ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTEMENT OF EARTH SCIENCES

SPATIAL ANALYSIS OF EROSION AND LAND DEGRADATION LEADING TO ENVIRONMENTAL STRESS: The Case of Lake Hawassa Catchment

A Thesis submitted to school of Graduate Studies of Addis Ababa University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Remote Sensing and Geographic Information System

By: *Tigneh Eshete G/Kidan*

Addis Ababa University

June 2009

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Approved by Board of Examiners: **Signature**

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Advisor: Dr. *Mohammed Umer*

Examiners:

Addis Ababa University
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Abstract

Land degradation mainly soil erosion and deforestation are principal environmental problems exacerbating environmental stress and food insecurity in developing countries including Ethiopia. Ethiopia loses about 1.5 billion tons of soil per year, and about 1.5 million tons of grain, as a result of soil erosion. The present study is aimed at analyzing erosion hazard and vegetation degradation, which is leading to environmental stress in Lake Hawassa Catchment. Satellite images of Landsat TM 1986 and ETM+ 2005, 30m resolution SRTM-DTED, and data on land use and conservation practices collected from field and secondary sources such as; agro-meteorological and livelihood data, were major data types used for the study. Data analysis were undertaken using GIS and Remote Sensing techniques involving satellite image processing, identification of erosion hazard areas using USLE model and finally estimating the degree of environmental stress using multi-criteria weighted overlay analysis of rainfall variability, erosion hazard, vegetation index and livelihood system. The result of the study indicates that nearly 8% of the catchment, particularly the escarpments in Shamena_Hurufa, Boricha_Bushulo and Lalima sub-catchments are highly and severely degraded with long and wide gullies. Further more, the overlay analysis of land degradation, rainfall variability, vegetation index and the livelihood system indicated that 15% of the catchment is found with high degree of environmental stress; while 35 % is in the range of moderate stress. Similar to the results of erosion hazard, the western and northwestern parts of the catchment especially Boricha_Bushulo, Shamena_Hurufa, Lalima and Shashemene_Toga sub-catchments are with in a moderate to high environmental stress regime. Environmental stress areas are found both on the escarpment and on the plain. The underlying factors causing this stress could be different and thus need further investigation using other techniques. Therefore, in order to reverse the adverse effects of environmental degradation and stress in the catchment, appropriate conservation and rehabilitation measures, community based integrated watershed management initiatives and alternative livelihood approaches should be promoted and implemented.

Key Words: Environmental stress, Erosion hazard, Vegetation index, Universal Soil Loss Equation.

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Lists of Abbreviations

BoFED	Bureau of Finance and Economic Development
C_Factor	Crop management factor
CSA	Central Statistical Agency
CV	Coefficient of Variation
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
EHRS	Ethiopian Highland Reclamation Study
EMA	Ethiopian Mapping Authority
EPA	Environmental Protection Authority
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
K_Factor	Soil Erodibility factor
L_Factor	Slope Length factor
LU/LC	Land use/ Land cover
MWR	Ministry of Water Resources
NDVI	Normalized Differencing Vegetation Index
NMSA	National Meteorological System Agency
P_Factor	Conservation Practice Factor
R_Factor	Rainfall Erosivity factor
RUSLE	Revised Universal Soil Loss Equation
SCRP	Soil Conservation Research Project
S_Factor	Slope Steepness factor
SNNPRS	Southern Nation and Nationalities Peoples' Regional State
t/ha/yr	ton per hectare per year
TM	Thematic Mapper
UNESCO	United Nations Education, Science, Culture organization
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WCED	World Commission on Environment and Development
WEPP	Water Erosion Prediction Project
WWDSE	Water Works and Design Supervision Enterprise
ZDoARD	Zonal Department of Agriculture and Rural Development

CHAPTER I

1. INTRODUCTION

1.1. Background

Land degradation is one of the world's major socio economic and environmental problems, which has been a major global issue since the late 20th century and has remained important in the 21st century because of its adverse impact on land productivity, on the environment, on food security and the quality of life (UNU, 2007). It has affected one billion people in 110 countries world wide and is prevalent across about 40 percent of the earth's surface. The loss of potential productivity due to soil erosion world wide is estimated to be equivalent to some 20 million tons of grain per year.

The renewable natural resources of many African countries have come under severe stress over the past three or four decades and most indicators point towards a continuation of this trend. The rate of degradation and depletion of these resources has been accelerated in proportion to the increasing population pressure. Deforestation, loss of biodiversity and a high rate of land use change have degraded the environment so that the food security and economic development of many countries are threatened. In Africa, it is estimated that about 500 million ha, or about one quarter of its dry lands, are affected by different types of soil erosion. The rate at which arable land is being lost is increasing and is currently 30-35 times the historical rate (UNEP, 1999; UNU, 2007).

Ethiopia is one of the most well endowed countries in sub-Saharan Africa in terms of diversified natural and cultural resources. Moreover, its location in the tropics combined with impressive altitudinal variations within short ranges allows the country to enjoy both temperate and tropical climates and these give a wealth of biophysical resources including rich biodiversity, relatively fertile soils, and huge fresh water resources. Despite the enormous biophysical potential, the country has been affected by the interlinked and reinforcing problems of land degradation and extreme poverty.

The causes of land degradation are complex and have diverse nature and dimensions depending on the biophysical environment and human interventions. The major causes in Ethiopia are largely anthropogenic including rapid population increase, bad farming practices, deforestation, fuel wood consumption and unbalanced crop and livestock production. In addition, the farming and livelihood system, particularly in the highlands, combined with poor land management practices and the consistent push of cultivation towards increasingly marginal areas, contributes to the current level of land degradation and to significant decreases in agricultural production. Utilization of dung and crop residues for fuel and other uses also intensify the problem (Girma, 2001).

According to Berry (2003) originally 65 % of Ethiopian land was under forest cover, in 1950s, the cover reduced to 16%. This percentage has dropped to only 2% in 2000, and continues to be reducing every year. Similarly, on average Ethiopia losses 12 tons of soil per hectare per year, and 1493 million tons of soil per year due to water erosion. On the other hand, the soil formation rate for Ethiopia is less than 2 ton hectare per year, which is very low compared to soil erosion rates. Annually, Ethiopia loses about 1-1.5 million tons of grain due to soil erosion (Hunri, 1988; Muhammed, *et al*., 2005).

1.2. Statement of the Problem and Justification

In Hawassa catchments land degradation is mentioned as a major environmental problem affecting the biotic and socio-economy of the surrounding people. Deforestation and soil erosion are major forms of land degradations identified, and are largely human induced (WWDSE, 2001). The indicators of soil erosion in the catchment are manifested with drying up of Lake Cheleleka, flooding of the foot hills flat farmlands, Lake level variation of Lake Hawassa and flooding of the adjacent settlements and farm lands, decline in soil productivity, moisture retaining capacity, and organic matter content, thereby declining production (Awedenegest M; Holden N.M. 2007, and WWDSE, 2001).

Water erosion, particularly rill and gully, is widespread in the catchment along the down sloping escarpments especially in Shemena_Hurufa, and Lalima. Sub-catchments 4 to 8 km long and 2-100m wide gullies are common (MWR, 2007). WWDSE (2001) study indicated that due to erosion hazard in 1998, flooding of roads (Bushulo to Shamena 6 km), 105 hectare of farm lands were flooded, severe gully (4-70 meter wide) were formed in the west and eastern parts, 210 households were lost, and 16,000 hectare of land was affected. In addition, in the same year there was flooding in some parts of the town of Hawassa, particularly across the Hawassa side 162 urban households and 13 business organizations were affected. The same study revealed, deforestation problem is prominent in the northwester part of the catchment where the agricultural produce covers less than 60% of the consumption demands and the community bases on firewood and charcoal sale as a source of income. Consequently mean biomass fuel inflow rate to Hawassa town is 750 G J/day.

According to Sidama ZBoARD report (2007), due to land degradation, erratic rainfall and population increase, most part of the catchement especially the western parts have been food in secured. In 2006, 18,040 people from Hawassa, 41,855 people from Boricha and 14,808 from Shebedino Woredas were registered as food insecured and have been under the support of safety net program (BoARD, 2007).

It is believed that environmental degradation worsens the livelihood of local communities and the sustainability of the natural ecosystem. Thus, there is a need to reverse the land degradation problems and implement appropriate watershed development schemes. Therefore, this study is aimed to access erosion hazard and land degradation problems which could lead to environmental stress in Lake Hawassa catchment and to recommend appropriate measures for the same.

1.3. Research Questions

Many researchers argue that the major causes of environmental degradation largely emanate out of the interaction of human beings with the natural environment. Human beings in what so ever level of development exacerbate environmental damage through over-dependence and misuse of natural resources coupled with lack of integrated environmental rehabilitation and management activities. Thus, in view of addressing the causes of environmental degradation the following research questions were formulated;

1. Is the catchment area prone to environmental stress due to erosion hazard?
2. What is the association between people's livelihood and environmental stress?
3. What type of relationship exists between predicted results of environmental stress and vegetation indices?

1.4. Significance of the Study

In view of predicting and identifying erosion hazard and environmental stress areas, the findings of this study may reveal the major factors that contribute for the deterioration of the natural environment.

Therefore, the findings of the present research may provide direction to policy formulation, decision makers and development practitioners so as to implement appropriate soil and water conservation system and participatory watershed development initiative in the catchment.

1.5. Research Objectives

1.5.1. General Objectives

The main objective of this research is to assess erosion hazard and environmental stress in Hawassa Catchment.

1.5.2. Specific Objectives

- To identify areas vulnerable to water erosion hazard
- To determine the degree of environmental Stress in the catchment
- To examine the association between erosion hazard and environmental stress
- To analyze the association existing between Normalized Difference Vegetation Indices (NDVI) and environmental stress
- To examine spatial rainfall variability and its association with environmental stress
- Based on the study findings to recommend appropriate measures and the way forward to reverse the situation of land degradation in the catchment.

1.6. Limitations

It has been tried to consider production and similar data required for this research. However, these were not fulfilled due to constraints of limited time, paucity of data resources and limited financial support.

CHAPTER II

2. DESCRIPTION OF THE STUDY AREA

2.1. Location

The Lake Hawassa catchment is located in the central part of the higher Ethiopian Rift region. It is part of the main Rift Valley Lakes Basin, and surrounded by gently to steeply sloping escarpments and hills forming concave closed system with a caldera Lake at the centre. It is situated at 275 km south of Addis Ababa, Hawassa Town taken as a geographic centre, across the road to Moyale with an area of 1,620km^2. Hawassa Town is the only rapidly growing city in the catchment-the regional capital of SNNPR. Geographically it extends between 6.81225^o – 7.22627^o latitude and 38.22711^o – 38.72221^o E longitude.

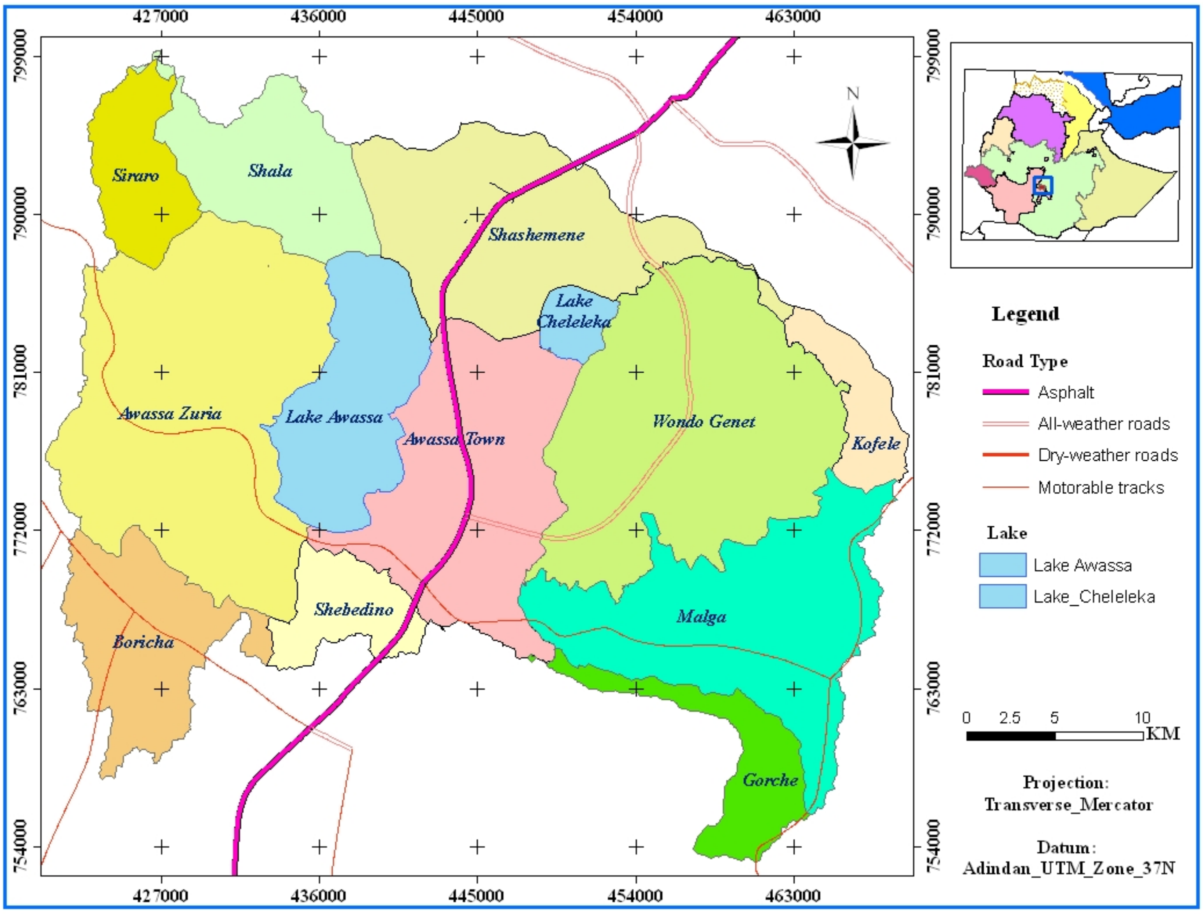

Fig.2.1. Location of Lake Hawassa Catchment

The catchment lies in two regional states, namely: SNNPRS in southern part composed of six administrative districts covering about 80 % of the total area, and the Oromia Regional State in the north, crossing four administrative districts (Table.1.1; fig. 2.1, and CSA, 2007). The area is relatively accessible with asphalt, all weather gravel, and dry weather roads.

2.2. Climate

There has been always unevenness in the spatial distribution of climate on the earth's surface due to an effect of altitude, angle of the sun, prevailing winds, cloud cover, ocean currents, and distance from the sea and so on. According to Makin, et al (1975) as cited in Tesfaye Chernet (1982) the sub-basin lies within humid, dry sub-humid or semi-arid agro-climatic Zones. The Climatic elements mainly temperature and rainfall are important factors in determining geomorphic processes, soil formation, human livelihood, and the bio-physical environment in general at a given geographical environment.

2.2.1. Rainfall

The rainfall pattern of Hawassa basin is characterized by bimodal distribution with spring /"belg" and summer (main) rainy seasons (Fig.2.3). However, the rainfall is continuously distributed with one dry season. The rainfall data collected from 1970s to 2006 at meteorological stations depict that significant rain starts during March and continues to increase up to May and then it slightly decreases during June, and then followed by big main growing season rain through July to September (Fig.2.2). The annual rainfall generally decreases on average from 1400mm in the east and southeast to 1000mm towards northwest.

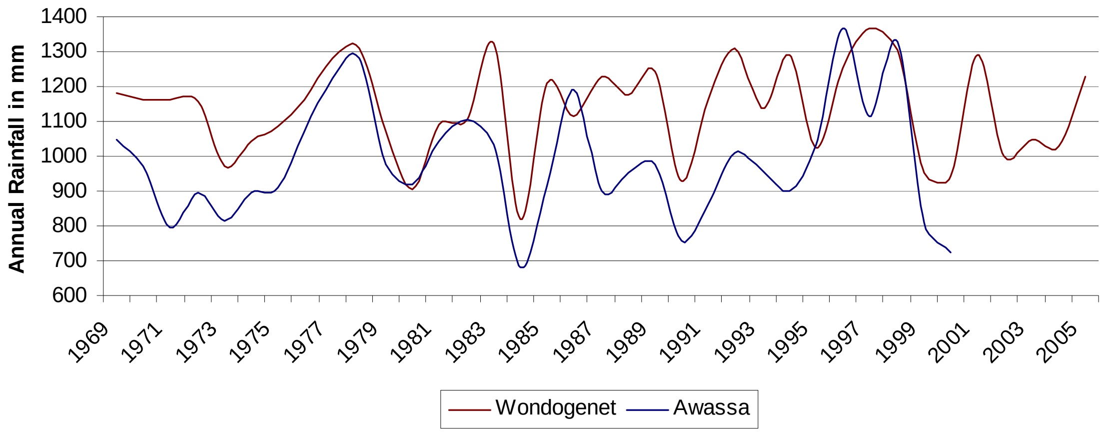

Fig.2.2. Mean Monthly Rainfall Distribution during 1970- 2005

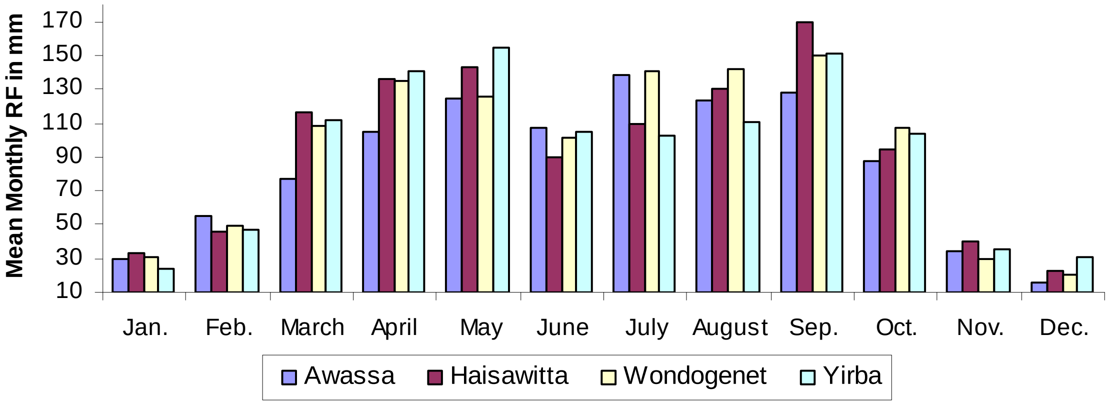

Fig. 2. 3. Mean Monthly Rainfall Distribution during 1970- 2005

2.2.2. Temperature

The mean annual temperature of the basin varies from 21^{O}C in the plains to the west of Lake Hawassa to 17^{O}C in the eastern mountainous escarpment where temperature is reduced due to the effect of altitude and humidity. At Hawassa Station the mean annual temperature is 19.5 ^{O}C with the minimum average ranging from 9.3 ^{O}C during December to 14 ^{O}C during July; and maximum temperature varying from 24 ^{O}C during July to 29.2 during March.

2.3. Geology

Geologically the sub-basin as a part of the Ethiopian/East African/ Rift System was formed during the tertiary uplifting following the regression of the Mesozoic Sea towards the southeast. The uplifting was associated and followed by intrusion of basaltic magma through fissures. Later tectonics and geomorphic processes resulted with the present shape of the area (Tesfaye Chernet, 1982). However, according to studies of the Ethiopian Geological Survey structurally there are numerous rift system faults with north and northeast trend along which Lake Hawassa is oriented. The faults are normal faults and are dominantly found to the south and southwest of the Hawassa. A line of young faults, which were extensions the Wonji Fault belt, shattered the rift floor in to several small horst and graven. As a result the Hawassa and Corbetti caldera occupied separate depressions. The corbetti caldera has two volcanic centers of Urgi and Chebbi. The Urgi and Chebbi centers were the sources for formation of Pumice and obsidian in the vicinity, respectively (Tadesse and Zenaw, 2003).

The major geological formations of the basin includes recent lacustrine and alluvial deposits, pyroclastic deposits, basalt, scoria cones, rhyolitic lava flows and associated ignimbrites, tuffs (lapilli tuff) and volcanic ash. Figure 2.4 depicts the distribution of geological units and structures within the basin.

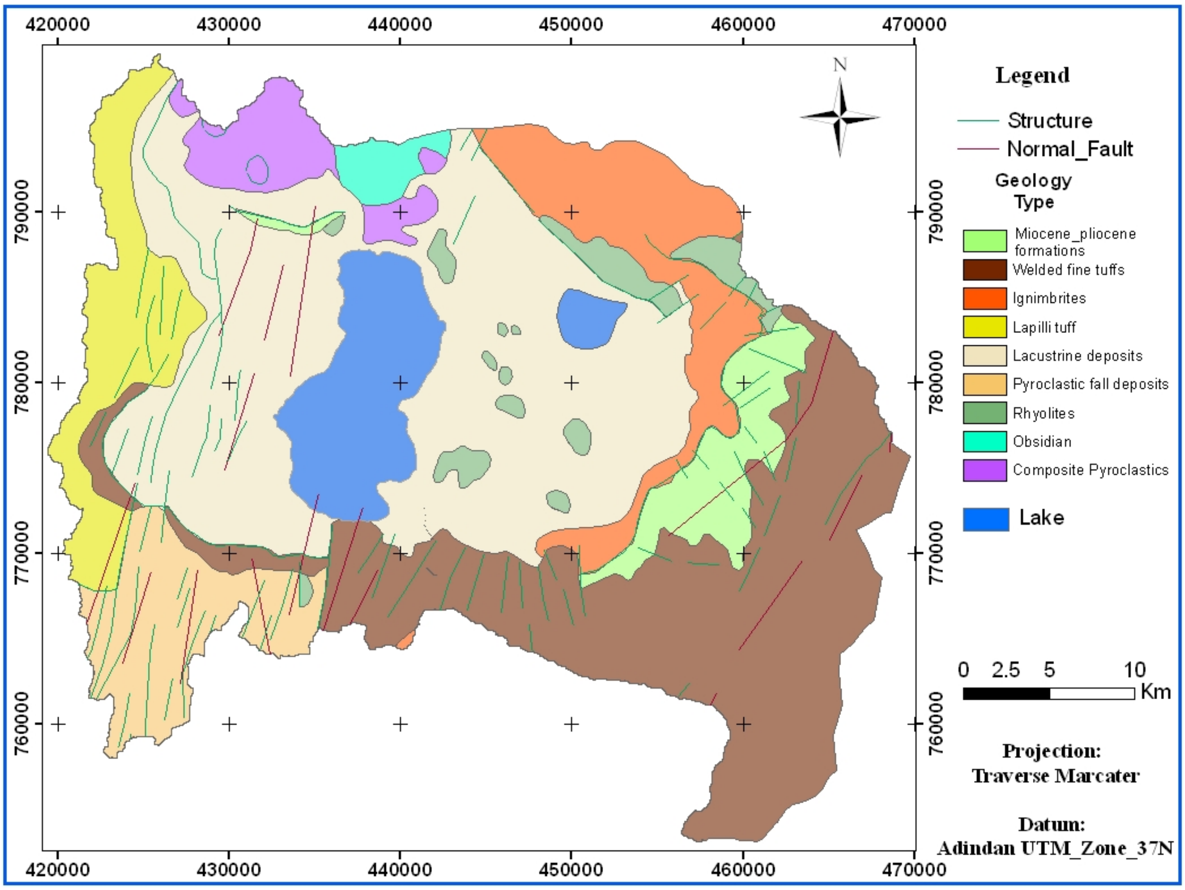

Fig. 2.4. Geological Map of Lake Hawassa Catchment

2.4. Relief and Drainage

The different relief features observed in the basin are the results of the recent geological episodes of the tertiary period and the subsequent geomorphic processes. The relief is complex and it is composed of gently undulating great caldera depression at the center; where Lake Hawassa and Cheleka Swamp are found, surrounded by sloping hills of wondo_Malga and Weransa escarpments in the southeast, and Shamena Hurufa ridge, Abaye and Chebi hill slopes in the northwest. Further, southeast of the eastern escarpments the high relief is characterized by highly dissected plateaus, intermediate hills and rugged topography which form sources of spring and streams draining toward the cheleleka swamp. In the western part of the basin remnants of the Corbetti caldera form steep slopes and high relief's of chebi and Urgi hills (Taddesse and Zenaw, 2003).

