing land for their food, which are grasses, shrubs, and tree leaves in the study area. This induces overgrazing and soil erosion, which led to land degradation due to the clearance of grasses and shrubs, which holds the soil intact. In the study area, cow dung droppings are collected for energy source, which could have been used to enrich the soil fertility, which is further putting a threat on the land for land degradation. Livestock population data were only available on zonal level.

Zone	Year	Cattle	Sheep	Goats	Horses	Asses
Sidama	2000	1,358,180	234,620	109,230	32,770	31,120
Sidama	2001	1,466,010	255,970	157,400	36,600	27,310

Table 13. Livestock Population of Sidama Zone in the Study Area, CSA (2002)

5. CHAPTER FIVE

5.1 Conclusions and Recommendation

5.1.1 Conclusions

Soil erosion by water continues to be a serious global problem, especially in Africa. The primary objective of this study was to develop a database for use in predicting erosion rates in the Awassa catchment in the Ethiopian rift. The computer model used to calculate soil loss from the catchment was the Universal Soil Loss Equation (USLE). The goal was to determine the erosion hazards in this area and target locations for appropriate initiation of conservation measures. All factors used in USLE were calculated for the catchment using data gathered during the course of this study. The empirical nature of the USLE implies that each factor is derived independently, while in reality the factors interact in a dynamic system and several assumptions have to be made to adapt the model to a given set of conditions.

Based on the analysis of the data, 97.51% of the study area is characterized by low to moderate soil erosion rate (0-10.09 t/ha/yr) and 2.49% of the study area is characterized by high to extremely high soil erosion rate (10.09-201.79 t/ha/yr). Out of 97.51% of the study area that is characterized by low to moderate soil erosion rate, 88.05% of it is associated with slope gradient factor less than one. 49.32% of areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are associated with slope gradient factor greater than or equal to one. And 6.37% (1.97 km²) of those areas with erosion rate greater than 10.09t/ha/yr (30.92 km²) are related to slope length greater than or equal to 4.5. As we can see from figure 21, high to extremely high erosion rates are associated either higher slope gradient factor or with degraded bare land, grassland and shrub land cover. Out of the whole catchment 30.24km² lies under high to extremely high soil erosion rate and this requires immediate conservation measures. While, most areas within the watershed that are covered by cultivation, scrub and bush land, swampy grassland, bush land and wood land are characterized by low to moderate soil erosion rate. From the above results, it can be deduced that erosion rates in the study area are more related to land cover type and slope gradient factor. Therefore, areas with higher slope gradient factors and degraded land cover should get attention of rehabilitation by planting trees which hold the soil intact by their roots so as to reduce the rate of erosion. Based on the rates of soil tolerance limits that are developed for tropical soils by Hurni (1980), Lal,(1983) as cited in

Ringo, (1999) and Hudson (1986), (0.2 and 11 t/ha/yr), 97.51% of the study area is under tolerable soil erosion rate.

But one thing to remember is that the USLE measures only rill and interrill erosion therefore, the overall soil erosion rate especially in the Muleti area where ground cracks are observed is much higher than the predicted by the USLE. Thus, estimation of soil loss from the ground cracks in Muleti area should done by other model.

The USLE model is a statistical and relatively simple soil erosion model, which is easy to parameterize and thus requires less data and time to run. Integrating the model with the GIS facilitates data manipulation, data input, and output display. Most importantly, GRID spatial display and analysis utilities allow the USLE model to be applied for individual cells (micro areas). Contrasted to traditional lumped methods for soil erosion prediction, this distributed approach can help land managers identify problem areas and adopt best management practices accordingly. Another advantage of the USLE approach is its ability to predict soil loss over large areas due to the interpolation capabilities. It is therefore possible to avoid the constraint of limited field data on soil loss and/or its factor controls at micro and macro-scale, by capturing and overlaying the USLE parameters in a GIS.

Therefore, the analysis of high-resolution remote sensing data combined with further spatial information in a GIS environment provides an integrated and cheap tool for resource management within the scope of sustainable development.