The altitude, in general, ranges from 2,983m.a.s.l in the extreme eastern mountainous part to 1,680m.a.s.l (GPS reading) at bed of Lake Hawassa (Fig.2.5. and 2.6).

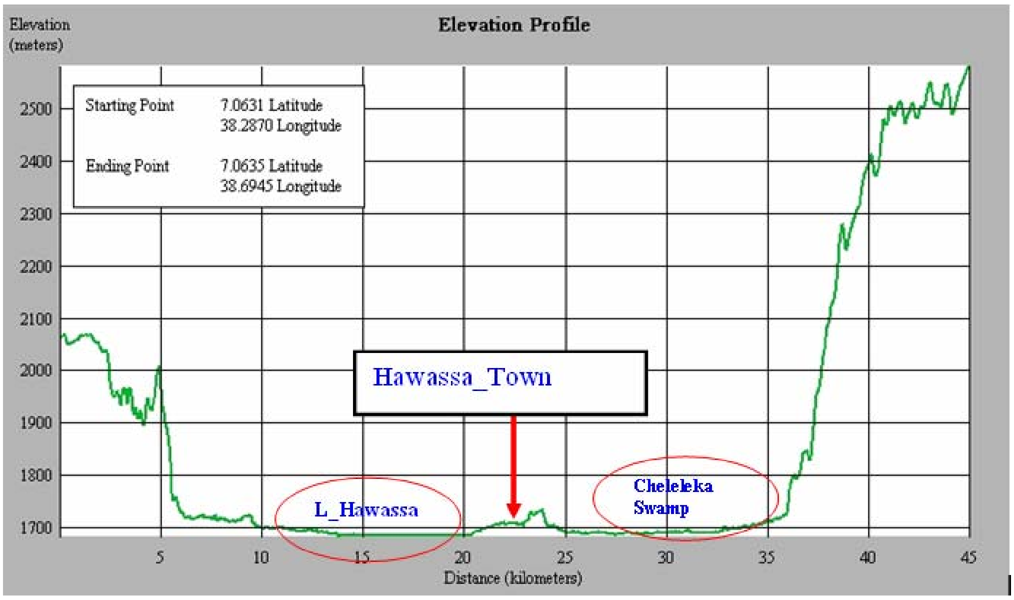

Fig.2.5. West to East cross-sectional profile of the basin

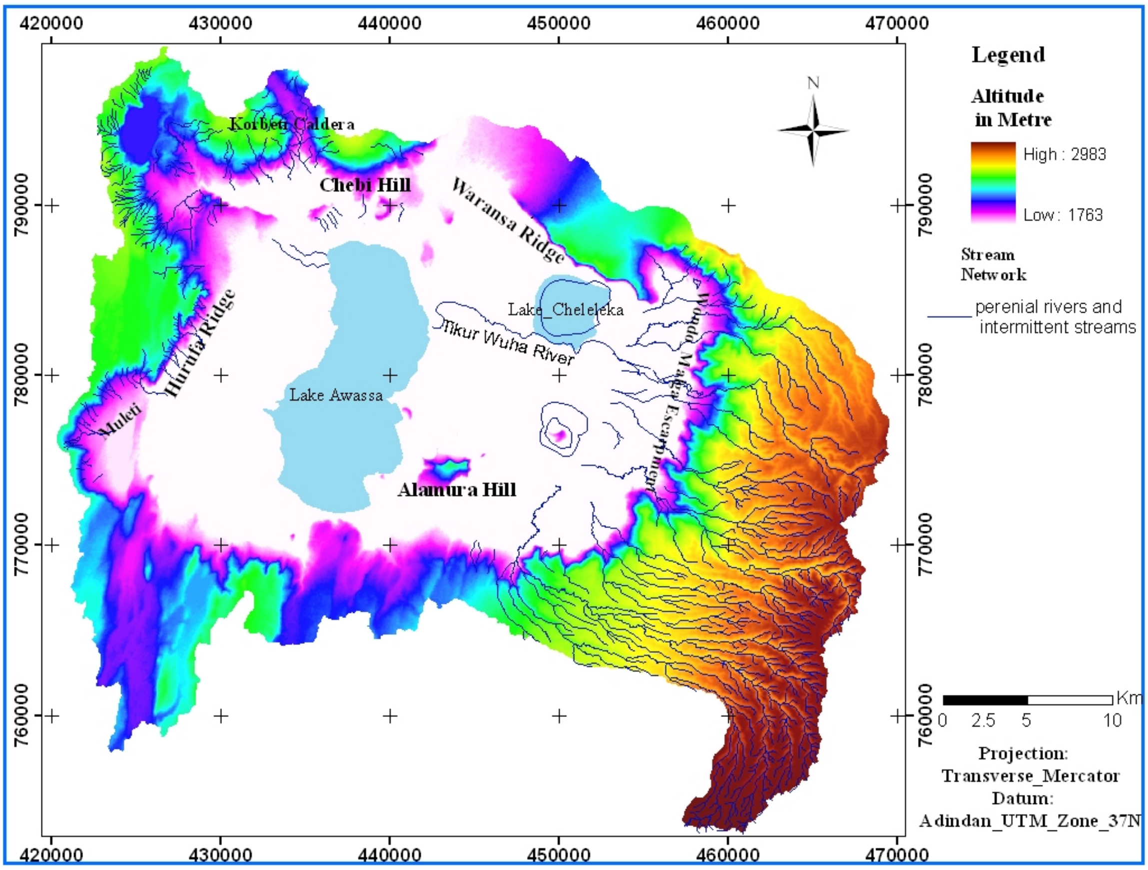

Fig.2.6. Relief and Drainage Map of the Basin

With in the basin the wetter south eastern part is drained by some perennial and intermittent streams. Rivers such as; Wesha, Lango, and Werka drain to Lake Cheleleka. While rivers Shenkora, Gemesho, Wedesa and Kerama drain to cheleleka swamp before reaching the Lake. These streams constitute the Tikur Wuha river drainage which, finally drains from Cheleleka swamp to Lake Hawassa (Girma Urgecha, 2005).

2.5. Soil

Soil formation is a factor of climate, parent rock material, the nature of the landform, soil organisms and time. Due to geology and time the soils of the basin are relatively young. These are derived from the late tertiary to quaternary volcanic rocks. According to 1:250,000 scale classifications, the soils of the catchment are Chromic and Haplic Luvisols; Chromic, Vertic and Eutric Cambisols; Vitric Andosols and Leptosols (MWR, 2007). Soil characteristics of the catchment area are briefly summarized in table 2.1.and figure 2.7.

Table 2. 1. Major Soil types, soil units, and their characteristics

Major soil type	Soil units	Texture	Consistence	Drainage
Andosols	Vitric Andosol	Medium and Coarse texture	Very friable, slightly sticky to non-sticky and slightly plastic to non-plastic	Well to excessive
Cambisols	- Eutric -Chromic - Vertic	Fine and medium texture	Friable, Slightly sticky to very sticky and slightly plastic to very plastic	Very poorly to excessive
Leptosols	Leptosol	Medium texture	Friable, slightly sticky and slightly plastic	Excessive/well
Luviols	Haplic Luvisol Chromic Luvisol	Fine and Medium texture	Friable to firm, sticky to very sticky and plastic to very plastic	Well

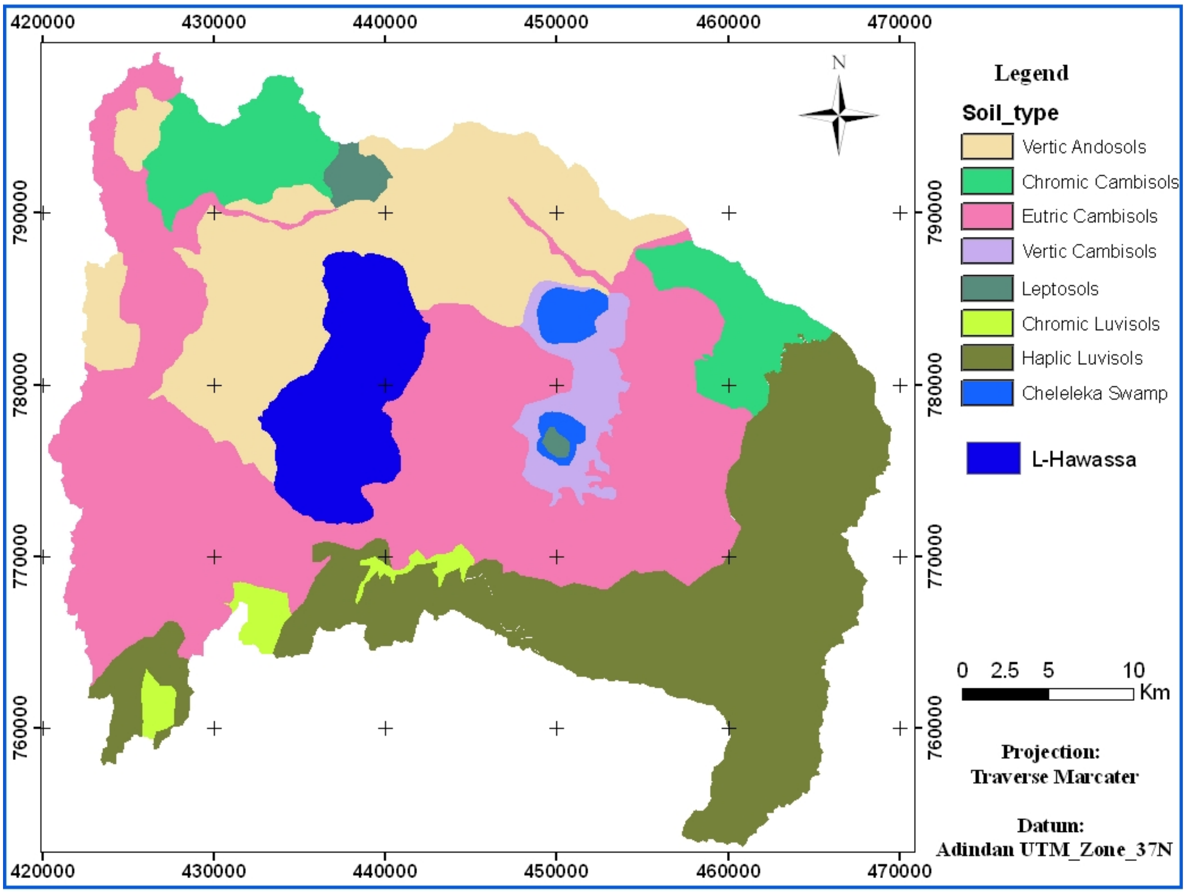

Fig.2.7. Soil Classification of Map

Source: Ministry of Water Resources

2.6. Socio-economic Setting

The study area covers people of two regional states with diverse socio-cultural attributes. The diverse agro ecological setting, as a result of wide range of altitude and the heterogeneity of cultural identities of the community makes the area to support different livelihood systems. The southeastern part of the catchment is densely populated with enset favorite Sidama people with a density of about 1000 people per Sq. Km (Table 2.2). The area is known in perennial cash crop production such as *Chat*, Coffee, Sugar cane, Avocado, *Enset* (indigenous to Ethiopia). *Enset* is the main staple food crop. People of same cultural origin occupied the western and southwestern part with a population density up to 500 people per Sq. km. However, due to semi-arid climatic condition and erratic rainfall maize the main agricultural produce and the people have been food in-secured for long and the area is the noticeable part of environmental degradation (BoARD, 2007).

The northern part of the catchment is settled by the Oromo agriculturalists. Maize and potato are popular agricultural produce. The main livelihood system of the people of the northwestern end of the catchment is agro-pastoral. The people are the Arsi Oromo pastoralists whose activities are largely based on livestock herding and dairy production.

Though physical factors affect the economic activities to a certain extent, the socio-economic activities of people play an important role on the land use and natural resource use pattern of the community. The people in the southeastern part practice agro-forestry and more than 60% of their agricultural produce is market oriented cash crops. Thus, they have sufficient income for living expenditure; their dependence on natural resources is marginal.

On the other hand the western maize and the northwestern agro-pastoral livelihood regions do not produce sufficient for their consumption demands. They have long been under food aid and depend on natural resources such as firewood and charcoal sale as source of income. As a result deforestation and land degradation are severe and become major environmental problems in the area.

Table 2. 2. The population Distribution of Hawassa_Hawassa Catchment (2007)

No.	Woreda	Region	Population (No.)	Area (Km^2)	Population density
1	Hawassa zuria	SNNPR	114,104	248.97	458
2	Boricha	SNNPR	33,630	83.68	402
3	Wondogenet	SNNPR	152,298	225.00	677
4	Malga	SNNPR	91,783	166.40	552
5	Gorche	SNNPR	29,943	45.47	659
6	Shebedino	SNNPR	36,921	38.33	963
7	Siraro	Oromia	10,903	46.51	234
8	Shala	Oromia	15,944	78.35	203
9	Shashemene	Oromia	47,815	148.52	322
10	Koffele	Oromia	8,562	31.51	272
11	Hawassa City Admin.	SNNPR	254,607	154.11	1652

Source: CSA, Population and Housing Census (2007)

CHAPTER III

3. LITERATURE REVIEW

3.1. Overview of Land Degradation

Land degradation is a composite term; it has no single readily-identifiable feature, but instead describes how one or more of the land resources (soil, water, vegetation, rocks, air, climate, relief) has changed for the worse. According to UNEP (1999), land degradation is the temporary or permanent lowering of the productive capacity of land. The U.N. Convention to Combat Desertification defines land as “the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system”, and land degradation as “reduction or loss of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from processes such as; (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, biological or economic properties of the soil; and (iii) long-term loss of natural vegetation”. Land Degradation adversely affects the productive, physiological, cultural and ecological functions and system dynamics of land resources, such as; soils, water, plants and animals. As a result it covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of crop lands and rangelands (UNU, 2007).

Soil degradation refers to the temporary or permanent decline in the productive capacity of soil (FAO, 2000). Soil degradation in broader terms can be defined as the change in physical, biological and chemical properties of soil. Thus, due to degradation agents such as; moving water, wind, sedimentation, water lodging, and prolonged cultivation the properties of soil is altered for the worst in its productive capacities (Ibid). However, soil erosion describes only the physical deterioration of the soil. Therefore, soil erosion refers to the wearing away of land surface by water and/ or wind as well as to the reduction in soil productivity due to the physical loss of topsoil, reduction in rooting depth, removal of plant nutrients and loss of water (Mahmud, et al, 2005).

World wide, land degradation has affected some 1.9 billion hectares of land. The loss of potential productivity due to soil erosion is estimated at 20 million tons of grains per year (UNEP, 1999). Particularly, in developing countries the competition on limited resources and poverty exacerbated the degradation of natural resources.

Land degradation, mainly soil and vegetation degradation has been identified as major environmental problems in Africa. Soil degradation has affected an estimated 500 million hectares of land, including 65% of the cultivated land. About 90 % of African soils are deficient in phosphorus a key nutrient in the production of biomass. The soils have low content of organic matter, and low water infiltration retention capacity due to surface crusting. More over, about half the cultivable land is under arid and semi arid conditions, so potential for irrigation is limited (FAO, 2000b). Regarding deforestation, according to FAO (1990) the total area of tropical forests in 1990 was estimated at 530 million hectares compared to 569 million hectares in 1980 with 0.7% annual rate of deforestation.

According to (FAO 2000a) documentation the various processes of land degradation have been grouped into six classes; water erosion, wind erosion, soil fertility decline, salinization, water logging, and lowering of the water table. However, there are other forms of land degradation such as deforestation, forest degradation and rangeland degradation.

3.2. Land Degradation in Ethiopia

Land degradation is a serious problem in Ethiopia, both in the highlands and low lands. Apart from the expanding desertification and the recurrent drought the land and water resource base of the country is highly threatened by deforestation, over cropping, over grazing, and massive dependence on fuel wood among others. However, soil degradation and deforestation are major forms of environmental degradations which directly or indirectly affects land productivity and thereby results into food insecurity.

The main factors determining land degradation are overgrazing, over cultivation with no fallowing, extensive clearing of vegetation for agriculture and fuel wood; deforestation; extensive cultivation of marginal lands; the use of inappropriate agricultural technology; poor management of arable land ; topography and soil characteristics among others. Generally environmental degradation, mainly soil depletion, and deterioration of vegetation cover, are among the major factors that results into decline in land productivity such as; farm lands, pasture, rangeland, forest and woodlands. Studies by FAO states that soil erosion is the most widely recognized cause of falling productivity; and the effect may include diminished food security, reduced calorie intake, economic stress and loss of biodiversity (FAO, 2000b).

The Ethiopian Highland Reclamation studies revealed that the Ethiopian highlands, which cover 44% of the country's total land area, are seriously threatened by land degradation. The country is noteworthy as the country of famine. Food shortages are endemic and since 1970 severe famine has occurred almost once a decade (1973; 1982 – 1984 early and late 1990's and 2002 –2003). As it is obvious, most of the agricultural production system is located on the Ethiopian Highlands where larger amount of the population lives. Nationally, forest reserves have been heavily depleted sequentially over much of the 20^{th} century from over 40 percent to around 2.7 percent in today (Berry, 2003). On average Ethiopia losses 12 tons of soil per hectare per year, and 1493 million tons of soil per year due to water erosion. On the other hand, the soil formation rate for Ethiopia is less than 2 ton hectare per year, which is very low compared to soil erosion rates. Annually, Ethiopia loses about 1-1.5 million tons of grain due to soil erosion (Hunri, 1988; Muhammed, *et al*., 2005).

The problem of arriving at a mutually agreed definition arises from continuously changing perceptions on what constitutes land degradation, its causes, processes and manifestations. This has led to the development of non-comprehensive land degradation assessment methods that focus on particular aspects of land degradation, either soils or vegetation. In the present study area a form of land degradation, that is soil erosion, is assessed.

3.3. Assessment of Erosion Hazard

3.3.1. Forms of Soil Erosion

There are various forms of water erosion such as; rain splash, overland flow/ sheet/ sub-surface flow, rill and gully erosion (Morgan, 1993).

Sheet erosion is soil movement from raindrop splash resulting in the breakdown of soil surface structure and surface runoff; it occurs rather uniformly over the slope and may go unnoticed until most of the productive topsoil has been lost. This type of erosion is observed in about 60% of the sub-basin. Its severity level is slight to moderate.

Rill erosion: Rill erosion results when surface runoff concentrates forming small yet well-defined channels. These channels are called rills when they are small enough to not interfere with field machinery operations. The same eroded channels are known as gullies when they become a nuisance factor in normal tillage. Rill erosion has slightly affected the plain, ridges, medium and high gradient hills and escarpments of the sub-basin.

Gully erosion: Gullies are relatively permanent steep-sided water courses which experience ephemeral flows during rainstorms. Compared with stable river channels which have a relatively smooth, concave –upwards long profile, gullies are characterized by a headcut and various steps or knick-points along their course. Gully erosion is the most noticeable form of water erosion, which removes the soil by large channels or gullies caused by concentrated runoff. Gully erosion cannot be removed by ordinary tillage practice.

3.3.2. Modelling soil erosion

The Universal Soil Loss Equation (USLE) and its derivative revised USLE are universally used models for erosion hazard assessment. The first attempt to develop soil loss equation for hill slopes was initiated by Zinge (1940) based on steepness and slope length. Further developments led to addition of climatic factor based on the Maximum 30-min rainfall by Musgrave (1947). Then Smith (1958) included a crop factor, a conservation factor and soil erodibility factor. Finally, in Wischmeier & Smith (1962) produced the universal soil loss equation by converging climatic factor to rainfall erosivity (Morgan, 1993).

Most of the models used in soil erosion assessment are of the empirical grey-box type. They are based on defining the input factors and, through the use of observation, measurement, experiment and statistical techniques relating them to soil loss. Although this approach was found to be unsatisfactory in meeting the model objectives in assessing spatial variability of soil erosion, the advancement in knowledge of how erosion system functions and responds to changes in controlling factors have made significant progress in stratification of factors for landscapes and geographical areas.

Universal soil loss equation (USLE) is an empirical model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping and management systems. It was developed for predicting erosion on a cultivated field so that erosion control specialists could choose the kind of measures needed in order to keep erosion within acceptable limits given the climate, slope and production factors (Morgan, 1986).

Erosion is seen as a multiplier of rainfall erosivity (the R factor, which equals the potential energy); this multiplies the resistance of the environment, which comprises K (soil erodibility), SL (the topographical factor), C (plant cover and farming techniques) and P (erosion control practices). Since it is a multiplier, if one factor tends toward zero, erosion will tend toward zero (Wischmeier and Smith, 1978).

The equation is:

A=R*K*L*S*C*P, …..(equation. 3.1).

where:

(i). **R, the rainfall Erosivity,** equals E, the kinetic energy of rainfall, multiplied by I30 (maximum intensity of rain in 30 minutes expressed in cm per hour). This index corresponds to the potential erosion risk in a given region where sheet erosion appears on a bare plot with a 9% slope.

(ii). **K, Soil erodibility,** depends on the organic matter and texture of the soil, its permeability and profile structure. It varies from 70/100 for the most fragile soil to 1/100 for the most stable soil. It is measured on bare reference plots 22.2 m long on 9% slopes, tilled in the direction of the slope and having received no organic matter for three years.

(iii). **SL, the topographical factor,** depends on both the length and gradient of the slope. It varies from 0.1 to 5 in the most frequent farming contexts in West Africa, and may reach 20 in mountainous areas.

(iv). **C, the plant cover factor,** is a simple relation between erosion on bare soil and erosion observed under a cropping system. The C factor combines plant cover, its production level and the associated cropping techniques. It varies from 1 on bare soil to 1/1000 under forest, 1/100 under grasslands and cover plants, and 1 to 9/10 under root and tuber crops.

(v). Finally, **P, support practice factor,** takes account of specific erosion control practices such as contour tilling or mounding, or contour ridging. It varies from 1 on bare soil with no erosion control to about 1/10 with tied ridging on a gentle slope.

3.4. Environmental Stress

The environment is a composite term which includes all the resources that supports all life forms on planet earth. The major environmental resources, i.e. land, water, forests, soil and trees as well as other forms of biodiversity, if not interfered, keeps the equilibrium of environmental system dynamics in one hand, and meet the basic needs for human survival such as food, water, clothing, shelter and clear living environment on the other hand (EPA, 1997). The pressure on the environment caused by human activities such as deforestation over cultivation, overgrazing, pollution, and by natural events such as drought refers to environmental stress. Environmental stress is compounded by population growth, resulting in declining resources and higher demand, and this will be a likely factor that intensifies conflict over the coming decades, UNEP (2009) argue.

Although some aspects of environmental problems are caused by natural factors such as; drought and desertification, most of it is poverty derived by human activity. Soil degradation, mainly soil erosion coupled with climate variability, population pressure, pest infestations, declining farm size, technological gaps, poor infrastructure and inadequate institutional support have been resulting in serious environmental stress (Awedenegest M; Holden N.M. 2007).