5.1.2 Recommendation

- The people should be provided by other means of energy source so that they preserve the vegetation cover.
- The degrade areas with high erosion rate should be covered by vegetation to reduce the current erosion rate.
- The government should make policies related to conservation means of the land that can be implemented at local level to conserve and rehabilitate the area.

- The government should provide the necessary information about the consequence of deforestation for the people in order to increase their awareness.
- The government should also facilitate the supply of improved agricultural inputs with low cost so as to reduce land degradation with increase population.
- Family planning policies should be implemented in order to reduce the rapidly growing population.
- Improved livestock management options should be introduced in order to reduce overgrazing and increase biomass productivity.

REFERENCES

- Ammer, U., Breitsameter, J., Zander, J., (1995). *Contribution of mountain forests towards the prevention of surface runoff and soil erosion*. Forstwissenschaftliches Central blatt 114, pp 232–249.
- Befekade Degefe and Berhanu Nega. (2000). *Annual report of the Ethiopian Economy: Volume I, 1999/2000*.the Ethiopian Economic association, Addis Ababa, Ethiopia.429 pp.
- B.M.Mati and A.Veihe (2001). *Application of the USLE in Savannah environment: comparative experiences from east and West Africa*. Journal of tropical geography,22 (2),pp 138-155.
- Berberoglu, S.,(2003). *Sustainable management for the Eastern Mediterranean coast of Turkey*. *Environmental Management*, 31(3), pp. 0442-0451
- Bezuayehu Tefera, Gezahegne Ayele, Yigezu Atnafe, Jabbar M.A. and Paulas Dubale (2002). *Nature and causes of land degradation in the Oromia Region: A review, socio-economics and policy research working paper 36*. IRLI (international livestock research institute), Nairobi, Kenya. 82 pp
- Blaikie. p. and H. Brookfield (1987). *Land Degradation and society*. Methaen. New York.
- Bobbe Bedaadi Woreka. (2004). *Evaluation of Soil Erosion in the Harerge region of Ethiopia using soil loss models, rainfall simulation and trails*. Doctoral Thesis. University of Pretoria. 5 pp.
- Boccaltti, M., Tilahun Mammo, Bonini,M.and Bekele Abebe (1994). *Seismo-tectonic of east African rift system: Evidence of active oblique rifting*.*Ann.tectonica*,8,87-99.
- Boccaletti, M., Bonini, M., Mazzuoli, R., Abebe, B., Piccardi, L.,Tortorici, L., (1998). *Quaternary oblique extensional tectonics in the Ethiopian Rift (Horn of Africa)*. *Tectonophysics* 287,pp 97–116.
- Bojo, J and Cassells, D. (1995). *Land Degradation and Rehabilitation in Ethiopia: A*

Reassessment, AFTES Working Paper No. 17. The World Bank, Washington, D.C.

Booth, W., (1989). Monitoring the fate of the forests from space. *Science*, **243**, pp 1428± 1429.

Brown, L. R., & Wolf, E. C. (1984). *Soil erosion: quiet crisis in the world economy*. Washington, D.C: World watch Institute.

Cesen (1986). *Biomass energy resources*. Ministry of Mines, Addis Ababa.

Chorowicz, J., Collt, B., Bonavia, F., and Korme, T.(1994).*Northwest to North-Northwest extension direction in the Ethiopian rift deduced from the orientation of extension structures and fault slip Analysis*. Geological. Soc.Amer.bulletin.,105,pp 1560-1570.

CIESIN. (2002). *Policies for Controlling Land Degradation and Desertification*. <http://www.ciesin.org/TG/LU/policy.html>. Accessed, April 2005.

CSA (2005). *Statistical abstract*. Federal democratic republic of Ethiopia, Central statistical Authority, Addis Ababa, pp 42-43.

CSA (2002). *Statistical abstract*. Federal democratic republic of Ethiopia, Central statistical Authority, Addis Ababa, pp 35-36.

Dagnachew Legesse, Vallet-Coulomb, C. and Gasse, F. (2003). *Hydrological response of a catchment and land use change in tropical Africa: Case study south central Ethiopia*. *Journal of Hydrology* 275: pp 67-85.

Darkoh.M.K. (1995). *The deterioration of the environment in Africa's drylands and river basins*. Desertification control bulletin, 24, pp 35-41.

de Ploey, J. (1983). *Rainfall simulation runoff and soil erosion*: Cremlingen-Destedt : Catena.