Ethiopia faces rapid population growth, that contribute to the environmental stress, which manifests it self in land and water degradation and loss of biodiversity caused by low agricultural productivity and high dependence on fuel wood. In order to meet the challenges of environmental stress, it is necessary to understand the relationships among natural resource management, technology, and agricultural productivity.

3.4.1. Livelihood System

The usefulness of livelihood based approaches to development has been recognized since late 1980s when the concept was popularized by international agencies such as; World Commission on Environment and Development (WCED). The growing popularity of livelihoods as analytical construct led shifts in development thinking towards participatory, people centered and holistic approach to development intervention. Livelihood approaches reflect the diverse and complex realities faced by poor people in specific contexts. Livelihoods analysis can identify causal factors behind vulnerability and food insecurity (Devereux S. *et al*., 2004).

Chambers and Conway defined livelihood as it comprises the capabilities, assets and activities required for a means of living. According to them a livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base. The most widely used concept of Rural Livelihood is the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from shocks and stress and maintain and enhance its capabilities and assets both now and in the future, whilst not undermining the natural resource base (Rick., et al., 2002).

Population growth and pressure on limited resources is becoming a major environmental issue during the last three decades in Africa. Among many environmental issues facing African population, majority of which derive their livelihood from subsistence farming and pastoral life, are drought and desertification which are believed to be major derivers of environmental stress. The expansion of the Sahara desert to the sahelian zone, further south and towards East Africa, is major manifestation of environmental stress in Africa. Droughts of the mid-1980s adversely affected more than 40 million people in sub-Saharan Africa (Oroda A.S., 2001).

Conditions of high absolute poverty induce the poor to become both agents and victims of environmental stress. In order to survive in a subsistence economy, farmers are forced to mine soil and cut down trees leading to land degradation and deforestation. Thus environmental stress becomes a result and a cause of economic stagnation and decline in productivity.

Consequently, environmental stress impacts human well being and livelihood through food insecurity and poverty. The poor are mostly the causes as well as the most vulnerable ones for the risk of environmental stress (Berry, 2003).

3.4.2. Climate Variability

Climate consists of several elements. The major ones are temperature, rainfall and other deriving indices like evaporation, humidity, etc. Rainfall is one of the most indispensable elements of climate that determine the lifeline of poor agrarian economies like Ethiopia. In tropics rainfall is an essential element used to delineate homogeneous climatic region. The annual and spatial pattern of rainfall in Ethiopia is drastically modified by relief, global circulation of the atmosphere (weather systems) and orientation of slopes to the main rain bearing winds.

The year-to-year variation of rainfall is mainly a good indicator of the changes in other components in the climate system. It is to be noted that the growth of Ethiopian economy is highly influenced by climate variability particularly drought.

The Sub Saharan African countries, in general, and Ethiopia in particular, have been constantly and severely affected by drought epidemic. According to NMSA (1996) "different types of drought such as meteorological, hydrological, agricultural, and economical are known in every day life". Although drought occasionally occur due to natural incidences such as change in the direction of wind and pressure belts most often it is caused by harmful human activities such as deforestation, overgrazing, bad agricultural practices and so on. During the recent decades meteorological droughts have been frequent phenomenon almost to the entire Ethiopia. For instance, according to NMSA in the 1980s Ethiopia has experienced two worst droughts (1984 and 1987). In the respective periods about 7.9 million and 5.2 million people were severely affected. In recent years drought happens to occur every year and become a common issue for our country. In recent times drought has been occurring every year in the region especially in the lowland and southeastern parts. Based on the DPPA report for SNNPR, two major droughts occurred in 1992 and 1995 E.C., and about 1,357,877 and 1,629,600 people were affected respectively (BoARD, 2007).

As drought is the immediate effect of rainfall variability and/or shortage of rainfall, the degree of rainfall variability explains the level of induced environmental stress.

3.5. Estimation of Degree of Environmental stress

In spatial analysis to meet a specific objective involving several parameters, a procedure known as Multi-Criteria Evaluation (MCE) is used in decision making. A criterion is some basis for a decision that can be measured and evaluated. A factor is a criterion that enhances or detracts from the suitability/stress of a specific alternative for the theme under consideration. But a constraint serves to limit the alternatives under consideration. In many cases, constraints will be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with zero and those open for consideration being coded with one (Parveen, 2005).

Multi-criteria evaluation (MCE) is most commonly achieved by one of the two procedures. Each method is characterized by different levels of control over tradeoff between factors and the level of risk assumed in the combination procedure. The first involves Boolean overlay, most simplistic type of aggregation, whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as; intersection (AND) and/or union (OR). The second is known as weighted linear combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. The weighted linear aggregation method multiplies each standardized factor Map (i.e., each raster cell within each layer) by its factor weight and then sums the results (Parveen, 2005).

In this study, since some of the indices used in estimating the degree of environmental stress are continuous factors, weighted linear combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, was used for pair wise weighting of the parameters and then applied weighted average.

CHAPTER IV

4. DATA SOURCE, MATERIALS AND METHODS

4.1. Data Source and Materials

The present research results were achieved with the utilization of different materials, spatial and attribute data /both primary and secondary/ and information collected in the study area such as; farmers perception, farm management practices, soil and water conservation practice, etc.

Both primary and secondary data sources were used. The primary data has two sub-categories, these include, data generated from remote sensing such as; satellite imageries, Shuttled Radar Terrain Model (SRTM), Global Positioning System (GPS) surveying. The second category includes, information collected from field using observation, focus group discussion, key informant interviews in the study area. Most of the spatial data is generated from DEM and Satellite Imageries in combination with ground control points collected using GPS.

On the other hand, secondary data such as; shape files, meteorological data, agricultural survey reports; data on soil conservation and farm management were collected from the concerned Federal, Regional, and Zonal Governmental organizations and development stakeholders in the area.

The main material used during the present study includes;

- Landsat imageries: Landsat5 TM and Landsat7 ETM+ with spatial resolutions of 28.5m with acquisition date of 21 of Jan. 1986 and 3rd of Dec. 2005 respectively were used in land cover classification and change analysis.
- Topographic Map: sheets of 1:50,000 scale covering the study area with sheet code and Name: 0738-C4 Hawassa, 0738-D4 Shashemene, 0638-A2 Leku and 0638-B1 Wijigra were used
- Meteorological data, mainly rainfall and temperature time series data from 1970s to 2005 were collected from National Meteorological service Agency
- GPS and Digital Camera: were used for the ground truthing field data collection.
- Census Map: 2007 Population and Housing census Map of the study area was collected from CSA.

- SRTM-DTED: NASA source DEM with a spatial resolution of 30m with acquisition date of Feb. 2000 by US was collected from Ethiopian Geological Survey.
- Soil and hydro geologic data were collected from Ministry of Water Resources.
- Socio-economic data: population number, soil and water conservation data, and livelihood data.

4.1.1. Soft wares used

ERDAS Imagine 8.6 and ENVI 4.2 were used for satellite image processing, land use land cover change analysis, and for accuracy assessment; Global Mapper 8, 3dem, ArcGIS9.1 and Idrisi32 were used for GIS based DEM processing, overlay and multi-criteria analysis, and for meteorological data processing. Besides, MS office packages including Visio 2003 were used for chart making, tabulation and word processing.

4.2. Methodology

Three major stages were executed as methodology in the present research work. First stage, satellite image processing, land use land cover classification, and change detection were conducted. Second stage includes, erosion hazard modeling using Universal Soil Loss Equation adapted for Ethiopia and applicable to the study area, and finally the degree of environmental stress was identified by integrating climatic attributes such as; rainfall variability, human interaction with the natural environment i.e., livelihood system, vegetation indices and erosion hazard using GIS based multi-criteria evaluation.

4.2.1. Image Classification Methods

Image classification is a power technique to drive thematic classes from multi-band image data. Multi–spectral image classification was used to extract thematic information from satellite images. Image preprocessing including band ratio, NDVI, PCA, tasseled cap, haze correction, re-projection were performed to correct the surface features reflectance characteristics.

Later, the land use land cover maps were produced from Landsat5 TM of 1986 and Landsat7 ETM+ of 2005, by a hybrid classification procedure combining both unsupervised classification with Maximum Likelihood supervised classification (Fig.4.1). The hybrid classification method was chosen, since it involves feature identification through both spectral and spatial pattern recognition and improves accuracy and efficiency of the classification (Lillesand and Kiefer, 2000). Using signature editor of unsupervised classes, supervised categorization of image pixels were made on the basis of their pixel by pixel spectral reflectance and spatial relationships of pixels with pixels surrounding them.

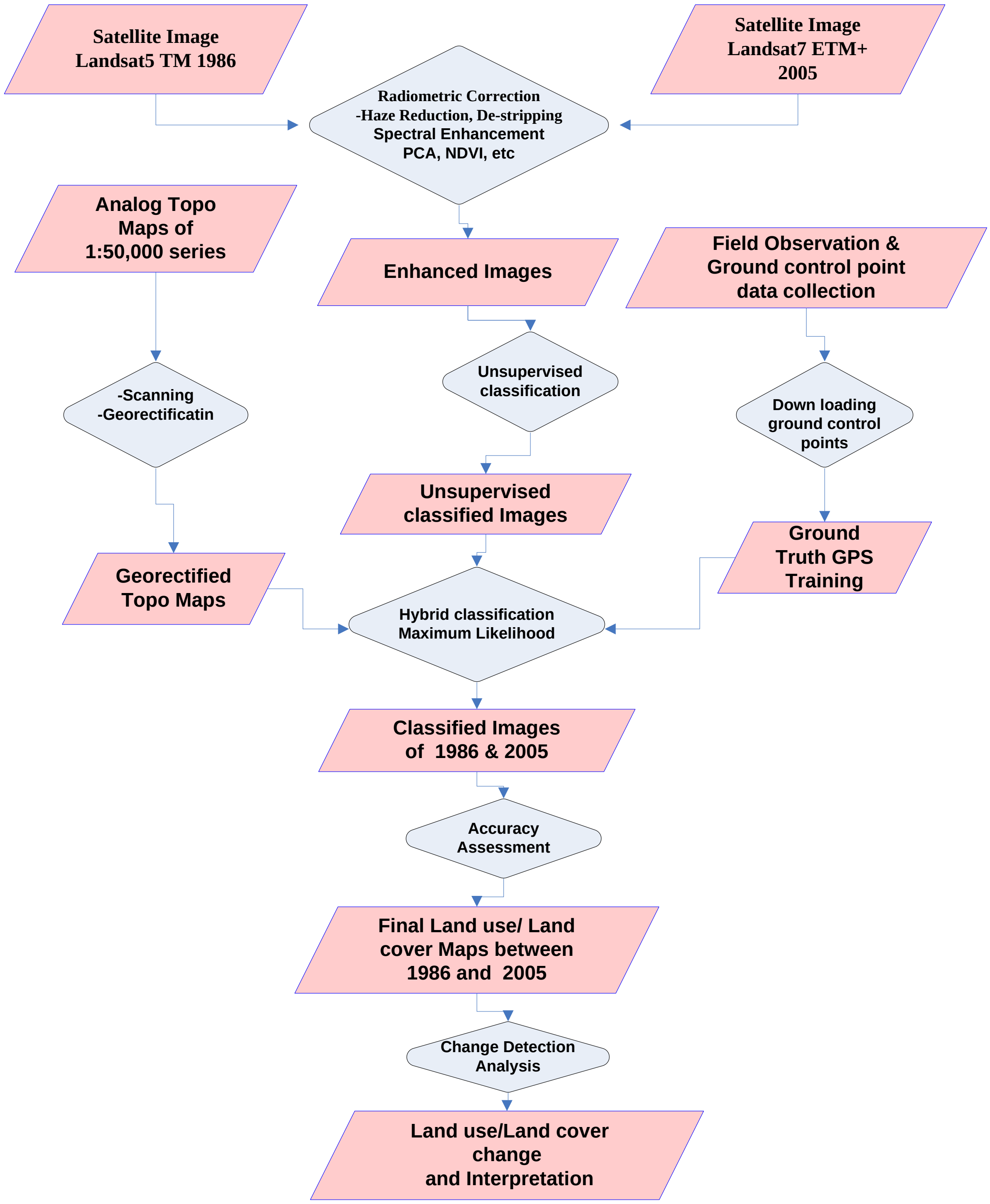

Fig. 4.1. Flow Chart of Land Use/ Land Cover classification

4.2.2. Erosion Hazard Estimation Method

The Universal Soil Loss Equation (USLE) which is adapted to the Ethiopian condition was used (Fig. 4.2). The equation is; A=R*K*L*S*C*P

Where;

A = Computed soil loss per unit area S = Slope steepness factor K = Soil erodibility factor

P = Support practice factor L = Slope length factor

R = Rainfall and runoff factor C = Cover and management factor

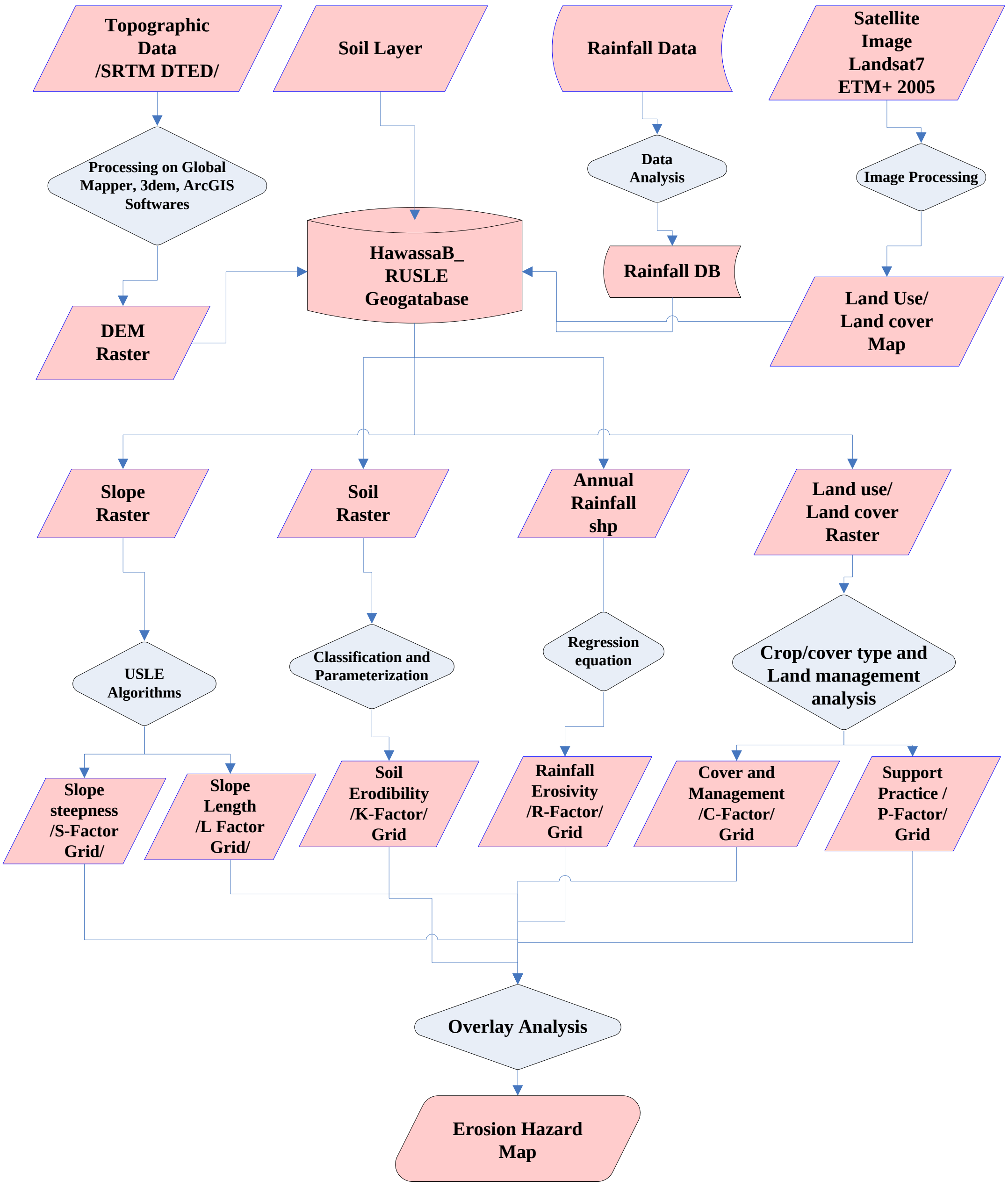

Fig. 4. 2. Flow Chart of RUSLE Modelling

4.2.3. Methods of Estimating Degree of Environmental Stress

In estimating the degree of environmental stress, indices of erosion hazard, Vegetation index, rainfall variability, and Livelihood (land use) system were used (Fig.4.3). Multi-criteria evaluation (MCE), which is based on *weighted linear combination* (WLC) wherein continuous criteria (*factors*) are standardized to a common numeric range, was used for pair wise weighting of the parameters. The factors are weighted based on previous studies by government organizations, expert knowledge and farmer's perception on environmental stress.

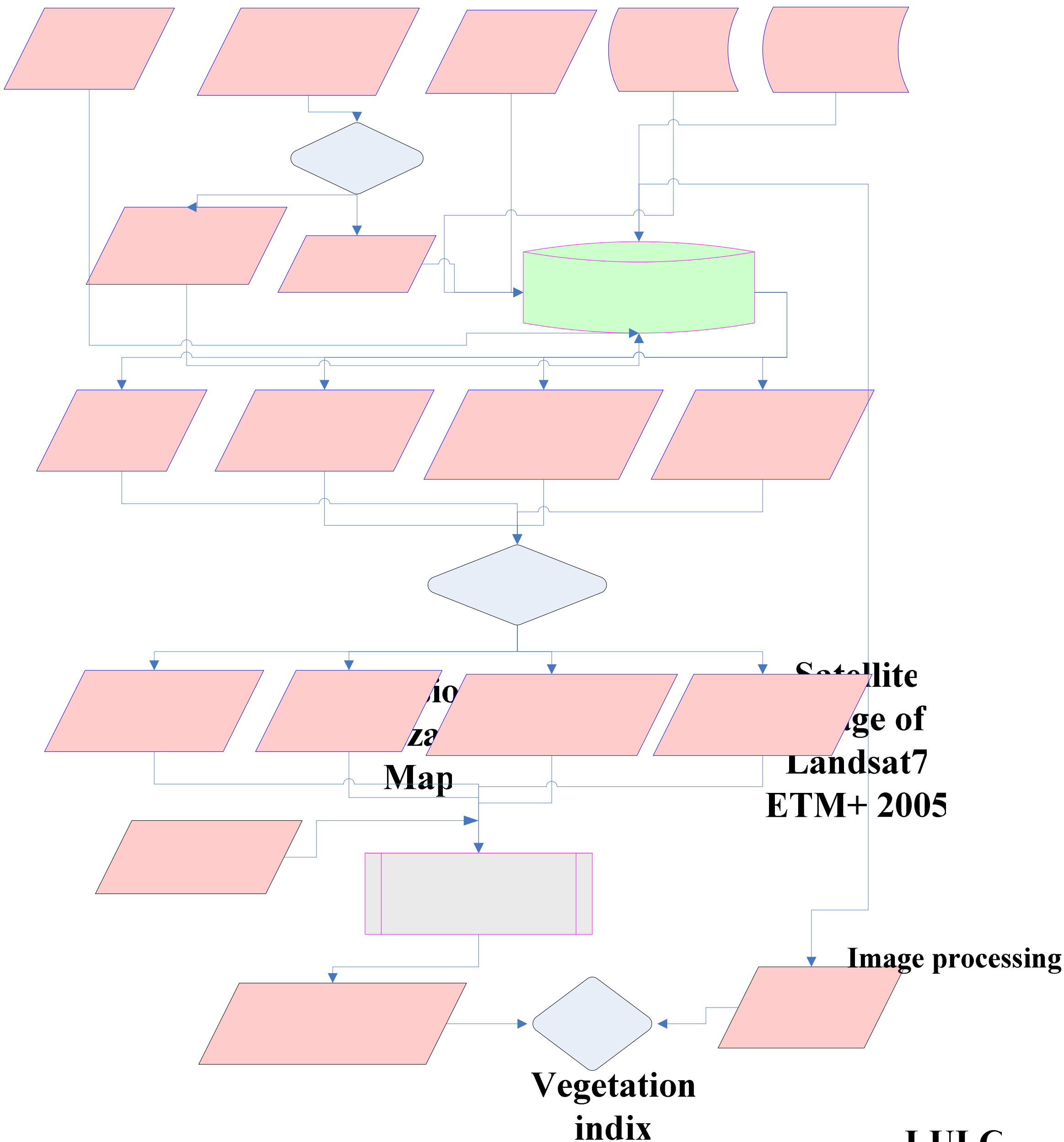

Fig. 4. 3. Flow Chart of Estimating Degree of Environmental Stress

CHAPTER V

5. DATA PROCESSING AND ANALYSIS

5.1. Database Development

Geodatabase organizes spatial data into a hierarchy of data objects. These data objects are stored in feature classes, object classes, feature datasets and raster datasets. An object class is a table in geodatabase that stores non-spatial data. All the geographical data features must contain spatial reference. The spatial reference describes the coordinate system, the spatial domain and data precision of the feature. In the present research work Adindan_UTM_Zone_37 coordinate system has been used. Image files were organized in a folder system and all the feature datasets, raster grids and object classes were organized in personal geodatabase described as L_Hawassa_Erosion. In addition, all the layers in this study are prepared in 1:250,000 scale.

5.2. Land Use/ Land Cover Analysis

5.2.1. Satellite Image processing

Preprocessing functions involve those operations that are normally required prior to data analysis and extraction of information. Selecting appropriate satellite imagery is the first task in image data processing. In this study, the imagery of Landsat5 TM 1986 and Landsat7 ETM+ of 2005 were used. Preprocessing was conducted to remove undesirable image characteristics produced by the sensor, atmospheric effects and angle illumination. Haze correction, re-projection and image resembling, radiometric correction such as de striping of image scan lines were made using the same anniversary 2000 satellite image. For clear discrimination of surface features, spectral profile of major cover types were plotted and highly separable band curves were selected (Fig.5.1). Later from the visible, infrared and mid infrared sections Band2, Band4, and Band7 (in RGB_742 bands) were selected for false color image display.

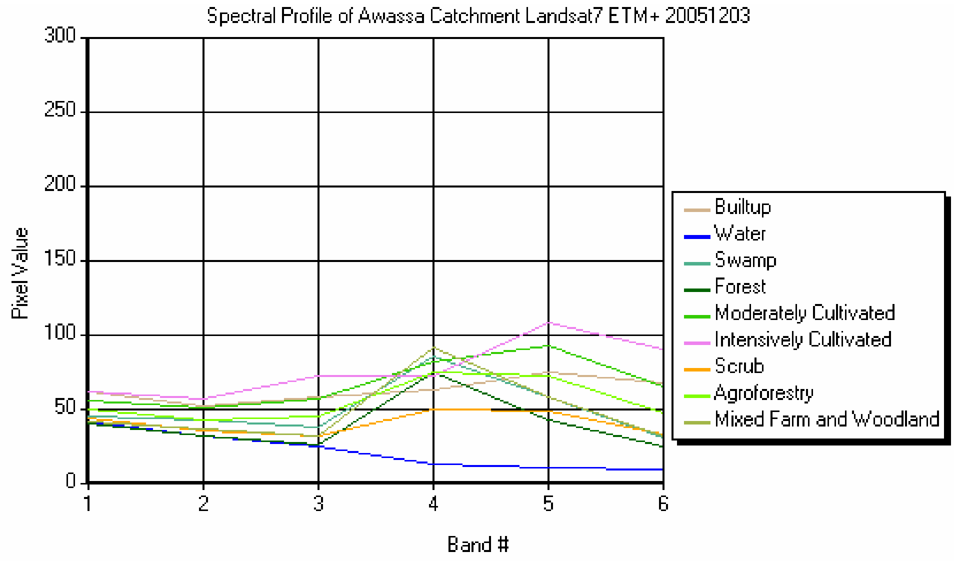

Fig. 5.1. Spectral profile of Cover types in Lake Hawassa Catchment

As the objective of image processing was land use land cover analysis, band rationing, NDVI, PCA, and Tasseled cap were performed to clearly discriminate land cover features.