Dessie Nedaw. (1997). *Hydrogeology of Awassa area*, unpublished. MSc. Thesis, Addis Ababa University. Addis Ababa.

Di paola,G.M.(1972).*The Ethiopian Rift Valley (between 7⁰⁰ and 8⁰⁴ lat. North)*, Bull. Of Volcanology, 36,pp 515-560.

Dissmeyer, G.E.& Foster, G.R. (1980). A guide for predicting sheet and rill erosion on forest land , Technical publication SA-TP11, Atlanta,Georgia:USDA Forest Service.

- Dregne, H.E. and Chou, N.T. (1994). Global desertification dimensions and costs. In: *Degradation and restoration of Arid Lands*. ed. H.E Dregne. Lubbock: Texas Technical University.
- Dudal, R. (1981). *An evaluation of conservation needs*. In *Soil conservation: Problems and prospects*, edited by R. P. C. Morgan, pp 3-12. London: John Wiley and Sons Ltd.
- EFAP (Ethiopian Forestry Action Program), 1994. Ethiopian Forestry Action Program, Vol. (2). The Challenge for Development. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa.
- Ehrlich, P., Ehrlich, A. and Daily, G. (1993). Food security, Population, and Environment. *Population Development. Review*, 19, pp 1-32.
- El-Swaify, S.A. (1997). *Factors affecting soil erosion hazards and conservation needs for tropical steep lands*. *Soil Technology* 11, pp 3-6. University of Hawaii Institute of Tropical Agriculture and Human Resources.
- El-Swaify, S.A and Hurni, H. (1996). Trans-boundary effects of soil erosion and conservation in the Nile basin. *Land Husbandry* 1: pp 6-21.
- Enters, T. (1998). *A Framework for Economic Assessment of Soil Erosion and Soil Conservation*. In: Penning de Vries, Agus and Kerr (eds). *Soil Erosion at multiple scales. Principles and methods for assessing causes and impacts*. Cab International.
- Eswaran, H., Lal, R., & Reich, P. F. (2001). *Land Degradation: An overview*. In E. M. Bridges & I. D. Hannam & L. R. Oldeman & F. W. T. P. de Vries & S. J. Scherr & S. Sombatpanit (Eds.), *Response to Land Degradation* (pp. 20-34). Enfield (NH) USA: Science Publishers, Inc.
- Evrendilek, F., Doygun, H., (2000). *Assessing major ecosystem types and the challenge of sustainability in Turkey*. *Environmental Management*, 26(5), pp. 479-489.
- Eweg, HPA, van Lammeren, R, and Fikru Yifter. (1997). *The GIS implementation*. In Feoli, E., *Project Coordinator, Rehabilitation of degraded and degrading areas of Tigray, Northern Ethiopia*, Final Report. Commission of the European Communities, STD3 Project No. TS3-CT92-0049, 1992-1996. University of Trieste, Italy, Department of Biology.
- FAO (2000). *Biophysical, socio-economic and environmental impacts of degradation*. <http://www.fao.org/landandwater/agll/madssea/topic3.htm>. Accessed, March, 2005.
- FAO (2002). *Food production Year Book 2002*. Vol.56.

- FAO (1986). *Ethiopian highlands reclamation study*, Final Report (Volume I and II). Food and Agriculture Organization (FAO), Rome.
- FAO (1984). *Agro-climatological Data for Africa*: Food and agricultural Organization of the United Nations, Rome.
- Farnsworth, N. R. and Soejarto, D. D. (1991). *Global importance of medicinal plants*. In: Akerele, O., Heywood, V. and Synge, H. (eds). *Conservation of Medicinal Plants*. Cambridge, UK; Cambridge University Press. pp. 35-50.
- Feoli, E., Gallizia, V. and Zerihun, W., (2002). *Processes of environmental degradation and opportunities for rehabilitation in Adwa, Northern Ethiopia*. *Landscape Ecology*, 17: pp 315-325.
- Fitsum Hagos, John Pender, Nega Gebreselassie (1999). *Land Degradation in the Highlands of Tigray and Strategies for Sustainable Land Management. Socioeconomic and Policy*. Research Working Paper No. 25. Livestock Policy Analysis Project International Livestock Research Institute. Addis Ababa, Ethiopia.
- Gezahegne Yirgu,, Di Paola, G.M., Kebede, F., Hagos, M., Teferi, A.,Tilahun, G., Gemetesa, N., (1997). Study report on ground fracturing in the Muleti area, Awasa Zuria Woreda. Addis Ababa University and SNNPR Professional Paper, Awasa, 7 pp.
- Gidey Woldegabriel and Aronson,J.L.. (1986). *Volcanotectonic history of the central Sector of the Main Ethiopian Rift* (Abs.), International Volcanological Congress, Auckland, New Zealand.
- Gidey Woldegabriel. (1987). *Volcanotectonic history of the central Sector of the Main Ethiopian Rift: A Georhological, Geochemical and Petrological approach*, unpublished. Ph.D. Thesis, Cleveland, Ohio, Case Western Reserve University.
- Gidey Woldegebriel , Aronson, J.L., & Walter, R. c.(1990). *Geology, Geochronology, and Rift basin development in the central sector of the main Ethiopian Rift*, *Geol. Soc. Am. Bull.*,102,pp 439-458.
- Gidey Woldegebriel, Walter, R., Hart, W.K, Mertman, S.A & Aronson, J.L. (in Press) *Temporal relations and Geochemical features of Felsic Volcanism in the Central Sector of the MER*, *Acta Vulcanologica*.
- Grubler.A.(1994).Tecnology. *In changes in Land Use Land Cover: a Global Perspective*. pp.287-328. Edited by W.B.Meyer and B.L.Turner. Cambridge University Press. Cambridge.

- HelldeÅ n, U., (1987), *An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia—A feasibility study on the use of remote sensing and GIS-analysis for planning purposes in developing countries* (Lund: Lund University Press).
- Houghton P.D and Charman, P.E.V. (1986). *Glossary of terms Used in soil conservation*, Sydney, Australia Soil Conservation service of New South Wales.
- Hudson, N. (1996). *Soil Conservation*. 3rd.ed .London: BT Batsford Limited.
- Hudson, N. (1986). *Soil conservation* (Second ed.). London: B.T. Batsford.
- Hudson, N., (1971). *Soil Conservation* Cornell Univ. Press, New York, USA.
- Hurni, H., (1993). *Land degradation, famines and resource scenarios in Ethiopia*. In *World soil erosion and conservation*, edited by D. Pimentel, pp 27-62. Cambridge: Cambridge University Press.
- Hurni, H., (1988). *Degradation and conservation of the resources in the Ethiopian highlands*. Mountain Research and Development, 8 (2/3): pp 123-130.
- Hurni, H.(1986). *Degradation and conservation of the soil resources in the Ethiopian Highlands*. A paper presented at the 1st International Workshop on African mountains and highlands, Addis Ababa, October 13 - 27, 1986.
- Hurni, H., (1985). *Soil conservation manual for Ethiopia*. First draft. Ministry of Agriculture, Natural Resources Conservation and Development Department, Community Forests and Soil Conservation Development Department. Addis Ababa.
- Hurni, H. (1980). *A nomograph for the design of labour-intensive soil conservation in rainfed cultivations*: In: Morgan, R.P.C (editor). *soil conservation, problems and prospects*. pro. Int. conf. soil cons., silose, U.K. John Wiley and sons, New York,. 185-210.
- Hyden, G., Kats, R. and Turner II, B.L. (1993). *Beyond intensification In: Population Growth and Agricultural change in Africa*, eds. B.L. Turner, G. Hyden and Kates, pp 401-439. Gainesville: University of Florida Press.
- Kahsay Berhe (2004). *Land use Land Cover Changes in the Central Highlands of Ethiopia: The Case Study of Yerer Mountain and its Surroundings*. MSc Thesis of Environmental Science, Addis Ababa University. pp 16-25.
- Kazmin,V. and Berh,S.m.(1978). *Geology and Development of the Nazeret Area, Northeren Ethiopian Rift*: Sheet NC 37-15,Memoir No, 3. Ministry of Mines, Addis Ababa, 26 pp.