5.2.2. Image Classification

Land cover mapping is mainly performed to obtain an inventory of land resources and for monitoring and land management practices (Lillesand and Keifer, 2000). In its broader sense, Land cover includes every thing from crop type, water bodies, infrastructure, snow and ice, and biomass including tundra, rainforest, grass land and barren land. Land covers undergo changes due to natural or man made causes over time. Spatial and temporal dimensions characterize changes.

Image classification is performed for the extraction of distinct classes or themes, land use and land cover categories from satellite imagery. In this study among the various classification methods, a hybrid classification procedure combining both unsupervised classification with Maximum Likelihood supervised classification was conducted. During supervised classification categorization of homogenous image pixels on the basis of their pixel by pixel spectral reflectance and spatial relationships of pixels with pixels surrounding them were conducted. Hybrid classification is particularly valuable in land classification where there is complex variability in spectral response patterns; hence this method increases classification accuracy and efficiency.

Procedurally the image classification was made first by conducting unsupervised classification for identifying the numerous spectral classes that need to be defined in order to adequately represent the land cover information classes to be differentiated in a supervised classification. This was prior to the field survey. Later, from field survey, GPS data with equal sample size from different cover classes were collected. Further, number of classes were determined, based on information extracted from field survey and unsupervised classification. Eleven classes were identified as legend (Fig.5.2, Fig.5.3). The GPS data were used for AOI training selection for the supervised classification. Following hybrid classification, Primarily 7 major classes were classified, and then rest of classes such as; swamp, built-up, mechanized farm and scrub lands were classified with supervised method, involving spatial pattern recognition.

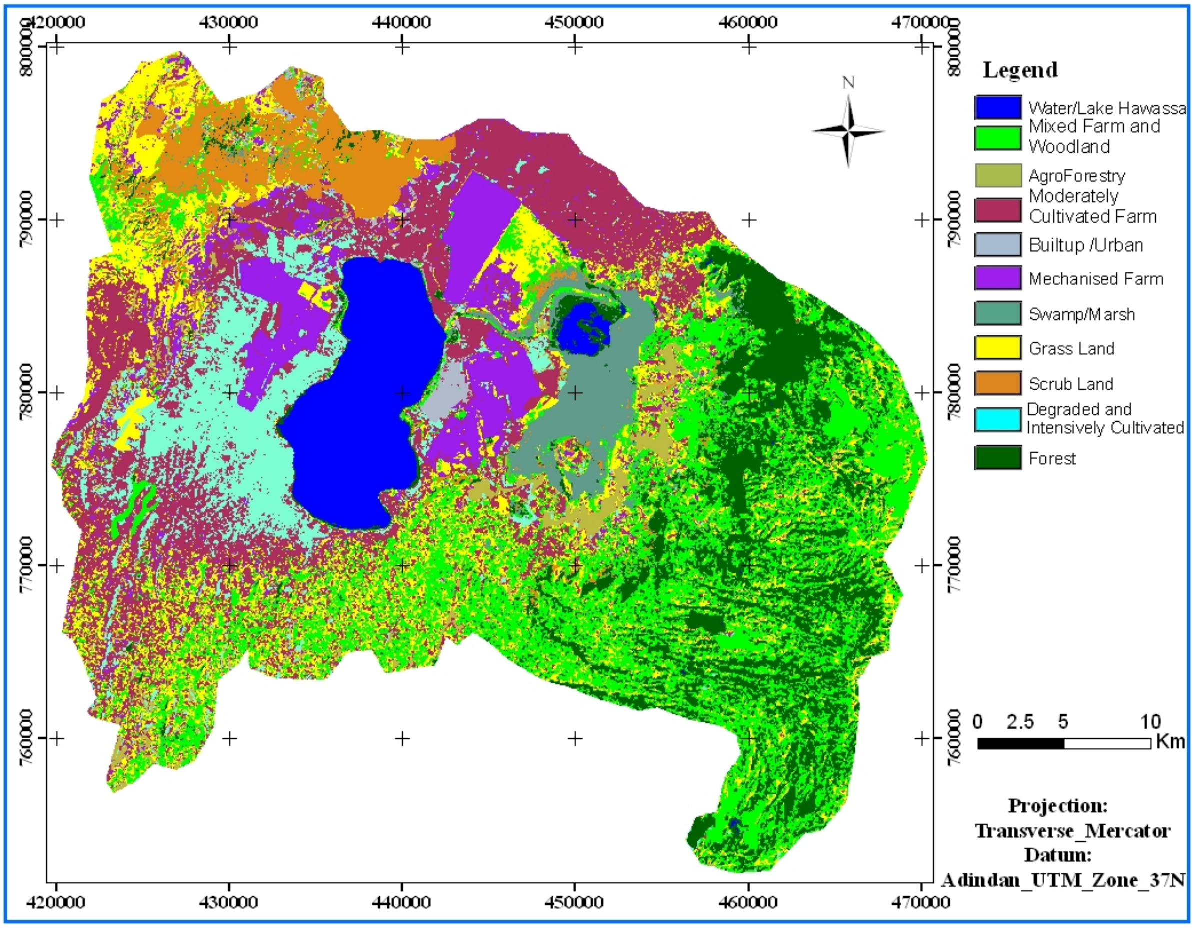

Fig.5. 2. Land Use Land Cover Map of Landsat5 TM 1986

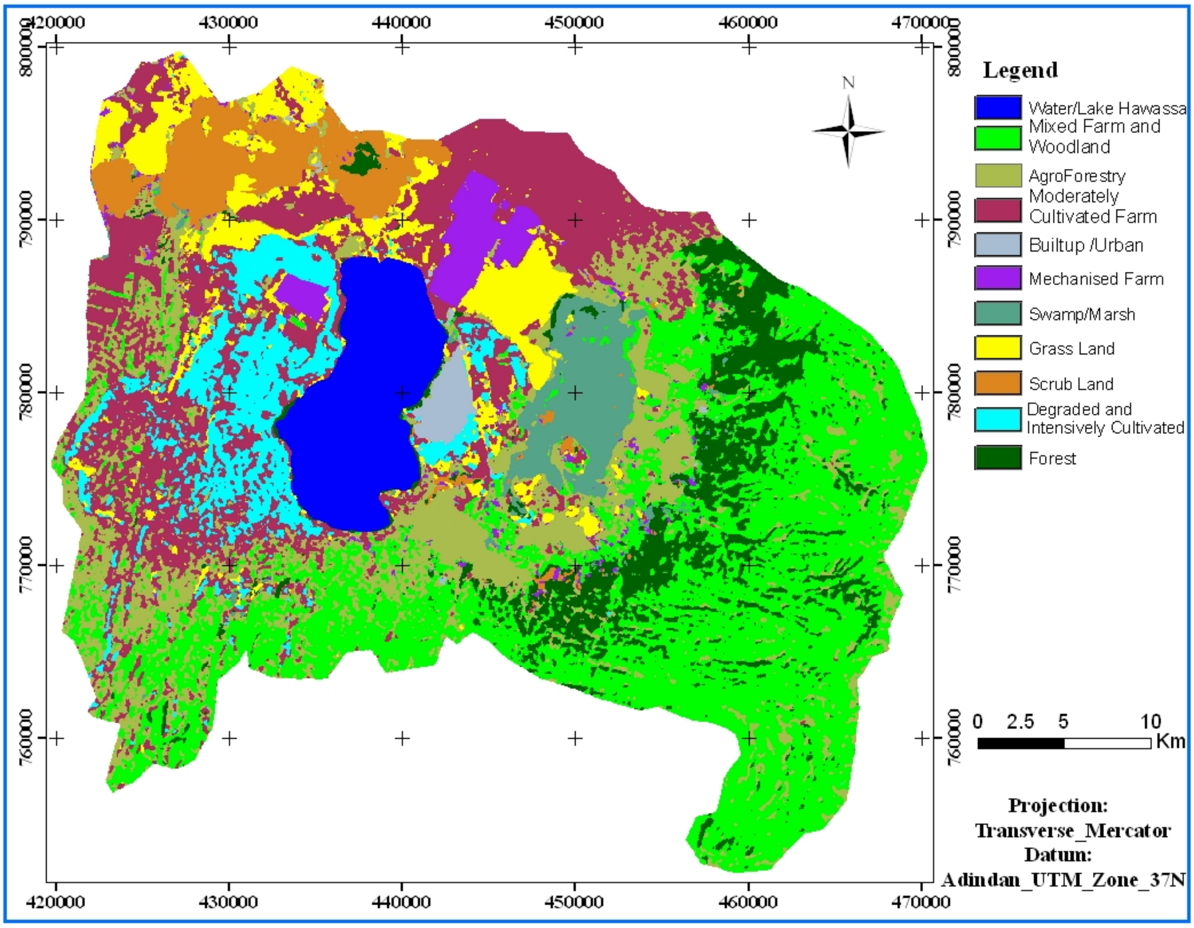

Fig. 5. 3. Land Use/ Land Cover Map of Landsat7 ETM+ 2005

5.2.3. Accuracy Assessment

The accuracy assessment is essentially a measure of how many ground truth pixels were classified correctly. In this study accuracy assessment was done for the recent satellite image of Landsat7 ETM+ 2005, for which the ground truth data is likely corresponding. An overall accuracy of 78.05% with a Kappa coefficient of 0.76 was achieved (Table5.1). The overall accuracy is a similar average with the accuracy of each class weighted by the proportion of test samples for that class in the total training or testing sets. Thus, the overall and the users' accuracy indicate the reliability of the classification for large class types land use land cover analysis.

Table 5.1. Accuracy assessment result of satellite image of Landsat7 ETM+ 2005

No.	Class Name	Reference	Classified	Number correct	Producers Accuracy	Users Accuracy
1	Water	4	4	4	100.00%	100.00%
2	Mixed F & WL	3	4	3	100.00%	75.00%
3	Agroforestry	4	3	2	50.00%	66.67%
4	Modedately Culti-Farm	4	3	2	50.00%	66.67%
5	Builtup	4	4	4	100.00%	100.00%
6	Mechanized Farm	2	3	2	100.00%	66.67%
7	Swamp	3	3	2	66.67%	66.67%
8	Grass Land	4	3	2	50.00%	66.67%
9	Scrub Land	6	6	5	83.33%	83.33%
10	Degraded land & int.- cult-Farm	3	3	2	66.67%	66.67%
11	Forest	4	5	4	100.00%	80.00%

5.2.4. Change Analysis

Changes in land use land cover can be categorized into two types; modification and conversion. Modification is a change of condition within a cover type; while, conversion is a change from one cover type to another, such as; deforestation to create cropland or pasture.

The extent of land use / land cover changes from 1986 to 2005 for Lake Hawassa catchment is presented in Table5.2. In addition, the statistics of land use/ land Cover were computed and summarized to detect the nature of major changes occurred during the two periods. The rate of change was calculated by using equation 5.1.

Rate of change R (in ha/year) = (X-Y)/Z … (equ. 5.1)

Where,

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

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

Z = interval between X and Y in years

Table 5.2. Rate of Land use/ land cover change (1986 -2005)

No.	Land Cover Type	Area in ha.			
		1986 (Y)	2005 (x)	Change	Rate of change (R)
1	Water	9,602.95	9,350.16	-252.79	-13.30
2	Grass Land	17,262.15	8,662.08	-8,600.07	-452.64
3	Degraded & Intensively cultivated	10,764.22	9,032.13	-1,732.09	-91.16
4	Moderately cultivated land	25,510.80	24,149.75	-1,361.05	-71.63
5	Built up	1,200.32	1,379.59	179.27	9.44
6	Forest	18,245.86	11,948.88	-6,296.98	-331.42
7	Swamp	5,448.43	5,516.47	68.03	3.58
8	Scrub	7,068.93	6,187.09	-881.84	-46.41
9	Mechanized Farm	10,215.26	3,843.59	-6,371.67	-335.35
10	Agro forestry	3,573.97	20,771.96	17,197.98	905.16
11	Mixed farm and Woodland	28,402.36	36,453.56	8,051.21	423.75

According to the results obtained, grassland, degraded and intensively cultivated lands, moderately cultivated land, forest, scrub land, mechanized farm, revealed negative rate of change which implies decline in area. On the other hand, built up, agro-forestry, and mixed farm and wood land have shown positive rate of change which implies increase in area coverage (Table5.2). The overall observed changes might be due to expansion of agro forestry practices, expansion of farm lands to marginal and grazing areas, and the progressive growth of Hawassa city. The pattern of change is figuratively indicated in the change statistics (Table 5.3; Fig.5.4).

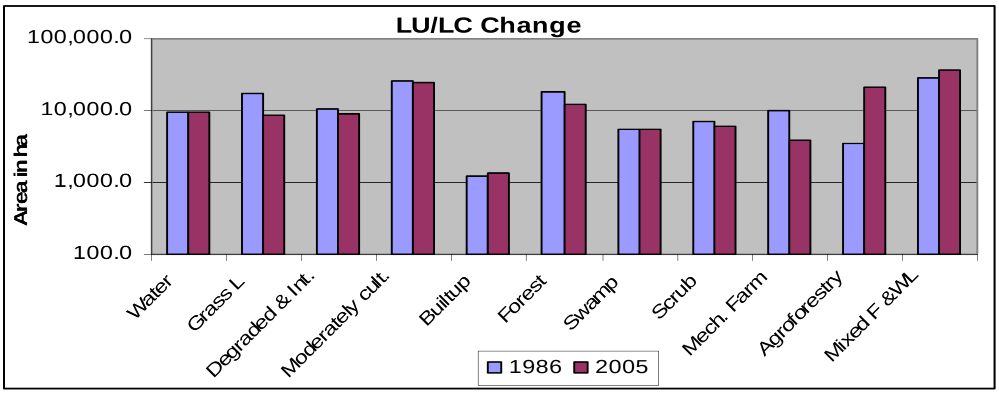

Fig.5.4. Land Use Land Cover Change b/n 1986 and 2005

Table 5. 3. Land use land covers change statistics (1986 to 2005)

		Initial State Image (Jan. 21st 1986)												
	Land Use/Land cover	**Water**	**Grass Land**	**S. Farm and Degraded Land**	**Moderately Cultivated F.**	**Built up**	**Forest**	**Swamp**	**Scrub Land**	**Mechanized Farm**	**Agro forestry**	**Mixed Farm and Woodland**	**Row Total**	**Class Total**
Final State Image (Dec. 03, 2005)	Water	8983	18	39	41	5	207	8	0	1	0	49	9351	9351
	Grass Land	39	6565	166	2649	4	10797	393	39	341	728	21629	43350	43375
	S. Farm and Degraded Land	1	6146	769	6945	56	564	596	543	1046	1922	4577	23164	23171
	Moderately Cultivated Farm	0	2822	4372	14089	111	151	187	648	2948	802	779	26909	26939
	Built up	0	51	96	274	578	11	2	46	221	1	108	1387	1387
	Forest	0	811	31	320	6	39	40	132	2282	43	398	4104	4105
	Swamp	553	287	33	206	1	546	3509	79	42	54	489	5799	5799
	Scrub Land	6	2384	511	1621	467	39	301	1124	1862	462	585	9362	9364
	Mechanized Farm	0	755	2	53	47	384	213	5037	50	4	808	7353	7359
	Agro forestry	0	96	4877	2147	7	10	1	10	1743	65	37	8992	8992
	Mixed Farm and Woodland	22	562	57	197	12	7375	245	459	20	18	3452	12418	12421
	Class Total	9604	20568	10962	28601	1299	20158	5494	8128	10566	4121	32972	0	0
	Class Changes	621	18184	6085	14511	720	12783	1985	3091	8284	2199	11344	0	0
	Image Difference	-253	-11204	-1969	-1661	88	-7737	305	-770	-6461	19050	10402	0	0

5.3. Erosion Hazard Analysis

The Universal Soil Loss Equation (USLE) model and its derivative the Revised RUSLE model are empirical models commonly used throughout the world to predict average annual soil loss per hectare resulting from rill and inter-rill (sheet) erosion. It is an empirical model to estimate soil erosion by raindrop impact and surface runoff.

The Universal Soil Loss Equation (USLE) adapted for Ethiopia (Hurni 1985) and the Renald et al., (1997) revised USLE model, with due consideration of climate and topography of the study area, were considered in this study. The parameter/ factors that participate in the model were processed with 30m by 30m cell size and while the final model output was set to 100m by 100m cell size to obtain the annual soil loss per hectare per year. Parameterization of each factor layer was performed as follows;

5.3.1. USLE Parameter Estimation

R_ Factor Estimation

The erosivity of a rainstorm is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops. The Rainfall erosivity of soil depends on the raindrop impact and the transporting capacity of runoff likely to be associated with the rainstorm i.e., on the kinetic energy of rainfall and runoff, and the rainfall intensity during specific time period (Kaltenrieder J.2007; Morgan R. 1986). Rainfall erosivity (R) is computed as total storm energy multiplied by the maximum 30min intensity in tropical regions (Morgan R. 1986; Renard et al., 1997).

$$R=EI_{30} \qquad \text{… (equ. 5.2).}$$

Where;

R = Rainfall erosivity factor in metric unit
E = Rainfall Kinetic Energy in Jm^{-2}
I_{30} = 30 minutes rainfall intensity, $mmhr^{-1}$

For the calculation of the erosivity value for a particular time span, e.g. one year, all EI_{30} indices of all storms occurred during the time are added together (SCRP 2000).

According to Hurni (1985) $R = -8.12 + 0.562*P$ … (equ. 5.3)
Whereas, Kaltenrieder-supervised by Hurni, (2007) $R= 0.36P + 47.6$ … (equ.5.4)
Where;

R= Rainfall Erosivity
P= Annual precipitation

Based on the SCRP database for Ethiopia, Hurni (1985) and Kaltenrieder (2007) R- factor estimations were compared (Table5.4). However, Kaltenrieder estimates reduce R-factor values by nearly 25 % which would have significant impact on the final USLE result. Since the study area is located partially in semi-arid climate with low rainfall, Hurni's regression equation was found more appropriate.

Table 5. 4. Comparison of Hurni (1985) and Kaltenrieder (2007) R- factor estimations

No.	Station	Annual	Hurni R-Factor	Kaltenrieder R-factor	R_Factor Difference	% Difference
1	Hawassa_32	1,025.40	568.15	416.74	151.41	26.65
2	Haissawita	1,132.00	628.06	455.12	172.94	27.54
3	Wondogenet	1,141.20	633.23	458.43	174.80	27.60
4	Kofele	1,241.10	689.38	494.40	194.98	28.28
5	Yirba	1,118.30	620.36	450.19	170.18	27.43
6	Kuyera	878.90	485.82	364.00	121.82	25.07
7	Morocho	1,419.60	789.70	558.66	231.04	29.26
8	Tula	1,108.00	614.58	446.48	168.10	27.35
9	Shamena	893.50	494.03	369.26	124.77	25.26
10	Shashemene	855.91	472.90	355.73	117.17	24.78

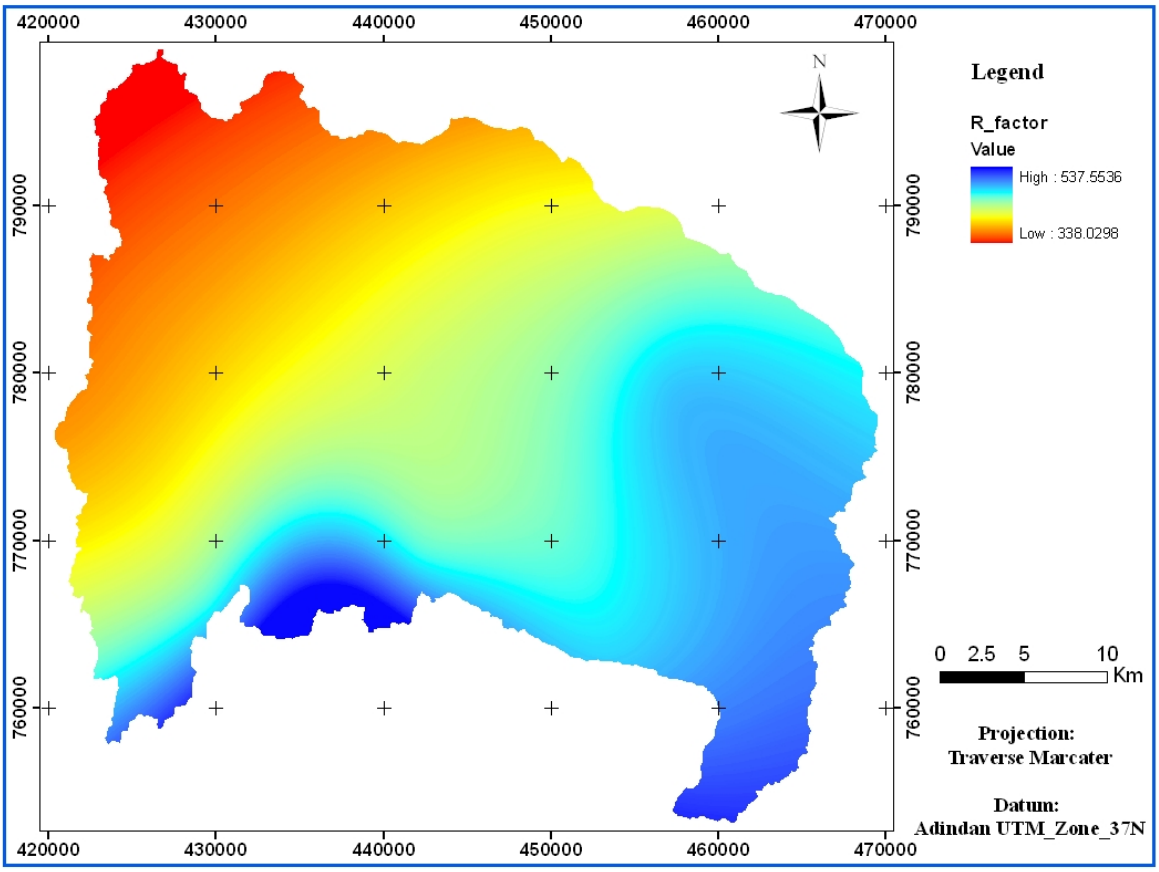

Fig. 5. 5. Rainfall Erosivity /R-Factor/ Map

The rainfall surface grid was produced using the annual rainfall distribution of 10 metrological stations within and nearby the catchment with 25 to 30 years of monthly rainfall data except for Shamena station, which is only for 3 years (Fig.5.5).

Soil Erodibility /K_Factor/ estimation

The soil Erodibility index is defined as mean annual soil loss per unit of erosivity for a standard condition of bare soil, no conservation practice, 5^o slope of 22m length (Morgan 1986). The K-factor reflects the ease with which the soil is detached by splash and surface flow. It also represents both susceptibility of soil to erosion and the amount and rate of runoff. It accounts for the influence of soil properties on soil loss on the hill slopes. The K-factor is related to soil texture, organic matter content, permeability and other factors. It is basically derived from the soil type, which is related to the grain size distribution.

In the USLE the 'K' factor is determined from monograph values (after Wischmeier, 1971) of percent silt and very fine sand and percent sand, organic matter content, soil structure and permeability (Morgan 1986). The value of K ranges from 0 to 1. Hurni (1985) in the study of Soil and Water Conservation Project (SCRP) developed a USLE for Ethiopian condition by adapting different sources and proposed the K values of the soil based on their color. In the present study Hurni adapted and modified by Rift valley Lake Basin Master Plan study K-factor estimations for different soil types is used. The K-factor for the soil types of Lake Hawassa catchment are presented in Table 5.5 and Figure 5.6.