- Kramer, R., Richter, D., Pattanayak, S., Sharma, D., (1997). *Ecological and economic analysis of watershed protection in Eastern Madagascar*. Journal of Environmental Management 49, pp 277–295
- Kidanu, S. (2004). *Using Eucalyptus for soil & water conservation on the highland vertisols of Ethiopia*. Tropical Resource Management. Papers, No. 52 (2004). Wageningen University, The Netherlands.
- Klink, C.A., A.G. Morera, and O.T. Solbrig. (1993). *Ecological impact of agricultural development in the Brazilian Cerrados*. In *The World's Savannas: Economic Driving Forces. Ecological Constraints and Policy options for Sustainable Land Use*. pp.259-282. edited by M.D. Young and O.T. Solbrig. UNESCO and Parthenon publishing Group. Paris.
- Kumar, H. D. (ed.). (1999). *Biodiversity and Sustainable Conservation*. Science Publishers, Inc. USA.
- Kunaporn, S., Wichaidit, P., Vearasilp, T., Hoontrakul, K., & Eswaran, H. (2001). *An assessment of land degradation in Thailand*. In E. M. Bridges & I. D. Hannam & L. R. Oldeman & F. W. T. P. de Vries & S. J. Scherr & S. Sombatpanit (Eds.), *Response to Land Degradation* (pp. 115). Enfield (NH) USA: Science Publishers, Inc.
- Lal, R. (1990). *Soil erosion and Land degradation*.
- Lal, R. (1994). Tillage effects on soil degradation. Soil resilience, soil quality, and Sustainability. Soil tillage research 59, pp 661-667.
- Lal, R., & Steward, B. A. (1994). *Soil processes and water quality*: Lewis.
- Lillesand, M. and Kiefer, R.W. (1999). *Remote sensing and image interpretation*. Fourth edition. John Wiley & Sons Inc. Newark, Chichester, Weinheim, Brisbane, Singapore, Toronto.
- L. Ayalewa, H. Yamagishi, G. Reik (2004). Ground cracks in Ethiopian Rift Valley: Facts and Uncertainties. Engineering Geology xx (2004) xxx–xxx. pp 2-4 .
- Lo, K.F.A. (1990). *Erosion Problems and Research Needs of Tropical Soils*. In: Ziemer, R.R., O'Loughlin, C.L., Hamilton, L.S. (eds). Research needs and Applications to Reduce Erosion and Sedimentation in Tropical Steeplands. Proceedings of the Fiji Symposium, June 1990. IAHS-AISH publ. no. 192.
- Malthus, T.R. (1978). *An Essay on the Principle of Population*. Amherst, NY: Prometheus Books. (Re-printed 1998).

- Messerli, B., and K. Aerni. (1978). *Cartography and Its Application for Geographical and Ecological Problems*. edited by B. Messerli, and K. Aerni (With Maps). Bern, Switzerland: Geographical Bernensia.
- Middleton.N.and Thomas.D.S.G.(1997). *World Atlas of Desertification*. 2nd ed. 182 pp. Published for UNEP. London: Edward Arnold.
- MNRDEP, (1992). Found on Food and Agriculture Organization of the United Nations Ethiopia.
- MoFED (Ministry of Finance and Economic Development) (2002). *Ethiopia: Sustainable Development and Poverty Reduction Program (SDPRP)*. Addis Ababa, Ethiopia. Also available on web at <http://www.worldbank.org/afr/et/prsp.htm>
- Mohr,P.A.(1967). *The Ethiopian rift System*, Bulletin. Geographical observation. Addis Ababa,12, pp 27-56.
- Mohr,P.A., and Wood,C,A.(1976). *Volcano spacing and lithospheric attenuation in the eastern rift of Africa*, Earth and planetary science letters,33, pp 27-37.
- Mohr, P.A.,Mitchell,J.G.& Raynolds,R.G.H.(1980).*Quaternary volcanism and faulting at O' caldera,central Ethiopian rift*,Bull.volca.,43, pp 173-189.
- Mohr,P.A.,(1983). *Volcano tectonic aspects of Ethiopian rift evolution*, Bull. Centers resch.explor.prd.E; f-Aquitaine, 7(1),pp175-189.
- Morgan, R.P.C. (1995). *Soil erosion and conservation*. Second Edition. Essex/New York.
- MoWR (2000). *Feasibility Study and Preliminary engineering design on Awassa water supply development and rehabilitation project (volume I Report)*. Ministry of water Resources, Addis Ababa.
- Muleta, B., Welde Aregay, K., (1998). *A short report on fracture development in the southwest of Awassa town (Muleti Village)*. Bulletin - Ethiopian Institute of Geological Surveys (Professional Paper, 9 pp.
- Mulugeta L.(2004). *Effects of Land Use Changes on Soil Quality and Native Flora Degradation and restoration in the Highlands of Ethiopia*. Doctoral Thesis, Swedish University of Agricultural Sciences Uppsala, pp 11-13.
- Murphree. M. W. and D. H. M. Cumming. (1993). *Savanna land use: policy and practice in Zimbabwe*. In *The World's Savanna's Economic Driving Forces. Ecological Constraints and*

- Policy option for sustainable land use*. PP 139-178. Edited by M.D.Young and O.T. Solbrig. UNESCO and Parthenon Publishing Group. Paris.
- Oldeman, L., Hakkeling, R.T.A. and Sombroek, W.G. (1991). *World map of the status of human-induced soil degradation: an explanatory note*. ISRIC, Nairobi UNEP, Wageningen.
- Oldeman, L. R. Hakkeling, R.T. A. and Sombroek, W.G. (1992). *World map of the Status of Human induced soil degradation: An explanatory Note*. Wageningen: ISRIC.
- Oldeman L.R. (1994). *The Global Extent of Soil Degradation*. In: D.J. Greenland and I. Sezabolcs (eds.). *Soil Resilience and Sustainable Land Use*, pp. 99-118. CAB International, Wallingford, UK.
- Pimentel, D., (1993). *World Soil Erosion and Conservation*. M.J. Cohen et al. / *Geoderma* xx (2004) xxx–xxx 17. 349 pp. Cambridge Univ. Press, New York, NY, USA.
- Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., (1995). *Environmental and Economic Costs of Soil Erosion and Conservation Benefits*. *Science* 267, pp 1117– 1123.
- Pilesjö, P., (1992). *GIS and remote sensing for soil erosion studies in semi-arid environments*. Avhandlingar 114, (Lund: Lund University Press).
- Reed, D. (1996). *Structural adjustment. The Environment and Sustainable Development*. Earthscan publications. London.
- Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., (1997). *Predicting soil loss by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. Handbook, vol. 703. US Department of Agriculture, Washington, DC, USA. 384 pp.
- Ringo, D. E. (1999). *Assessment of erosion in the Turasha catchment in the lake Naivasha area, Kenya*. Unpublished MSc Thesis, Enschede. The Netherlands.
- Rockwell, R.C. (1994). *Culture and cultural Changes. In changes in Land use Land cover: a global perspective*. pp.357-381. edited by W.B.Meyer and B.L.Turner. Cambridge University. Press Cambridge.