Table 5. 5. Soil Erodibility 'K-Factor Estimated

No.	Soil Type	K_factor
1	Andosols	0.2
2	Cambisols	0.13
3	Luvisols	0.11
4	Leptosols	0.22

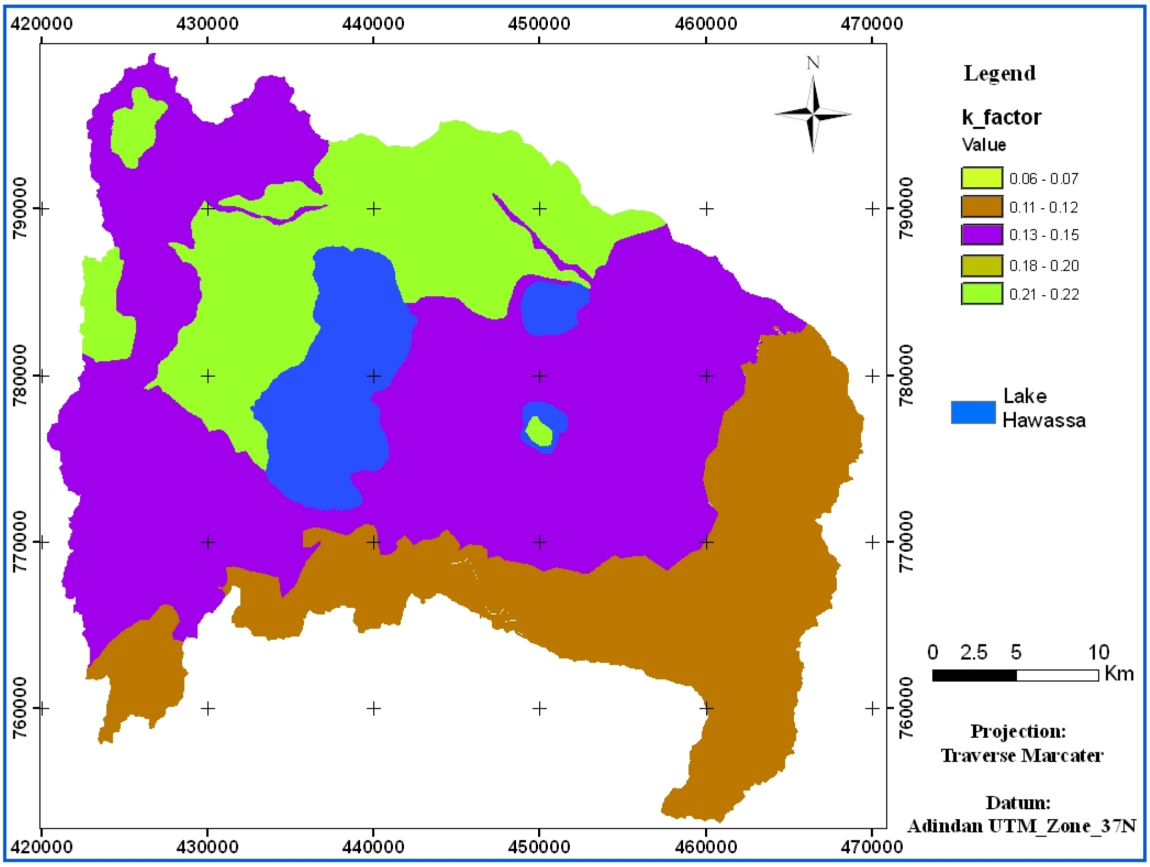

Fig. 5. 6. Soil Erodibility /K-factor/ Layer

Slope Steepness /S_ Factor/ Estimation

Slope is the inclination of the soil surface from the horizontal. It is the change in vertical distance divided by the horizontal distance and can be expressed as percent or degree measure. Soil loss increases rapidly as slope gradient increase. Soil loss is heavily affected by the shape of a slope; convex or concave. S_Factor is dimensionless. (Kaltenrieder, 2007*)*.

The S_factor is calculated directly from the slope angle grid using the two RUSLE algorisms that are differentially applied according to a break point at the experimentally modeled 9% gradient (Wischmeier and Smith 1978; Van Remortel, *et al.,* 2001; Kaltenrieder J. 2007).These are:

$\mathbf{S= 16.8*sin}\ \theta - 0.5$ … for $\theta >= 9\%$ (5 degree) slope angle … (equ. 5.5)

and

$\mathbf{S= 10.8*sin}\ \theta + 0.03$ … for $\theta < 9\%$ (5 degree) slope angle … (equ. 5.6)

On Spatial Analyst raster calculator the S-factor is computed with a conditional equation as:
Con([slope_degre] >= 5, 16.8 * Sin([slope_degre] - 0.5), 10.8 * Sin([slope_degre] + 0.03))

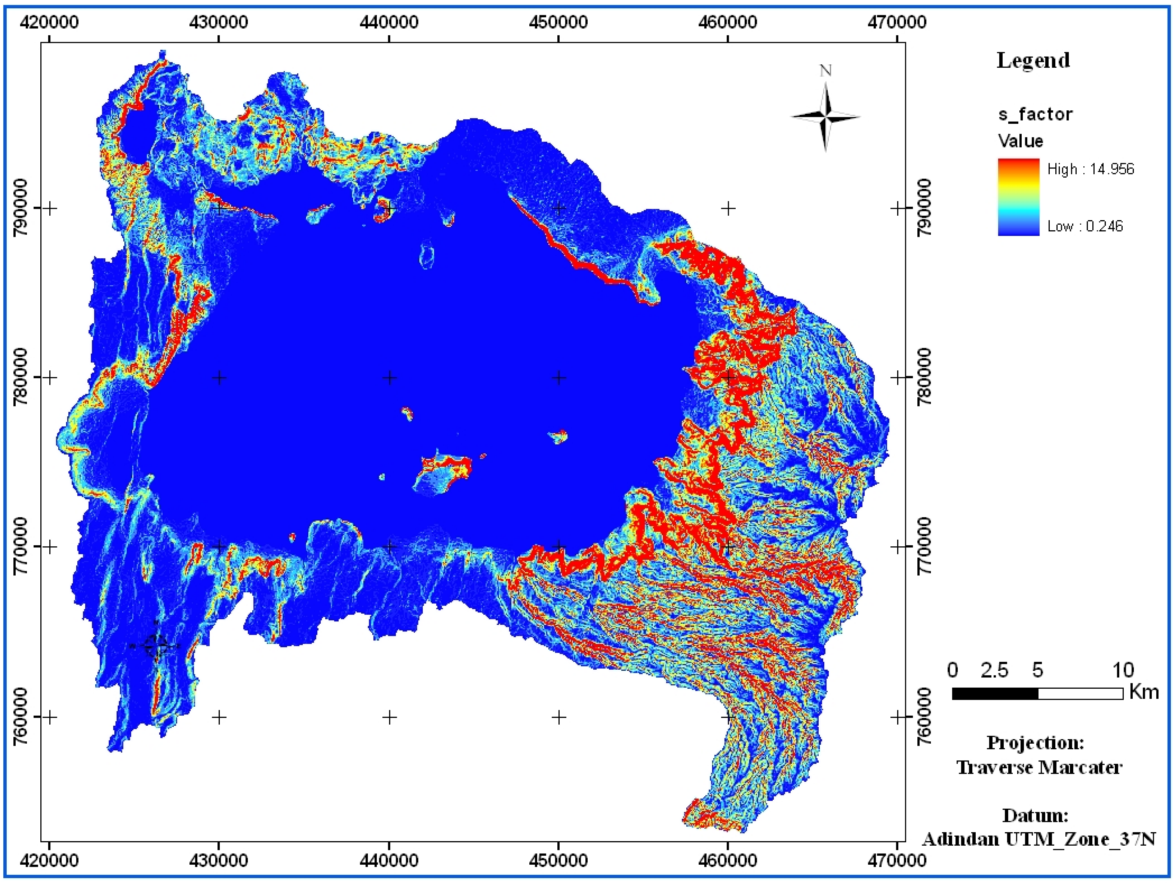

Fig 5. 7. Slope Steepness /S-Factor/ Layer

Slope Length /L_factor/ Estimation

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well defined channel (Wischmeier and Smith, 1978). Soil loss generally increases substantially as slope length increases because greater accumulation of runoff on the longer slopes increases detachment and transport capacities. For slopes with gradient less than 1% L is very difficult to determine. The L Factor is dimensionless. (Van Remortel, *et al.,* 2001; Kaltenrieder, 2007).

The RUSLE algorism for calculating the L factor serves to reference the erosion estimate for the horizontally projected slope length (HPSL) to the experimentally measured erosion for a 22.1m (72.6ft) reference slope length (RSL), to the power of a designed slope length exponent (m) value (Renald, et al, 1997; Van Remortel, *et al.,* 2001).

Slope Length (L-Fator) is computed as;

$L = (\lambda/22.1m)^m$ … (equ. 5.7)

L=Pow([hori_proj_sl] / 22.1, [M_value_Lf])

$\lambda = (\cos\theta)*15$ feet
or
$\lambda = (\cos\theta)*4.6$ metre

$m = \beta/(1 + \beta)$

m= (2 * [beta_valve_L]) / (1 +(2 * [beta_valve_L]))

$\beta = (\sin\theta/0.0896) / [3(\sin\theta)^{0.8} + 0.56]$

β = ([sinslopq_ras] / 0.0896) / (3 *(Pow([sinslopq_ras], 0.8)) + 0.56)

Where: L= slope length

λ = the horizontally projected slope in meter

θ = slope angle

m = designated slope length exponent

In a land where more sheet than rill erosion is expected, like in rangeland and woodland dominant covers, there will be low ratio of rill to sheet erosion, and thus $\beta/2$ is used in computing the slope length exponent. Conversely, for a high ratio of rill to sheet erosion 2β would be used; while for a moderate ratio of rill to sheet erosion β would be used as it is (Van Remortel, *et al.,* 2001; Kaltenrieder, 2007).

In case of Hawassa catchment, as based on the stream network generated, more rill than sheet erosion was observed and thus high ratio of rill to sheet erosion is expected, hence 2β is used in the calculations of L-factor.

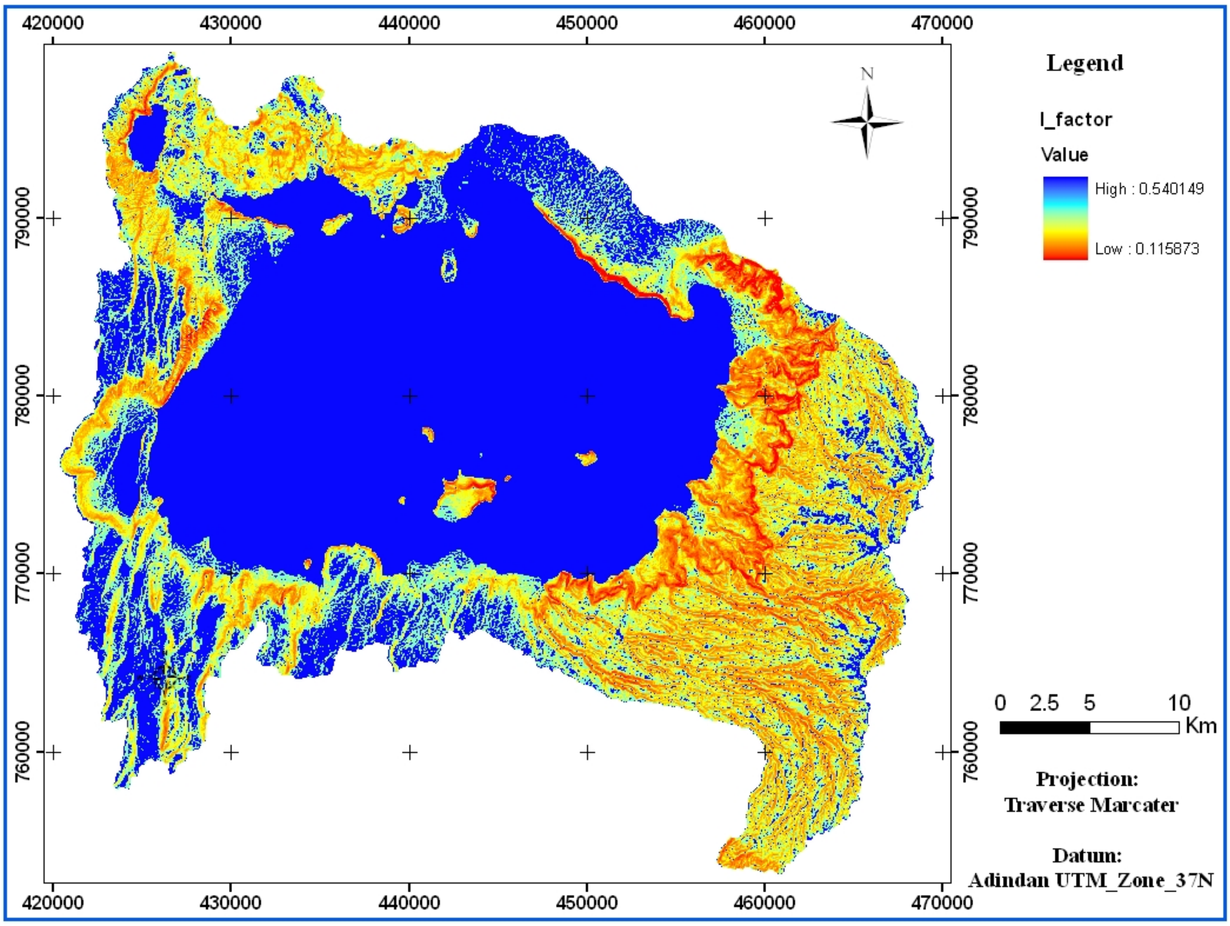

Fig. 5. 8. Slope Length /L-Factor/ Layer

Cover and Management /C- Factor/ estimation

C_Factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow land. It reflects the effect of ground and vegetation cover on the reduction of soil loss by reducing rainfall and runoff (Wang, 2003). In the revised USLE the C_factor combines 5 sub-factors, including prior land use, canopy cover, surface cover, surface roughness and soil moisture (Renald et al., 1997 its production level and the associated cropping techniques. It is reflecting the effect of a specific crop type, the management practices used along with it and the climatic conditions under which the crop is grown and the soil is managed on the erosion rate. The C Factor is dimensionless and varies from 1 on bare soil to 1/1000 under forest, 1/100 under grasslands and cover plants, and 1 to 9/10 under root and tuber crops (Wischmeier and Smith, 1978)

The land use land cover Map derived from Landsat7 ETM+ 2005 image (Fig.5.3) and data and information collected from field and Sidama Zone Agriculture and Rural Development Department were used for the estimation of C-factor.

Based on field observation, focus group discussion in Hawassa Zuria, key informant interview and data of Sidama ZDoARD, in Western part of the catchment such as in Hawassa Zuria, Boricha and Shebedino Woredas, maize, potato and pepper are dominantly cultivated. The crop residues of maize have been used for livestock feeding. In addition, in Boricha and Shebedino eucalyptus and coffee are grown in some parcels of land. In the eastern lower slopes from Monopol village; now part of Hawassa town, all the way to WendoGenet, the flat lands surrounded by the eastern escarpment of Wendo–Melga hills are covered with agro-forestry including chat, *enset*, coffee, sugar cane, eucalyptus, remnant warka trees, maize crop and fruits such as; banana, avocado, and papaya. Agro-forestry is typically practiced in this part of the catchment. Hawassa Zuria woreda is the most exhausted part of the catchment in that there is no enset, chat, coffee and other plantations, which are believed to have paramount importance both in securing livelihood to the community and in reducing soil and water erosion.

Therefore, based on information on cropping pattern, cultivated crop types, farm management

Plate 2. Environmental stress in Shamena_Hurufa area

practices and surface cover, the C-factor derived by Wischmier and Smith (1978), adapted for Ethiopia by Hurni (1985) and Kaltenrieder (2007) were used for the model. However, in situation of intercropping, mixed cropping and crop rotation average of the C-factor values were taken (Table 5. 6).

Table 5. 6. Estimated C & P_Factor values of LU/LC Classes derived from Landsat7 ETM+ 2005 Image

No.	Land cover/crop type	Area in Hectare	C_Factor values	P_Factor Value
1	Water	9350.91	-	-
2	Mixed Farm and Wood Land	43374.69	0.05	0.8
3	Agro forestry	23171.22	0.05	0.8
4	Moderately Cultivated Farm(Maize, Haricot bean & Potato)	26939.16	0.15	0.9
5	Built-up	1387.08	0.01	0.8
6	Mechanized Farm (strip cropping & Maize)	4104.90	0.1	0.76
7	Swamp	5798.70	0.001	0.8
8	Grass Land	9363.51	0.05	0.8
9	Scrub Land	7358.67	0.04	0.8
10	Degraded Land and Intensively cultivated farm (Maize and Haricot bean)	8992.26	0.25	0.9
11	Forest	12420.90	0.01	0.7
	Total	152262.00		

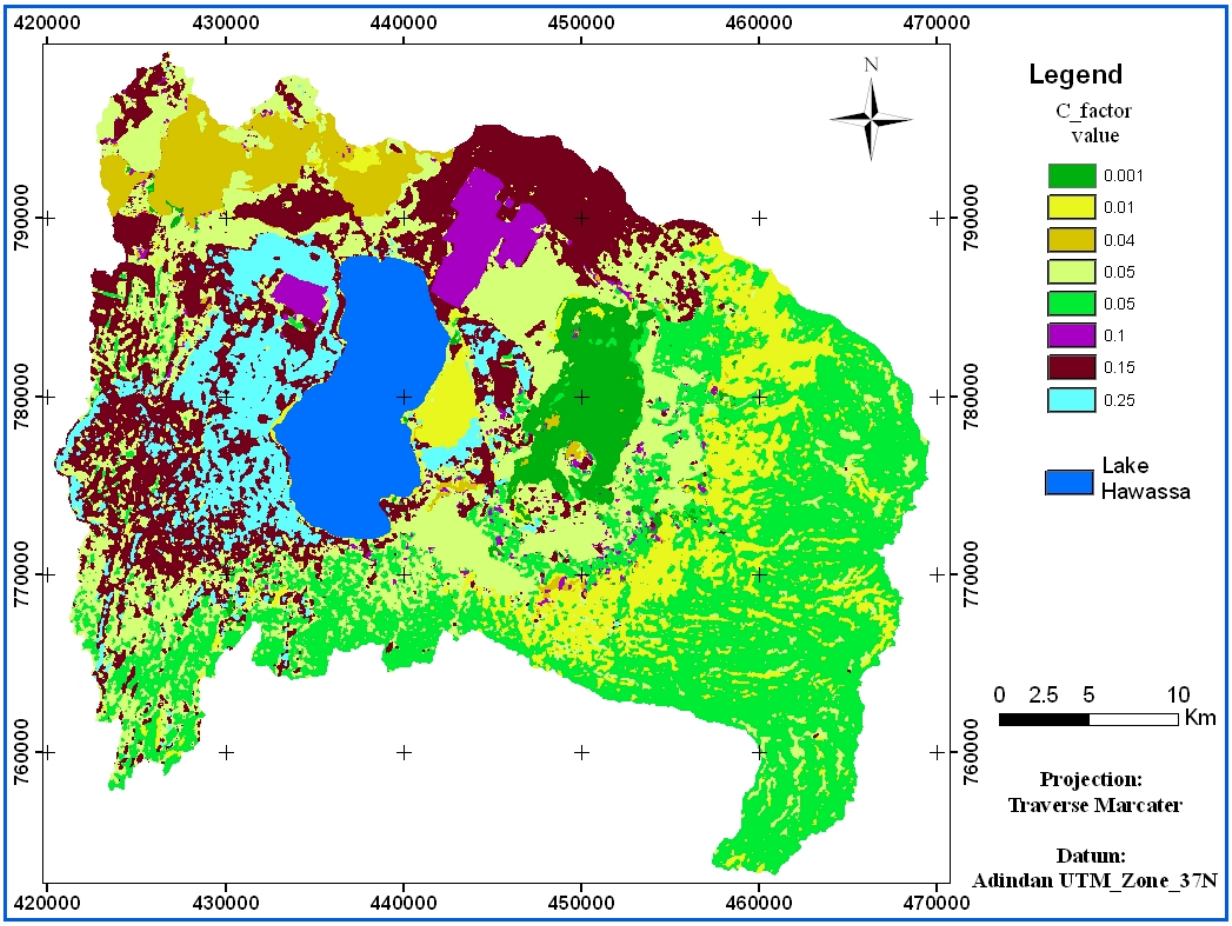

Fig.5. 9. Cover and Management /C_Factor/ Layer

Support Practice /P_Factor/ Estimation

The Support (P) Factor is defined as the rate of soil loss with a specific support practice to the corresponding loss with up-and-down-slope (Wischmeier and Smith 1978; Morgan, 1986). The most important supporting practices are contour tillage, strip-cropping, terracing and others (Ibid). The P Factor is reflecting the impact of supporting practices in reducing the erosion rate. It is dimensionless and has values between 0 and 1. In situations where there is no support practice the value of p is 1.

In Lake Hawassa catchment it is found that in recent years support practices such as; protection plantation and soil and water conservation structures like; soil bunds, stone terraces, Fanya juu, Micro basins, and area closure (for natural regeneration and for construction of physical structures with in the closure) have been practiced in most of the degraded lands in Hawassa Zuria, Boricha and Shebedino Woredas.

According to Information from Sidama ZDoARD and Mr. Tedla (Coordinator of Forum “Concern for Environment”), in Hawassa Zuria Woreda alone for the last 10 years over 20 million seedlings were planted, and in the current year about 400 hectare area was enclosed, 2.3 km soil bunds were constructed and 1.5 million seedlings were planned to be distributed.

The management practice factor P indicates the effect of conservation practices on soil erosion, wherein the land that has adequate conservation interventions will have a lower P factor value, i.e. a lower degree of erosion. The value of P factor ranges between zero and one; zero indicates that the land is perfectly protected, while one indicates plowing up and down the slope.

Plate1. Some Degraded Areas in Lake Hawassa Catchment

In determining P_factor values soil and water conservation work done in the study area were evaluated from Sidama ZDoARD reports.In addition, field observation were also made for verification. Similar to C_Factor, the p_values were also determined based on Hurni (1985) estimations for Ethiopia (Table 5.6).

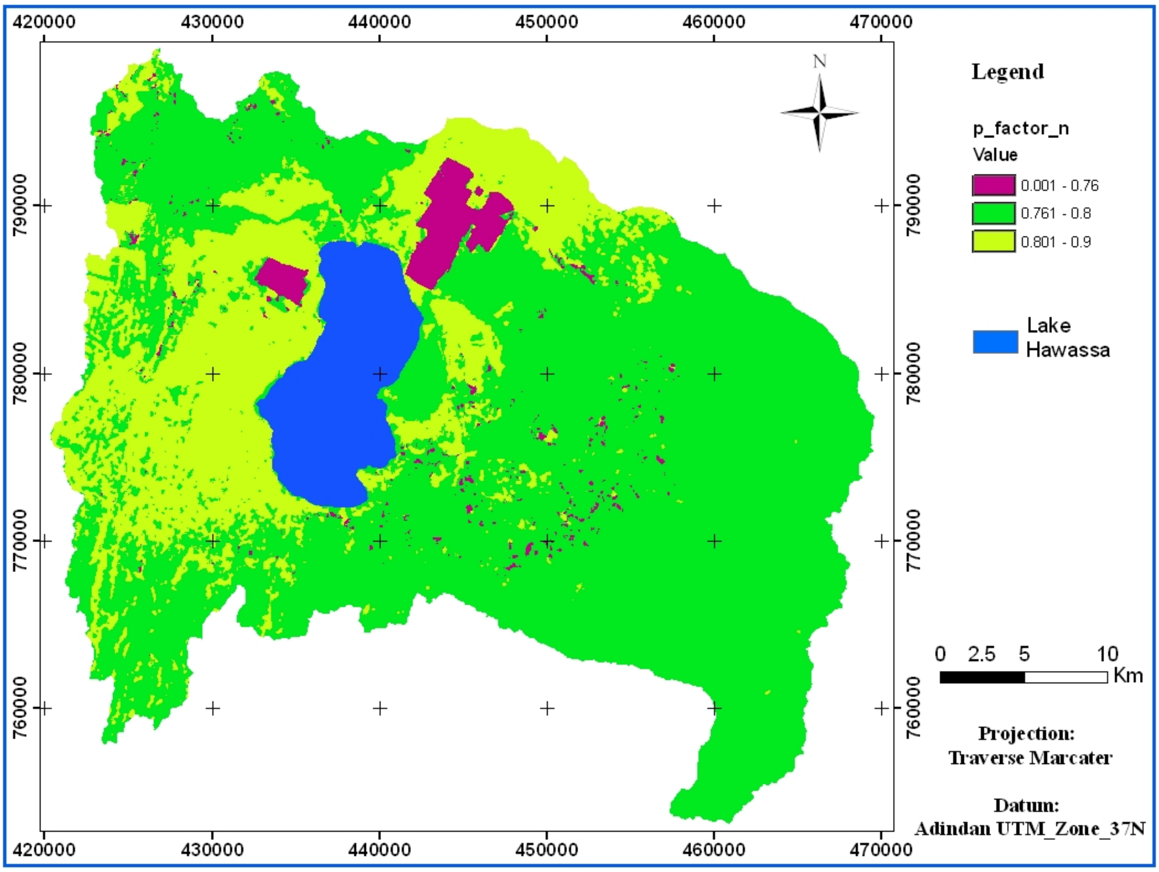

Fig5.10. Support Practice /P_Factor/ Layer

5.3.2. The USLE Model Outcome

The universal soil loss model estimates the long time average soil loss per hectare per year. Among the model parameters the topographic factors (L and S factors) and soil erodibility (K-factors) do not affect the time dimension of the model result, since they are not easily altered within short period of time. However, the time dimension of R-factor, C_factor and P_factors strongly influence the model results. Thus, the final soil loss result (fig.5.11) was achieved with due consideration of some 25 years of meteorological data, soil and water conservation and information on the farming practices during the last two decades.

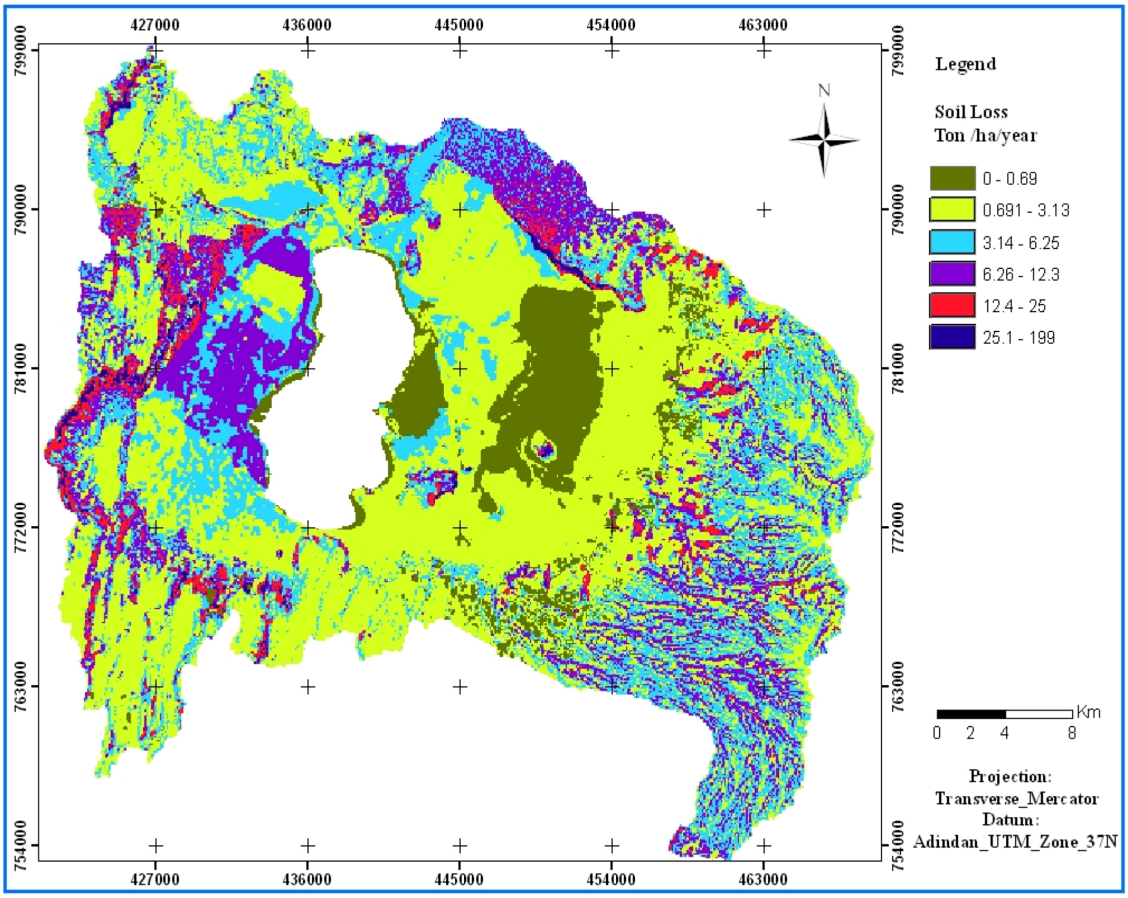

Fig.5 .11. The spatial distribution of Mean annual soil loss in Lake Hawassa Catchment

As the objective this thesis is to identify the degree of erosion hazard in the catchment, the USLE model result was reclassified in to different erosion hazard classes. Studies have shown that the USLE model is more appropriate to show areas with differing degree of erosion hazard rather than their qualitative soil loss (Van Remortel, R., 2001). Based on WBISPP (2001) classification of soil loss classes, the extent of soil erosion in the catchment was classified into five erosion hazard classes (table; Fig. 21).

Table 5. 7. Erosion Hazard Classes and area coverage in L. Hawassa Catchment

No.	Soil Loss in ton/ha/year	Equivalent top soil removal in mm	Area in hectare	Level of Hazard
1	Nearly 0	-	11977	-
2	0.78 – 3.125	<0.25	68396	Very low
3	3.125 – 6.25	0.25 – 0.5	38510	Low
4	6.25 – 12.5	0.5 – 1	7248	Moderate
5	12.5 – 25	1 – 2	1411	High
6	>25	> 2	203	Very High

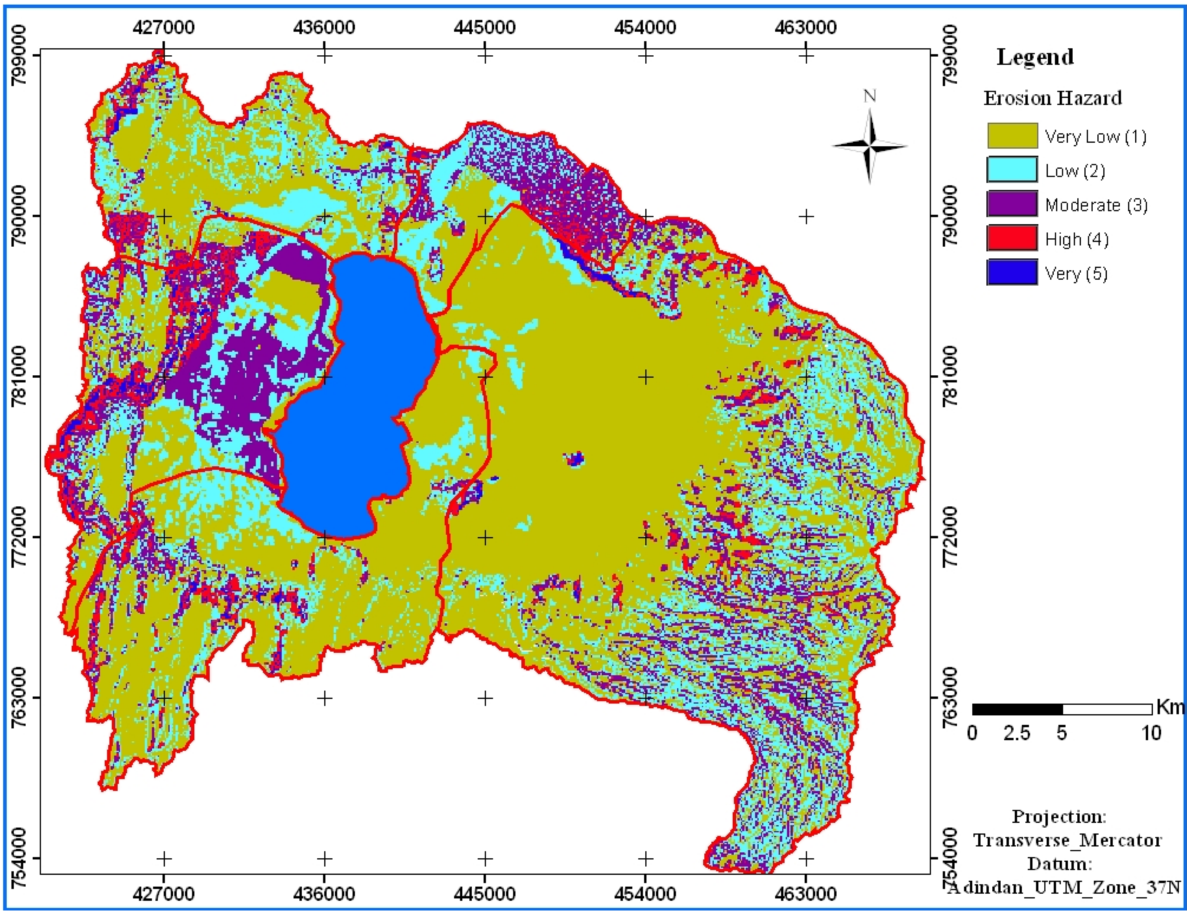

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Fig.5 12. The degree of erosion hazard in Lake Hawassa catchment

5.4. Rainfall Variability Estimation

Growing concern for possible causes of environmental stress has generated a strong body of opinion that the general rainfall variability and irregularity during the recent decade is due to the change in atmospheric composition induced by human activities.

Measuring rainfall variability in its spatial and temporal extent is a difficult task, since there are no accurate and reliable agro-metrological data records. According to NMSA (1996) reports in monitoring the impact of rainfall variability on crop production, the absence or presence of rainfall at a certain stage, especially during the flowering stage could be critical. The years of variable or deficient rainfall not only led to production losses but also decline in vegetation cover which in turn makes the land susceptible to degradation agents such as running water and wind.

Therefore, to evaluate the variability of rainfall within the catchment long term monthly rainfall records of 7 meteorological stations were considered. Accordingly, the monthly and seasonal variability of rainfall showed almost high variability for all the stations in the catchment, while the annual variability values coincide with the NMSA rainfall variability Map for Ethiopia (Lemma Gonfa, 1996). Thus, annual rainfall variability of the stations for the years 1970s to 2004/5 were computed (Fig. 5.13, 5.14 and 5.15). In the analysis the coefficient of variation of rainfall were used during the measuring years.

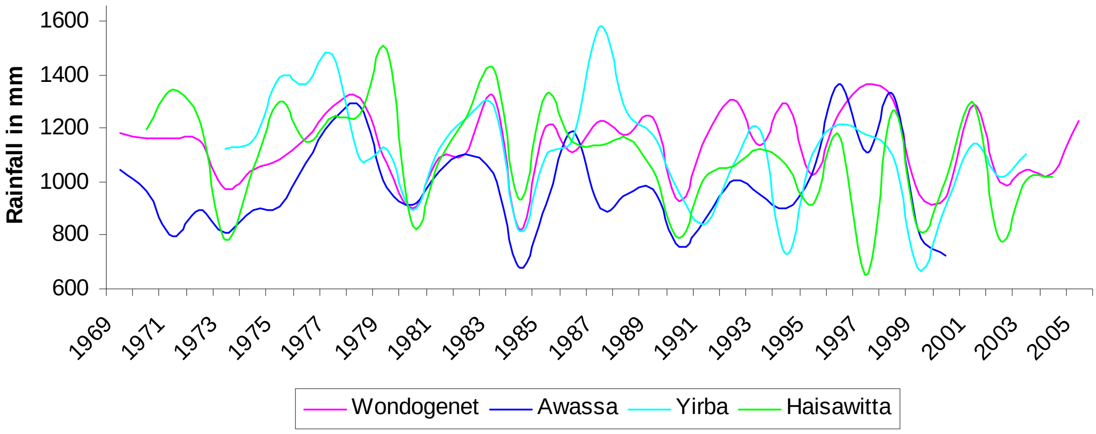

Fig.5. 13.The trend of mean annual rainfall (1970s - 2005)

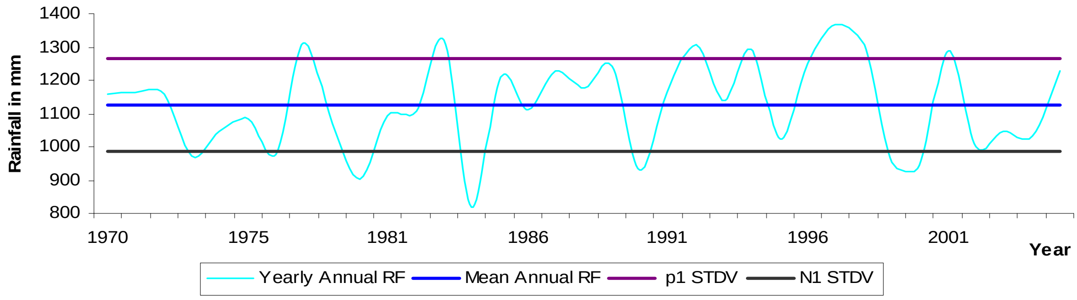

Fig.5. 14. Rainfall Variability of Wondo_Genet Station

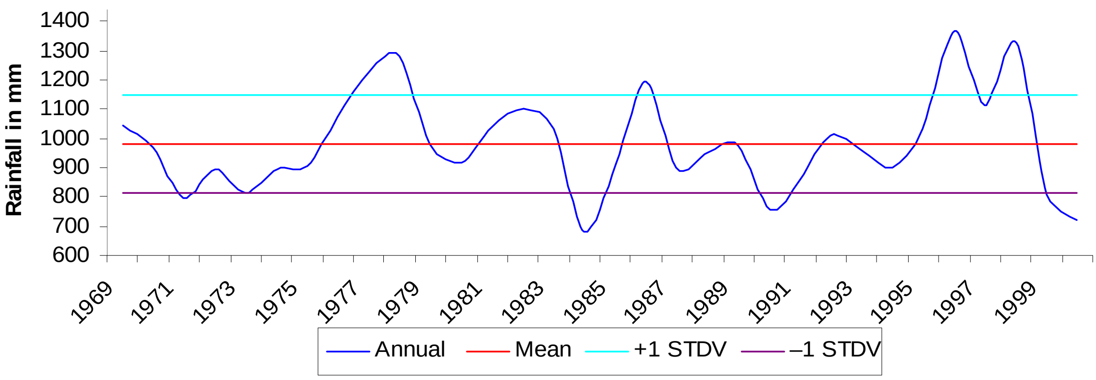

Fig.5. 15. Rainfall Variability of Hawassa Station

The coefficient of variation (CV) of the annual rainfall for each of the meteorological stations is estimated using individual years rainfall data (X_i) as follows:

$$CV = \left[\frac{S}{\bar{x}}\right] * 100\%$$

$$\bar{X} = \frac{\left[\sum_{i=1}^{n} X_i\right]}{n}$$

$$S = \sqrt{\frac{\left[\sum_{i=1}^{n} (X_i - \bar{x})^2\right]}{n}}$$

Where $\bar{x}$ = mean annual rainfall (mm)

S= standard deviation of annual rainfall, (mm)

n= number of years for which the rainfall data are available, for a given station.

Xi = annual rainfall (mm) of year I of a given station

Table 5. 8. Rainfall Variability of 7 metro-stations within and nearby Hawassa Catchment

Station Name	Year	Mean Annual RF in mm	Standard Deviation	Coefficient of Variation (CV)	CV in percent
Hawassa_32	1969-1998	1039.38	266.78	0.26	25.67
Haissawita	1970_2004	1096.46	197.80	0.18	18.04
Wondogenet	1970_2005	1126.46	139.39	0.12	12.37
Kofele	1968-2005	1187.59	213.39	0.18	17.97
Yirba	1973-2003	1103.60	230.77	0.21	20.91
Morocho	1979-2005	1378.19	379.78	0.20	20.00
Shashemene	1989-2006	850.44	253.32	0.30	29.79

Based on NMSA classification of rainfall variability the coefficient of variation < 20 is taken as low variability, between 20 to 30 to moderate variability, and >30 to high variability (Lema Gonfa, 1996). Later, values of the coefficient of variation for the metrological stations within the catchment were interpolated into surface grid using spatial analyst regularized tension method and reclassified in to high, moderate and low variability zones (Fig.5.16).

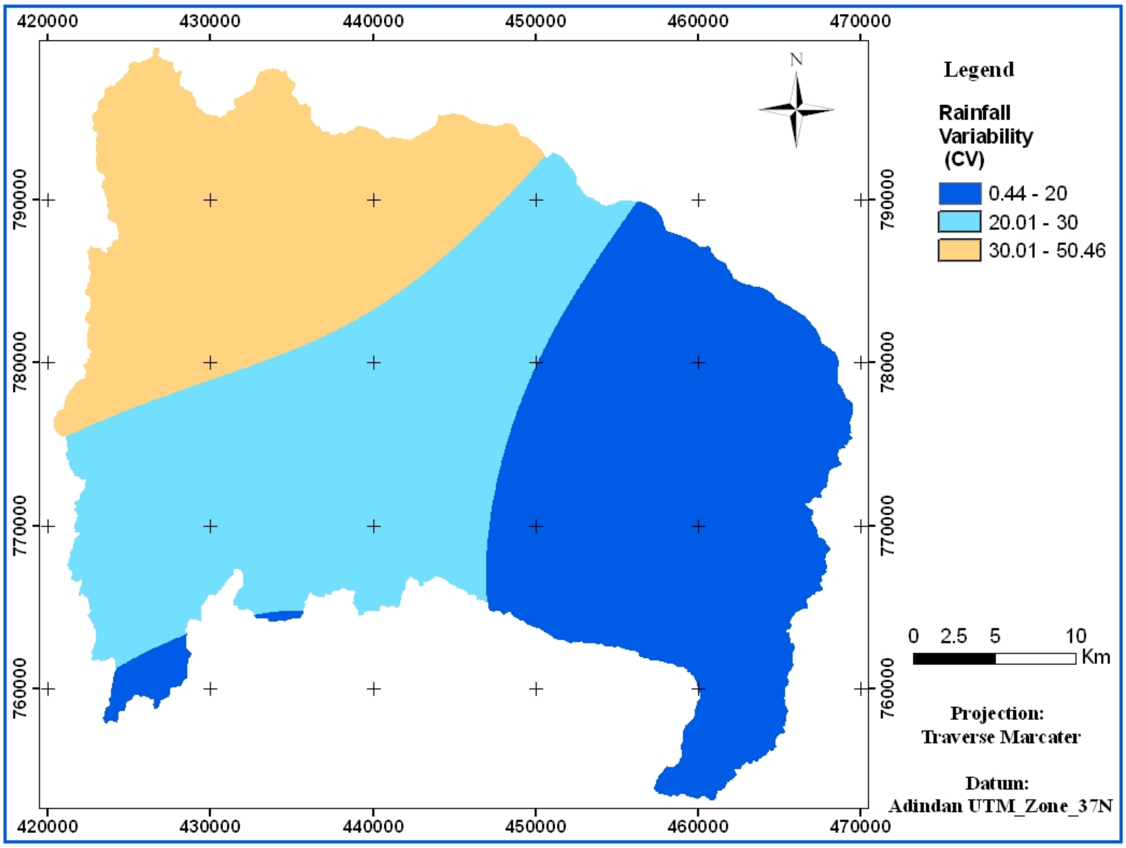

Fig.5 16. Rainfall Variability Layer

5.5. Livelihood Analysis

The usefulness of livelihood based approaches to development has been recognized since late 1980s when the concept was popularized by international agencies such as the World Commission on Environment and Development (WCED) (Devereux S. *et al*., 2004).

As clearly explained in the review of literature the concept of Rural Livelihood refers to the capabilities, assets and activities required for a means of living. In livelihood analysis, the livelihood strategies i.e., the means that enable local communities or a particular household to survive are critical to assess the resource use pattern. According to Ellis (2000) Livelihood activities can be categorized in to natural resource based activities such as collection of wood, gathering of wild fruits, agro-pastoral, farming; and non-natural resource based activities such as rural trade, cottage industries and remittances and other transfers.

Population growth and pressure was one of the factors mentioned for environmental stress in the catchment. However, high population density is not necessarily leading to environmental stress; instead it is the land use and the livelihood system that would deplete environmental resources.

According to the reports of SNNPR Agriculture and Rural Development Bureau (2005), based on the sources of food, sources of cash in case of food shortage and minimum expenditure, the livelihood zones in Lake Hawassa Catchment are delineated in to Agro-pastoral, Maize, Enset and Barley; Chat and *Enset*, and Coffee Livelihood zones (Fig.5.17, Table5.9).

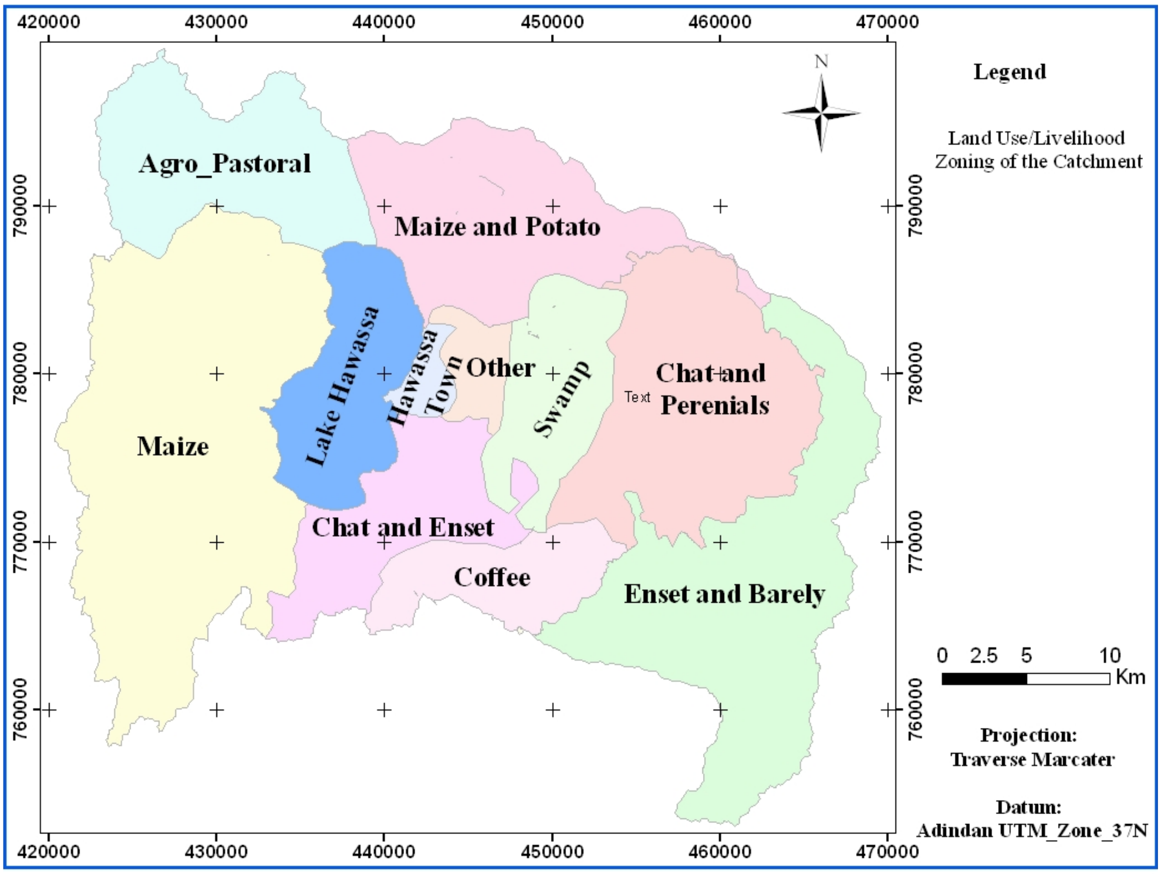

Fig.5. 17. Livelihood Zoning of Hawassa Hwassa Catchment

A livelihood is sustainable when it can cope with and recover from shocks and stress and maintain and enhance its capabilities and assets both now and in the future, whilst not undermining the natural resource base (Rick., et al., 2002).