- Reusing, M., Schneider, T., Ammer, U., (2000). Modelling soil loss rates in the Ethiopian highlands by integration of high resolution MOMS-02/D2-stereo-data in a GIS. *International Journal of Remote Sensing* 21, 1885– 1896.
- Sanchez, P.A., Palm, C.A., Buol, S.W., (2003). *Fertility capability soil classification: a tool to help assess soil quality in the tropics*.
- Sanderson .S. (1994). *Political-Economical Institutions. In Changes in Land use and Land Cover: A Global Perspective*. pp.329-356. Edited by W.B.Meyer and B.L. Turner. Cambridge University. Press Cambridge.
- Sayer, A.J. Harcourt, S.C. and Collins, M.N. (1992). *The conservation atlas of tropical forests Africa*. IUCN, Cambridge, UK. 288 p.
- Schmink.M. and C.h.Wood.(1987). *The political ecology of Amazonia. In Lands at risk in the Third World: Local-level perspectives*. pp.38-57. Edited by P.D. Little and M.M.Horowitz. Westview Press. Boulder. Colorado.
- Shestha, D. P. (2002). *Soil degradation processes*. Lecture note. ITC, Enschede, The Netherlands.
- Solomon Abate (1994). *Land use dynamics, soil degradation and potential for sustainable use in Metu area, Illubabor Region, Ethiopia*. African Studies Series No. A 13. *Ph.D. Thesis*, University of Berne, Switzerland. 135 pp.
- Stdman-edwards.P(1998). *Root causes of Biodiversity Loss: An analytical Approach*. World Wide Fund for Nature. Washington. D. C.
- Sutcliff, J.P. (1993). *Economic Assessment of land degradation in the Ethiopian highlands: A case study*. National Conservation secretariat, Ministry of Planning and economic Development, Addis Ababa, Ethiopia.
- Tamirie Hawando (1997). *Desertification in Ethiopian Highlands*. Rala report no.200. pp 75-86.
- Telford,R.(1998). Diatom stratigraphies of lake Awassa and tillo (Ethiopia): Holocene records of Ground water Variability and climate change. Ph.D Thesis. University of Wales at Aberystwyth.115pp
- Tesfaye Korme, Chorowicz, J., Collette, B., and Bonavia, F.F. (1997). Volcanic Vents rooted on extension fractures and their geodynamic implications in the Ethiopian rift,J.Volcanolo. geotherm. Res., 79,pp 205-22.

- Tewelde Berhan Gebre Egziabher, (1989). *The rates of ecological crises in Ethiopia*. In: pp 103–110, Proceedings of the First Natural Resources Conservation Conference. Addis Ababa, Ethiopia (mimeographed).
- Tiffen, M., Mortimore, M. and Gichuki, F. (1994). *More People, Less Erosion: Environmental Recovery Kenya*. Chichester: John Wiley & Sons.
- Ulanbek Turdukulov.(2000). *Soil erosion modeling using Remote Sensing and GIS*. (Morgan Approach). A Case Study of Bata River Basin, HP, A project report, Indian institute of remote sensing. 8 pp.
- UNCCD (United Nations Convention to Combat Desertification). (1994). *United Nations convention to combat desertification in those countries experiencing serious drought and/or desertification, particularly in Africa*. Paris: UNESCO Publications.
- UNEP, (1993). *Good news in the fight against deforestation*. Desertification control bulletin, pp 22,3.
- Wali, M.K., N.M. Safaya, F. Evrendilek., (2002). *Ecological rehabilitation and restoration in the Americas with special reference to the United States of America*. In: *Handbook of Restoration Ecology*, edited by M. R. Perrow and A. J. Davy, Volume 2, Cambridge University Press, Cambridge, pp. 3-31.
- Wischmeier, W.H., Smith, D.D., (1978). *Predicting Rainfall Erosion Losses*. Agricultural Handbook 537. U.S.D.A.-Sci. and Educ. Admin. Washington, DC.
- Wolde Aragaye Berehe (1996). *Twenty years of soil conservation in Ethiopia*. A personal overview. Regional Soil Conservation Unit/SIDA.
- World Bank,(2002). *The World Bank group, 2002*. Country profile Table. Ethiopia Data.
- World Bank (1984). *Ethiopia issues and options in the energy sector*. Report No. 4741-ET of the Joint UNDP/WB Energy Sector Assessment Programme.
- World Conservation Monitoring Center (1992). *Global biodiversity. Status of the earth's living resources*. Chapman and Hall, London.
- WRI (World Resource Institute) (1997). *The last Frontier Forests: ecosystem and Economics on the edge*. Washington D.C., USA.
- WWDSE (2001). *The study of Lake Awassa Level Rise*. Interim Report, Water Works, Design and Supervision Enterprise, Addis Ababa, Ethiopia.

Young. M.D. (1993). *National and international influence that drive savanna land use. In the world's savanna's economic driving forces. Ecological Constraints and Policy Option for sustainable land use.* pp.81-89. edited by M.D.Young and O.T.Solbrig. UNESCO and Parthenon Publishing Group. Paris.

Zemenu (2000). *Engineering geological study of Awassa town and its surroundings.* MSc. Thesis, Addis Ababa University. pp 13-25.

Appendices

Appendix 1: Erosion Assessment

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

The values of the rainfall erosivity factor, slope length factor, slope gradient factor, land cover factor and management factor are taken empirically by Hurni at trial plots in various parts of the Ethiopian highlands, the quantitative soil erodibility factor are based on the FAO soil degradation assessment methodology and were adjusted to this erosion model. All values are listed.

Rainfall Erosivity Factor

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

P = annual precipitation (mm)

Soil Erodibility Factor

K = 0.10, if the soil type is

Acrisols: Ferric (Af) or Humic (Ah)

Cambisols: Ferralic (Bf) or Humic (Bh)

Chernozams (C)

Rendinas (R)

Ferralsols (F)

Gleysols Calcaric (Gc) or Humic (Gh) or Mollic (Gm)

Phaezems (R)

Lithosols (L)

Fluvisols : Calcaric (Jc)

Luvisols: Ferric (Lf)

Nitosols (N)

Riatosols (Q)

Arenosols (Q)

Regosols: calcaric (Rc)

Andosols: humic (Th) or mollic (Tm)

Rankers (U)

Solonchaks: mollic (Zm)

K = 0.15, if the soil type is:

Acrisols: gleyic (Ag) or Plinthic (Ap)

Cambisols : Chromic (Bc) or dystic (Bd) or eutric (Be) or gleyic (Bg) or calcic (Bk)

Gleysols: dystic (Gd) or eutric (Ge) or plinthic (Gp)

Fluvisols: dystic (Jd) or eutric (Je)

Kastanozems (K)

Luvisols: chromic (Lc) or gleyic (Lg) or calcic (Lk) or orthic (Lo)

Greyzems (M)
 Podzols:humic (Ph) or leptic (Pl)
 Regosols: dystic (Rd) or eutric (Re)
 Solonetz: mollic (Sm)
 Andosols: orthic (To) or vitric (Tv)
 Planosols: humic (Wh) or mollic (Wm)
 Solonchaks: gleyic (Zg) or orthic (Zo)

K =0.20, if the soil type is:

Cambisols:Vetric (Bv) or gelic (Bx)
 Podzoluvisols (D)
 Gleysols: gelic (Gx)
 Fulivisols: thionic (Jt)
 Luvisols: albic (La) or plinthic (Lp) or vertic (Lv)
 Podzols: ferric (Pf) or gleyic (Pg) or orthic (Po) or placic (Pp)
 Regosols: gellc (Rx)
 Solonetz:gleyic (Sg) or orthic (So)
 Vertisols (V)
 Planosols : dystic (Wd) or eutric (We) or Solodic (Ws) or gelic (Wx)
 Xerosols: (X)
 Yermosols (Y)
 Solonchaks : takyric (Zt)
 High surface stoniness decrease this factor by 0.05

3. Slope Length Factor:

Slope length factor	Slope length
1.2	<50m
2.5	50-200
3.8	>200

4. Slope Gradient Factor:

Slope gradient factor	Slope gradient percentage
0.1	<1%
0.1	1-2%
0.2	2-4%
0.35	4-6%
0.6	6-8%
1	8-13%
2	13-25%
3.2	25-40%
4.2	40-55%
5.5	55-100%
10	>100%

5. 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

6. Management Factor

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.

Appendix 2 Land use classes and their corresponding *C* factor near Lake Tana in the central Ethiopian Highlands.

M. Reusing, T. Schneider and U. Ammer

International Journal of Remote Sensing, 2000, vol. 21, no. 9, 1885± 1896.

Land use classes and their corresponding *C* factor.

Land use	<i>C</i>-factor
Forest land	0.001
Woodland	0.010
Bushland	0.050
Shrubland	0.100
Grassland/wet	0.030
Grassland/dry	0.030
Cultivated land/ploughed	0.250
Cultivated land/harvested	0.250
Cultivated land/fallow	0.100

DECLARATION

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

Name: Hamelmal Hagos Mesfin

Signature: _____

This Thesis has been submitted for examination with our approval as university advisors

Name

Signature

Dr. Tesfaye korme

Dr. Bekele Abebe

Date and place of Submission: Remote Sensing and Geographic Information

System Programme

Addis Ababa University

July 2005