Table 5.9. Livelihood Zone Description of the Catchment

No.	Livelihood Zone	Woreda Included	Zone Description	Environmental Status
1	Maize	HHawassa Zuria Boricha and Shashemene	-Main crop is maize -Harricot bean and potatoes are also grown -highly erratic rainfall -Produce < than half of the food requirement (Food in-secured) -Cattle and goats are important to the better off	Largely depend on natural resources as a source of income such as firewood and charcoal sale to the nearby towns. -no fallowing, intensive cultivation; hence the environment is prone to stress
2	Chat and Enset	Majority of wondogenet and partly Shebedino and Malga	-Chat is the primary cash crop -Densely populated -Live on cash crop and livestock sale -Coffee is also important -Food secured	-The expanding agro-forestry and enset crop have regulatory effect on in reducing evapo-transpiration and soil moisture retention but rainfall is declining. -as a result the environment is sensitive due to high population density and deforestation.
3	Enset and Barely	Majority of Malga, Gorche and Kofele	-Situated at high elevation -Dense stock of enset -Reliable rainfall, Livestock and vegetables are sources of cash, Food secured	-Due to reliable rainfall and good cover of enset crop the environment is less susceptible to stress
4	Coffee	Some parts of Shebedino, Wondogent, and Malga	-Coffee covers nearly 60% of the land use -Enset is the main food crop -densely populated, but largely food secured	Due to rainfall variability and drought seedlings dry up, people consume immature *enset* leading to declining land cover and environmental stress.
5	Agro-pastoral	Siraro and Shala	-The grass and scrub lands are extensively used for browsing and grazing -the basis of the economy is cattle and milk products. -Food insecured	-Over grazing and dependence on firewood and charcoal as source of income make the environment highly sensitive to stress.

The Socio-environmental characteristic of each livelihood zone is described in table 5.9. On the basis of the dependence of the community on natural resources, the impact of the livelihood system on the environment is classified in to less, moderate, high and severe sensitive classes (Fig.5. 18).

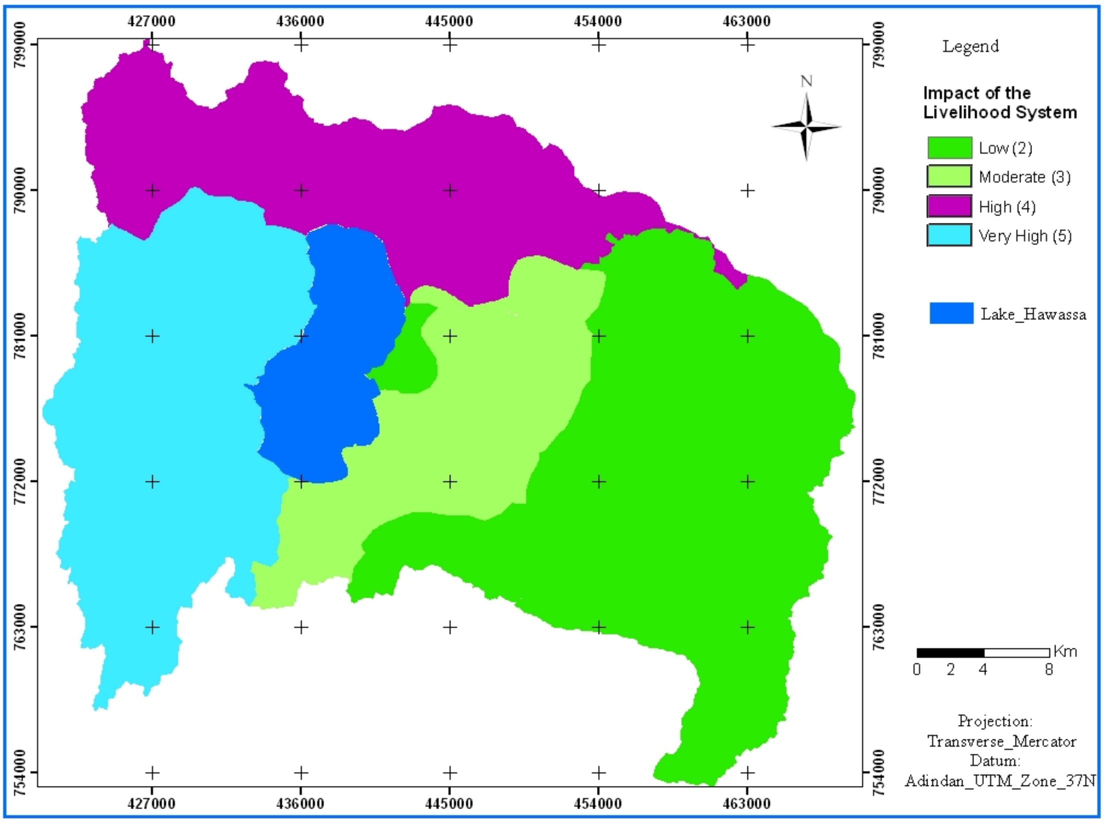

Fig.5. 18. Map showing degree of Livelihood impact on the environment

5.6. Vegetation Index

Various mathematical combinations of spectral bands of satellite images can be used for distinguishing the physical characteristics of surface features. Vegetation indices such as simple Vegetation Index and Normalized Difference Vegetation Index which are computed from channel 1 and channel 2 for AVHRR NOAA, Channel 2and 4 for Landsat MSS, and Channel 3 and 4 for Landsat TM and ETM+ are used for local to regional / global scale temporal vegetation monitoring (Lillesand, 2000).

Satellite images provide a good knowledge of the spatial distribution of the vegetation cover and other land classes such as soils and parent rocks (Haboudane D. *et al.*, 2002). In fact, NDVI is primarily preferred for delineating vegetation stress and in classifying vegetation, water, soil and bad / degraded lands since it can compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors (Leica Geosystems, 2005; Lillesand 2000).

The spectral reflectance properties of vegetation for instance leaf in the 0.4 to 2.5 micro meter region is a function of the leaf pigments, the leaf cell morphology, internal refractive index discontinuities, and water content. The pigments of the chlorophyll group are primary control from 0.4 to 0.7 micro meter, the cell morphology and internal refractive index discontinuities are the primary control from 0.7 to 1.3 micrometer, and the water content is the major control in the 1.3 to 2.5 micrometer region (Lillesand 2000). Vegetation Indices are used to create ratio images by mathematically combining the DN values of different bands from surface covers.

For Landsat TM/ETM+, Normalized Difference Vegetation Index

NDVI = (NIR- Red)/(NIR+Red)…………………………….. (equ. 5.8)
= (B4-B3)/ (B4+B3)

The NDVI values for vegetation range from 0.05 degraded vegetation, to a high of 1 for dense healthy vegetation , while clouds, snow, and non vegetative (bare surfaces) have NDVI values of Less than 0 (Lillesand, 2000). Accordingly in this research, based on the spectral reflectance values of known land cover features, NDVI values were used to classify the catchment's land cover in to different vegetation stress and degradation levels using Landsat7 ETM+ 2005 imagery (Fig. 5.19).

Table 5. 10. NDVI based estimated land degradation levels

No.	NDVI Value	Land cover type	Estimated Stress level
1	<-0.119	Lake / Water	-
2	-0.119 – 0.0745	Degraded land and Built-up, parts of intensively cultivated lands	Severe
3	0.0746 – 0.246	Degraded, Scrubland, grassland, and moderately cultivated lands	High
4	0.267 – 0.45	Agro-forestry, mixed farm and woodland, and wetland	Moderate
5	> 0.45	Forest and healthy vegetation	Less

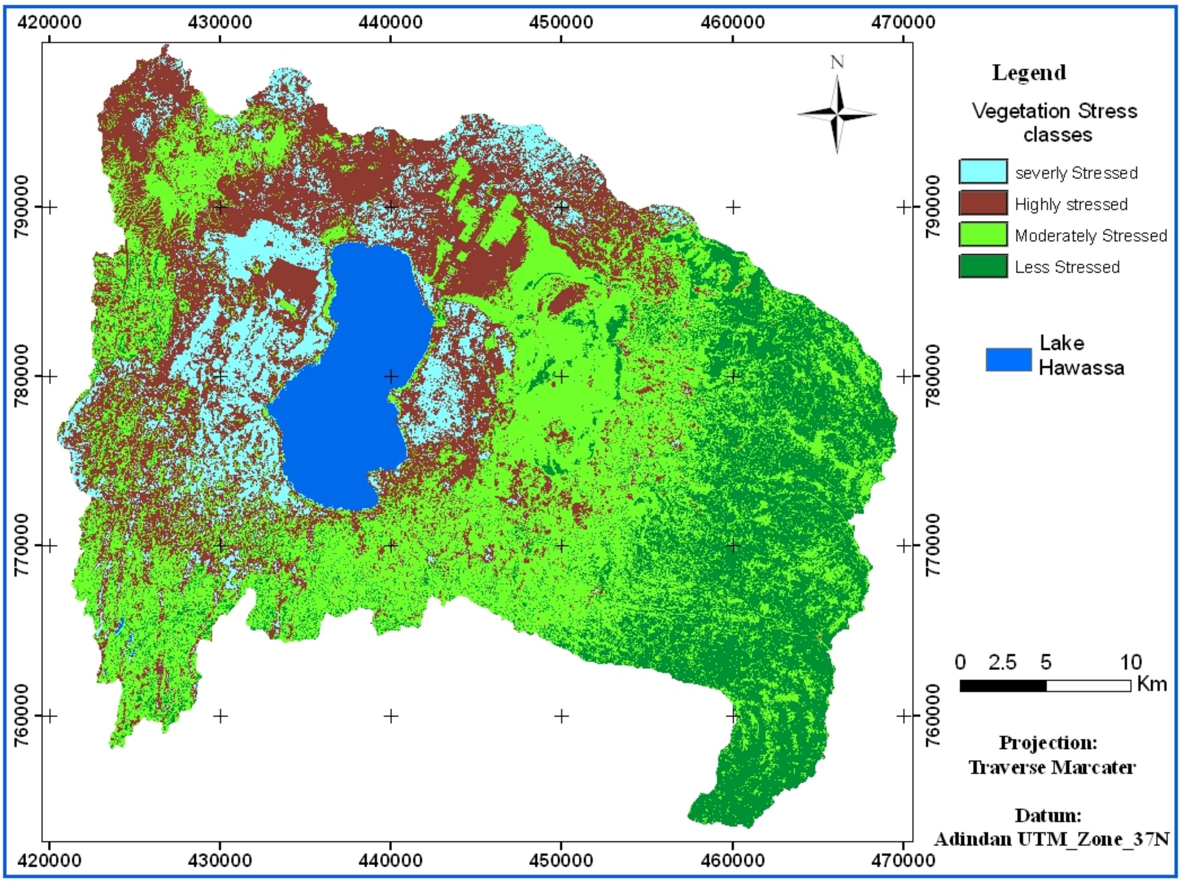

Fig.5. 19. NDVI based Land Cover Stress classes

5.7. Estimating Degree of Environmental Stress

The deterioration of the natural environment is one of the major causes for declining land productivity. Topography, soil, vegetation cover and climate are major components of the natural environment that determine the ecosystem dynamics. Unhealthy human intervention in competing for the scarce resources in developing countries including Ethiopia, where means of livelihood is virtually based on natural resources, can change the environment for the worse and disrupt the functionality of the system.

The vulnerability indices for mapping the degree of environmental stress are broadly categorized as biophysical such as erosion hazard and vegetation indices; climatic such as; rainfall variability, and anthropogenic (human livelihood) indicators. The indices were weighted and aggregated in to an overlay vulnerability index that allowed the identification of degree of environmental stress.

The sensitivity of each factors for environmental stress were estimated based on the predefined classification of the parameters in influencing the environment; and the degree of influence was used as a base to construct the Factors Maps. The degree of stress defined include: Very High_5, High_4, Moderate _3, Low_2, Normal_1.

Multi-Criteria Evaluation technique was used to assess the contribution of each factor during the overlay analysis using GIS based modeling and decision making. The standardized raster layers were weighted using Eigen vector that is important to show the importance of each factor as compared to others in estimating the degree of environmental stress. Accordingly, the Eigen vector of the weight of the factors was computed in Idrisi32 software using Decision Support/Weight Analysis. Using these factors as criteria, a pair wise comparison matrix was constructed in nine-point continuous scale, which ranges from 1/9 extremely less important to 9 extremely more important. In MCE using weighted linear combination, it is necessary that the weights sum is to be 1 (Parveen, 2005).

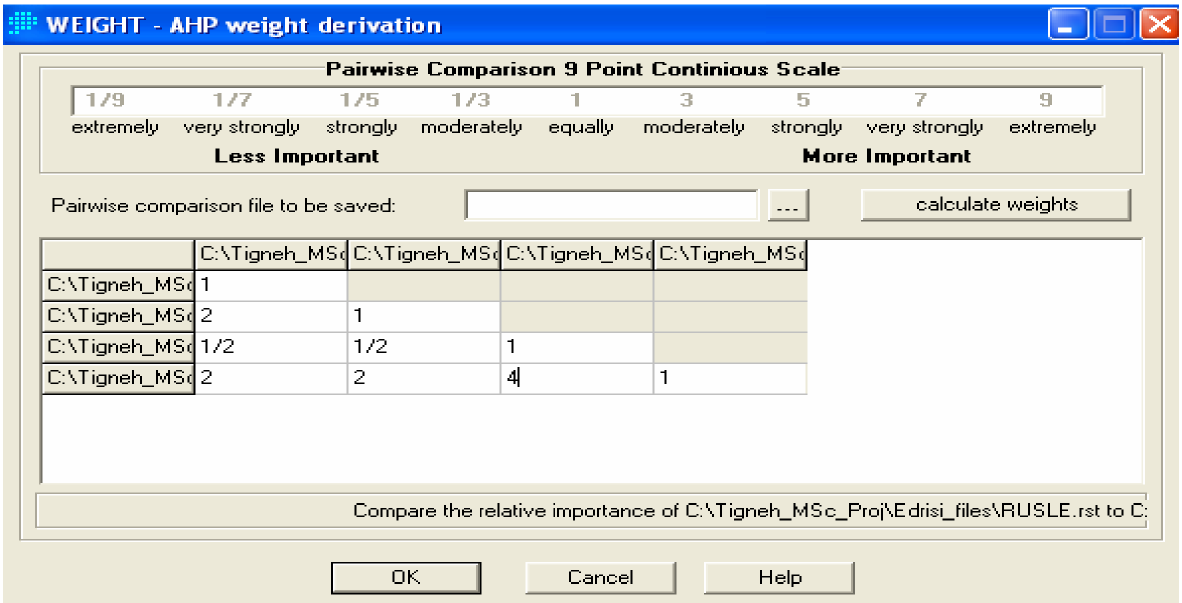

Fig.5. 20. Pair wise Comparison Matrix for weighting factors for environmental stress

The principal eigenvector of the pair wise comparison matrix using the factors was calculated as:

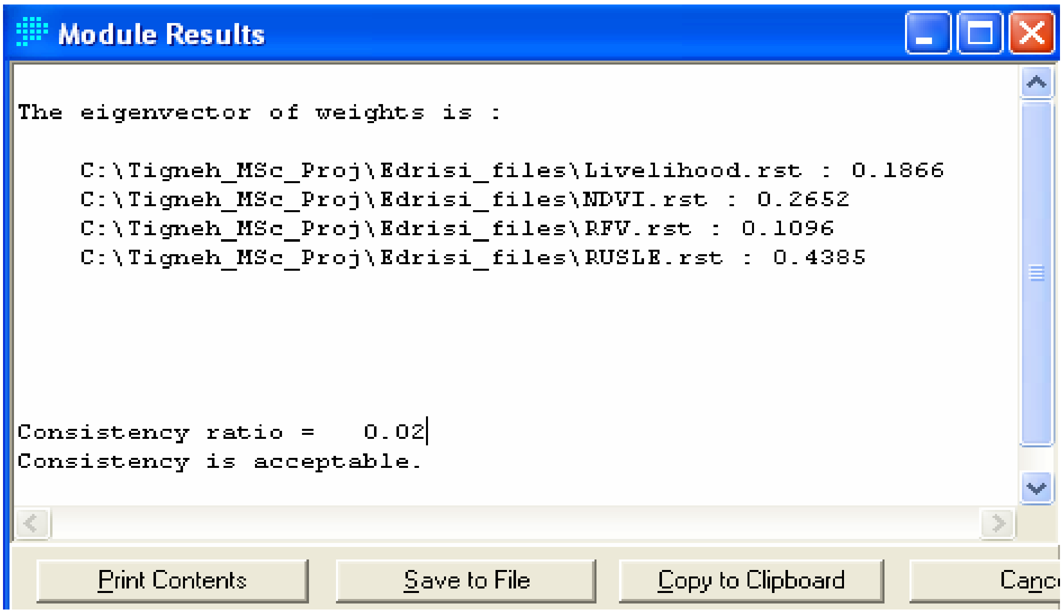

Fig.5. 21. Weights derived by calculating the principal eigenvector of the pair wise comparison matrix

The computed Eigen vectors were used as a coefficient for the respective factor maps participating in the Weighted Overlay. Once the composite layers and their weights were obtained, the MCE procedure within ArcGIS9 was applied to produce the Map of degree of environmental stress.

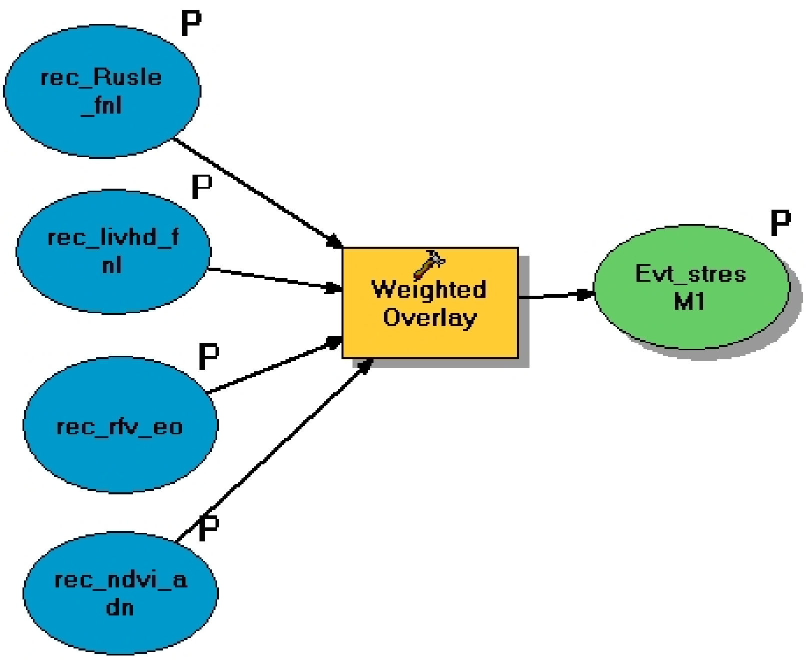

Fig.5. 22. Weighted Overlay of Environmental stress parameters

Table 5. 11. Weighted Classes of Factors for Environmental Stress

No.	Factor	Weight	Factor class	Degree of Stress
1	Rainfall Variability (coefficient of Variation)	0.1096	<20	Low (2)
			20 – 30	Moderate (3)
			> 30	High (4)
2	Erosion Hazard (tone/hectare/year)	0.4385	0 – 3.125	Normal (1)
			3.125 – 6.25	Low (2)
			6.25 – 12.5	Moderate (3)
			12.5 – 25	High (4)
			>25	Very High (5)
3	Livelihood Zone	0.1866	Maize	Very High (5)
			Maize and Potato	High (4)
			Chat and Enset	Moderate (3)
			Enset and Barely	Low (2)
			Coffee	Low (2)
			Agro-pastoral	High (4)
4	Vegetation Index /NDVI Values/	0.2652	<-0.119	Hawassa
			-0.119 – 0.0745	Low (2)
			0.0746 – 0.246	Moderate (3)
			0.267 – 0.45	High (4)
			> 0.45	Very High (5)

5.8. Farmers' perception on environmental degradation

The complex nature of sustainable natural resource management demands research that uses a systems approach; i.e. research combining the bio-physical and socio-economic dimensions. Recent approach of development studies realized that development efforts that ignore indigenous knowledge, local systems of knowledge generally fail to achieve their desired objectives. Participation by the local community in the development initiative is critical for achieving sound natural resource management to utilize the full potential of indigenous knowledge system. The local communities have their own understanding to local environment, indigenous knowledge of adaptation mechanisms for environmental shocks (Tripathi N, et al., 2004).

In developing world, including Ethiopia the previous approach of natural resource management and conservation was ignorant of the local people and indigenous knowledge. Due to such and the like reasons natural resource conservation and management activities were undertaken so far remained ephemeral instead of being sustainable.

Table 5. 12. Pair Wise Matrix of Farmers Perception

Problems	Population Pressure	Soil erosion	Deforestation	Erratic rain fall	Lack of Conser.	Score	Rank
Population pressure						2	3
Soil erosion	Population					1	4
Deforestation	Deforestation	Deforestation				4	1
Erratic rain fall	Erratic RF	Erratic RF	Deforestation			3	2
Lack of Conservation	Population	Soil erosion	Deforestation	Erratic RF		0	5

In the study assessing the perception of farmers on environmental degradation will augment the research apart from Model results. In addition, equivalent with the scientific approach the local knowledge of the farmers is critical in assessing the causes of soil degradation and the consequent decline in land productivity.

The information collected on farmer's perception in Hawassa Zuria Woreda, using key informant and focus group interviews, were analyzed using a pair wise matrix in order to prioritize and rank what they perceive the major causes of environmental degradation.

It was with this conviction, that a farmers’ perception assessment was organized in the area under study. In the assessment of farmers’ perception eight farmers took part on the focus group discussion.

Among the factors assessed, the major ones are presented in the table 5.12 presented above. Based on the results obtained from the assessment on environmental stress, farmers perceived that the major problem of environmental stress is related to deforestation and rainfall variability, in that order.

Although farmers are often more acutely aware of the condition of their land than is sometimes assumed by experts, they may not be fully aware of land degradation, its causes, or consequences. Farmers may not observe ongoing erosion or nutrient depletion problems. While they do observe low or declining yields and associate it with declining rains. Farmers' perceptions and attitudes can have a major bearing on promoting indigenous knowledge and participatory land management activities.

CHAPTER VI

6. RESULT AND DISCUSSION

6.1. Erosion Hazard in Lake Hawassa Catchment

Based on the USLE model erosion hazard analysis, the total annual soil loss in Lake Hawassa catchment was found 533,846.36 tons per year, with a mean soil loss of 4.179 tons per hectare per year; excluding the area of Lake Hawassa. The soil loss ranges from zero on the plains to 198 ton/ha/yr on the escarpments. Among the Sub-catchments, Shamena_Hurufa and Shashemene_Toga with a mean loss of 6.25 and 6.05 ton /ha/yr. respectively were found with high and severe erosion hazard (Table 6.1, Fig.6.1). Although, Boricha_Bushulo and Lalima catchments have soil loss results below the mean, they have spot area that with high and severe erosion hazard (Fig.6.2).

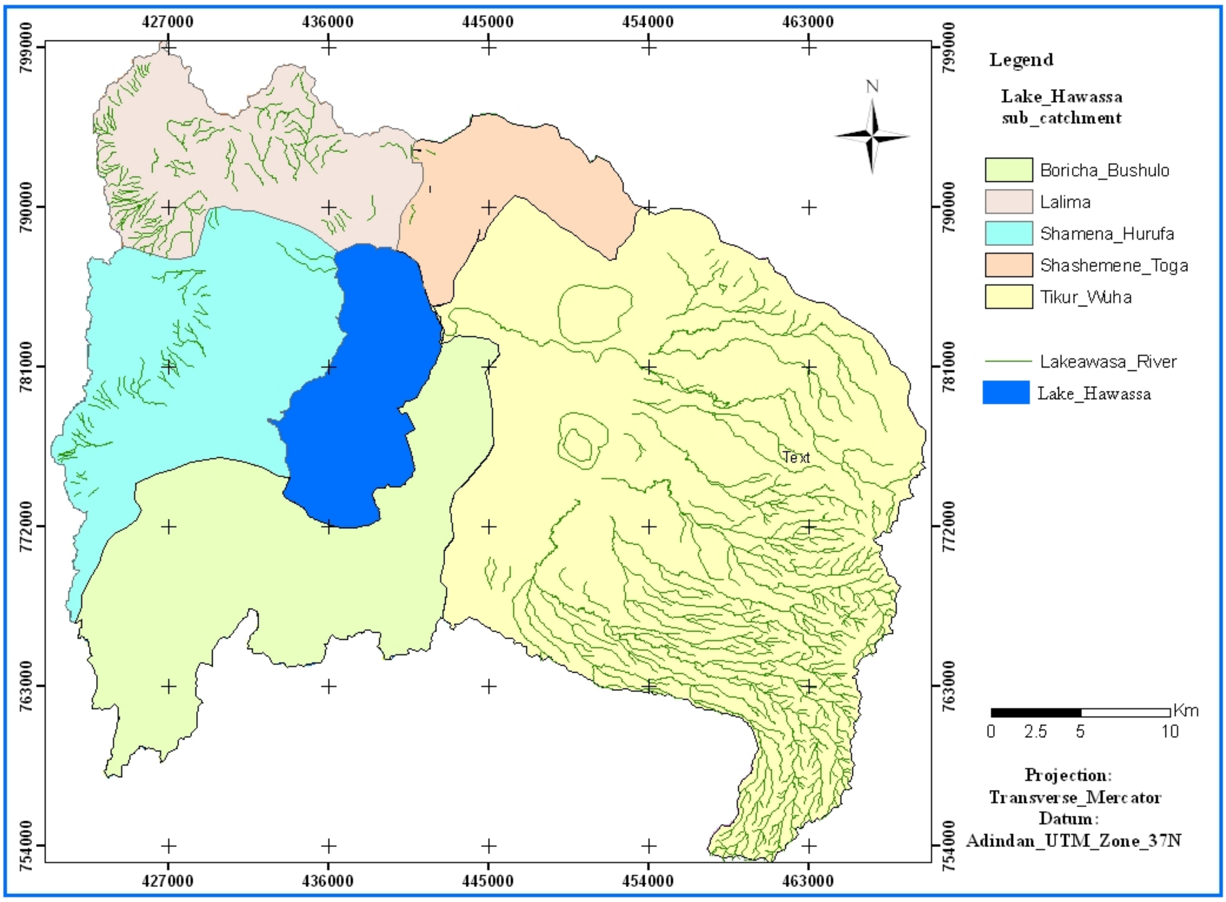

Fig.6.1. Lake Hawassa Sub-catchments

The results of study falls within the ranges of the estimated soil loss for Ethiopia, which was ranging from 0 to 300 tons/ha/yr with mean of 12 tons/hectare/year (Hurni, 1985), but with low exaggerations than the national average.

Table 6.1. Soil Loss Vs Sub-catchments

No.	Sub-catchment	Area(ha)	Mean Soil Loss (Ton/ha/yr)	Total Soil Loss (Ton/ha/yr)	% Soil Loss
1	Shamena_Hurufa	19,162.00	6.25	119,793.26	22.44
2	Lalima	13,691.00	3.96	54,266.77	10.17
3	Shashemene_Toga	7,271.00	6.07	44,130.89	8.27
4	Tikur_Wuha	63,573.00	3.12	199,508.41	37.37
5	Boricha_Bushulo	23,817.00	3.43	81,618.87	15.29
	Total Catchment	127,745.00	4.18	533,846.36	100

In the catchment areas about 7% of the total area was under moderate to high erosion hazard with soil loss of greater than 6 ton/ha/yr, 30% was moderately degraded while about 10% of the area experienced tolerable soil loss (Table 6.2).

Table 6. 2. Area Coverage of Soil Loss classes

No.	Soil Loss Ton/ha/Yr	Degree of erosion	Area (ha)	% of total area
1	0 _ 0.69	-	11,977	9.38
2	0.7 - 3.125	Very Less	68,396	53.54
3	3.126 - 6.25	Less	38,510	30.15
4	6.251 - 12.5	Moderate	7,248	5.67
5	12.501 – 25	High	1,411	1.10
6	>25	Very high	203	0.16
	Total		127,745	100.00

Some studies conducted on soil erosion assessment in the study area revealed different rate of soil erosion. For example; Girma Urgecha (2005) estimated mean soil loss of 8 ton/ha/year; while the result achieved in this study was 4.179 ton/h/year which have reduced USLE result exaggerations by 50%. The difference in results is due to different methods of USLE algorism used in parameter estimation, especially L, S and R factors were estimated using the improved USLE algorisms, which take in to consideration the topographic influence. As USLE results are highly exaggerated when compared with actual field measurements, the results of the present study were relatively better than the previous ones.

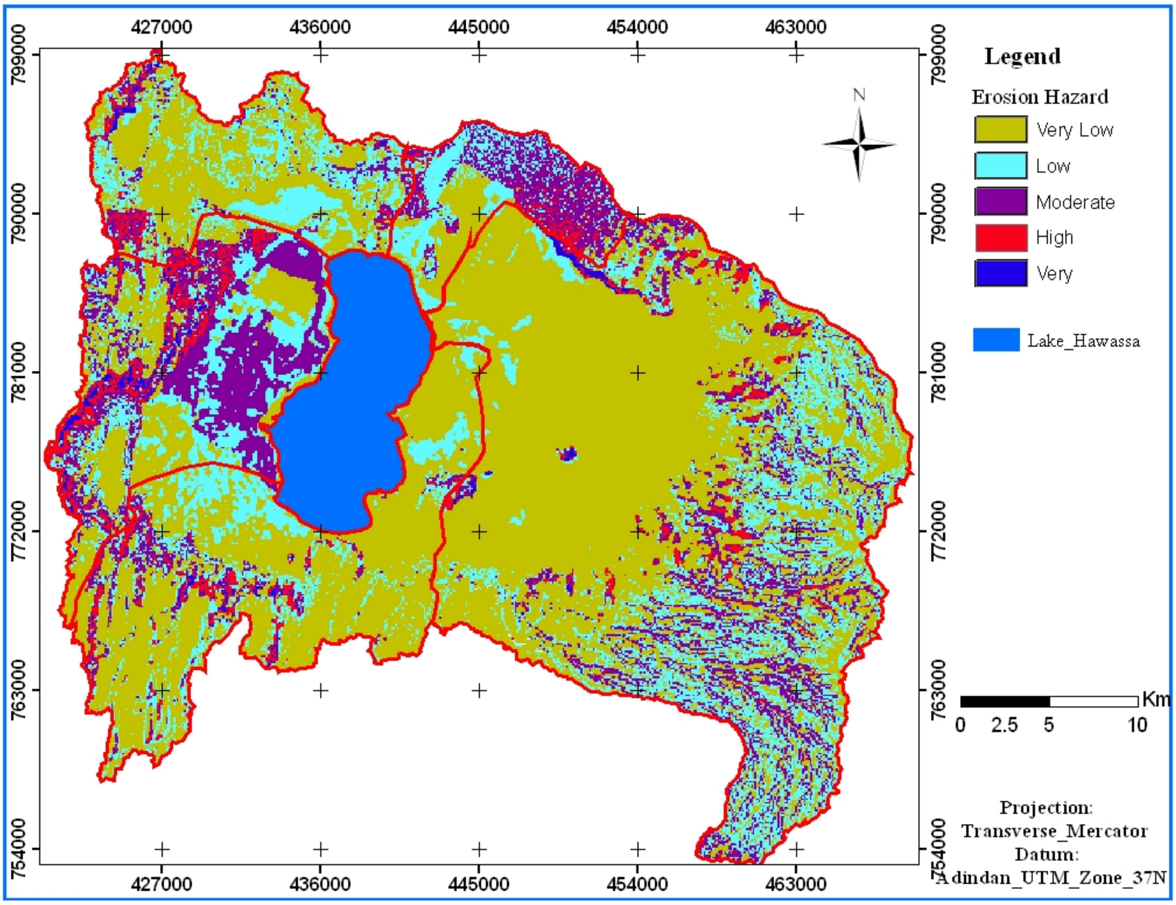

Fig.6.2. Mean Soil Loss Map

However, one of the objectives of the present study is to assess the erosion hazard in Lake Hawassa catchment. According to the study findings, the majority of high and very high erosion hazard areas are located in the western part of the catchment. These are Shamena-Hurufa, Lalima and Boricha Bushulo sub-catchmnents including Umbulo-Kejima, Lebu Koromo, and hill slopes running from Boricha to Shamena Hurufa. In the north-eastern and eastern part of the Shashmene_Toga sub-catchment: waransa ridge and parts of Shashmene moderately cultivated farms to the east of the road from Shashemene to Hawassa are high erosion hazard areas. Besides, few deforested and cultivated slopes from Tikur Wuha sub-catchment along the escarpments have high erosion hazards. The intensively cultivated lands to the west in Shamena_Hurufa and Boricha sub-catchments and the moderately cultivated lands to the north in shashemene_toga areas have moderate erosion risk. All the flat plains from wondo-genet to Lake Hawassa, including the Cheleleka swamp and most of the gentle slopes in the catchment are characterized by low erosion hazard. The majority of the undulating eastern highlands touching the parts of Wondo-Genet, Malga, Gorche, Kofele and Shebedino; the Scrub and Grasslands of Chebi and Urgi highlands in the Lalima sub-catchment experience moderate to low erosion hazard.

6.2. Degree of Environmental Stress in Hawassa Catchment

Land degradations such as soil loss, deforestation, over grazing, inappropriate land use, and natural resource based livelihood system and natural factors like climate variability and topographic factors, among others, put together will lead to environmental deterioration. The overlaying erosion risk, rainfall variability, livelihood system, and vegetation indices (NDVI) were used in identifying the degree of environmental stress in the catchment. Environmental stress areas are found both on the escarpment and on the plain.

The result found indicates that nearly 49% of the catchment is within high to moderate degree of environmental stress while about 50% of the catchment is with in mild degree of environmental stress (table 6.3; Fig. 6.3).

Table 6. 3. The degree of Environmental Stress

No.	Degree of Stress	Area (in Hectare)	% Area
1	Normal	1004.36	0.78
2	Mild	64,843	50.07
3	Moderate	44,691	34.5
4	High	18,149	14.01
5	Very High	804	0.62

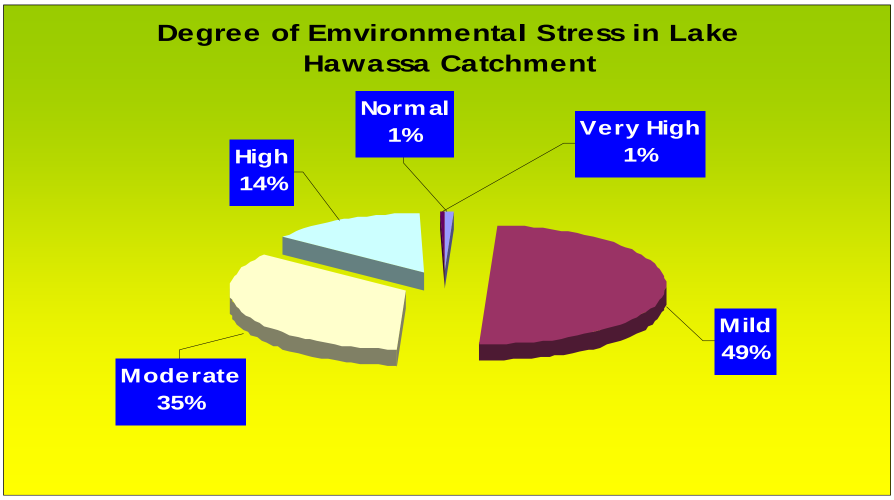

Fig. 6. 3. Pie-chart showing degree of environmental stress

Similar to the erosion hazard, the western parts of the catchment such as Shamena-Hurufa, Lalima, and Boricha_Bushulo sub-catchments including areas: Muleti, Lebu-Koromo, Umbulo-Kejima escatpments and the ridge running from Boricha to Shamena are areas of high and severe environmental stress. Besides, in the Shashemene_Toga sub-catchment, the Waransa ridge, and parts of the moderately cultivated lands to the east of the road from Shashemne to Hawassa are also areas of high environmental stress.

The majority of Boricha and Hawassa Zuria woreda in the south-west, Siraro and Shala scrub and grasslands in north-west, and moderately cultivated lands of Shashemene belong to the moderately stressed areas. The majority of the eastern highlands in Wondo-Genet, Malga, Shebedino, Gorche and Kofele are environmental low stress areas; this might be due to better vegetation cover and agro-forestry practices.

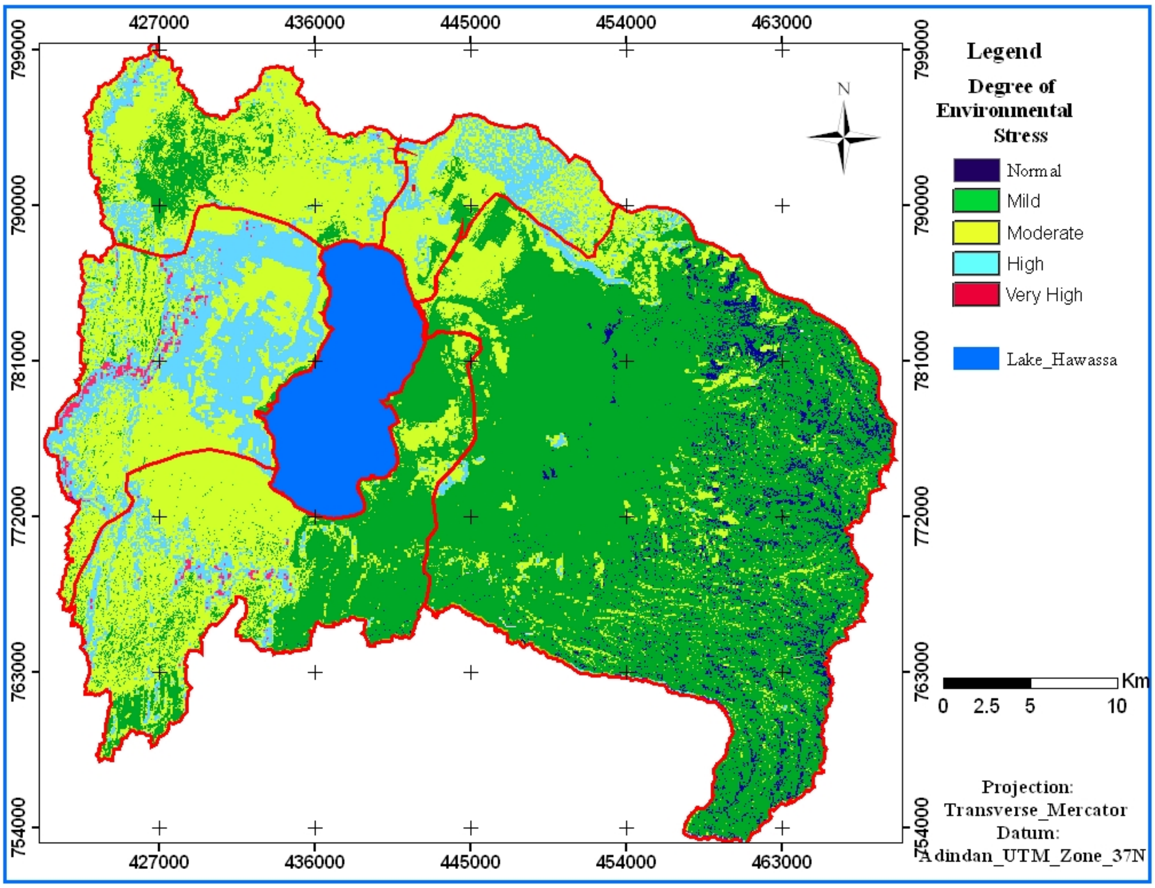

Fig. 6. 4. The degree of Environmental Stress

According to key informant and observation made, the intensively cultivated plains to the west, in Shamena_Hurufa sub-catchment, were highly stressed mainly due to severe degradation of the surrounding escarpments of Shamena–Hurufa ridge and Ubulo-Kejima. In these areas, the expansion of state and private farms three decade back forced the local farmers to settle along the slopes. As a result the ridge was exposed to deforestation and followed by severe erosion of the top soil. The continued erosion hazard had overlain the flat plains of the foothills with the sub-soil. This devastation led to the formation of rills and wide gullies the overall effect of which resulted into severe environmental stress.

6.3. Environmental Stresses Vs Erosion Hazard

The degree of relationship between two continuous variables is known as correlation coefficient. The index of correlation coefficient ranges from -1 to 1. The relationship between variables is interpreted by the square of the correlation coefficient (r^2) which is called the coefficient of determination.

In this study, the association between degree of environmental stress and the factors such as erosion hazard, rainfall variability, vegetation index, and livelihood system has shown significant positive correlation (Table 6.4). The combined effect of these factors may show the degree of influence of each factor on environmental stress. However, due to time limitation regression modeling was not conducted in the present study.

Table 6. 4. Correlation between the Degrees of Environmental Stress and the layers of independent Parameters

No.	Variables	Correlation coefficient (r)	Coefficient of determination (r2)
1	Degree of Environmental Stress and Soil Loss	0.63	0.3969 (39.6%)
2	Degree of Environmental Stress and NDVI	0.77	0.5929 (59.3%)
3	Degree of Environmental Stress and Livelihood	0.76	0.5776 (57.7)
4	Degree of Environmental Stress and Rainfall variability	0.51	0.2501 (24%)

The study indicates that areas of high erosion hazard are also areas of high environmental stress. This is observed in Shamena_Hurufa, Boricha_Bushulo and Shashemene_Toga sub-catchments and it is manifested with the correlation coefficient of 0.63.

6.4. Environmental Stresses Vs Rainfall Variability

Areas of high environmental stress are also areas of high rainfall variability with coefficient of variation greater than 30. Rainfall variability and deficient rainfall would lead to drought, which in turn led to decrease in vegetation cover. This phenomenon exposes the land to water and wind erosion leading to land degradation thereby resulting into environmental stress. The years of variable or deficient rainfall not only led to production losses but also decline in vegetation cover which in turn makes the land susceptible to degradation agents such as running water and wind (NMSA, 1996).

Based on the rainfall data analysis and perception of the local community, there is an observed declining trend of rainfall in the catchment, and it was significantly varying in the western part of the catchment (Fig.5. 13).

6.5. Environmental Stresses Vs Vegetation Index (NDVI)

NDVI values indicate the condition of the vegetation cover of area under investigation. The computed NDVI values indicate the level of vegetation cover and land degradation in the catchment. Areas with NDVI values greater than 0.3 which are found in Tikur Wuha sub-catchment including Wondogenet, Malga, Shebedino, Gorche, and Kofele high land areas have less environmental stress. On the other hand, typically the Shamena_Hurufa sub-catchment has severe environmental stress as NDVI value is near 0, which means devoid of vegetation indicating degraded lands (Table 5.10 on NDVI analysis). The correlation coefficient (r = 0.77) between environmental stress and NDVI indicate high degree of positive relationship.

6.6. Environmental Stress Vs Livelihood System

As livelihood system is determined from the means of living that is derived from land use, the sustainability and the change in land cover and land use expose land surface to degradation, which is leading degree of environmental stress. The land use land cover change analysis between 1986 and 2005 indicated that forests, scrub lands and grass lands are changed in to other land cover/use types. This was happened mostly in the western part of the catchment in Shamena_Hurufa and Lalima sub-catchments where the livelihood zone belongs to Maize and Agro-pastoral. Such unsustainable land cover/ land use and the dependence of the livelihood on natural resources created moderate to very high environmental stress in area. The observed correlation (r = 0.77) between environmental stress and livelihood system indicate that the resource use pattern of the local communities is also determines the degree of environmental stress.

CHAPTER VII

7. CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

Environmental problems are complex and multidimensional as their cause and effect vary with range of geographical environments. The understanding of the links between environmental stress and its major causes, including the natural and anthropogenic ones, has paramount importance for future management intervention.

Soil degradation, deforestation, erratic rainfall, cultivation of marginal lands, over grazing, natural resource based livelihood systems are found to be major factors for environmental stress and declining land productivity. Consequently, world wide, land degradation and environmental stress have been mentioned as primary causes of declining productivity and food insecurity. Similarly, the problems of soil erosion, deforestation, and rainfall variability were mentioned for declining productivity and worsening food insecurity in Lake Hawassa catchment. Hence, assessment of erosion hazard and environmental stress areas in the catchment were the main objectives the study.

The Universal Soil Loss Equation and Multi Criteria Evaluation involving weighted linear combination, using GIS and remote sensing techniques, were methodologies adopted for identifying erosion hazard and environmental stress areas, respectively in the catchment.

This study found out that the level of erosion hazard in Lake Hawassa catchment varies with factors such as topography, vegetation cover, farming practices, soil type, and human interference. About 8 % of the catchment is with high and severe erosion hazard and 30% is in low erosion hazard. Specifically, the escarpments of Shamena_Hurufa, Lalima, Boricha_Bushulo and Shashemene_Toga sub-catchments are the most degraded parts.

15 % of the catchment particularly most of Shamena_Hurufa and Shashemene_Toga sub-catchments are with high and severe environmental stress and about 35% of the catchment; almost in the western part, is under moderate environmental stress. The remaining 50% area is in low and mild environmental stress-mainly in the Tikur_Wuha sub-catchment.

Areas of high rainfall variability in the catchment also coincide with areas of high environmental stress. Rainfall variability leads to decrease in vegetation cover as manifested in low NDVI value and high erosion hazard.

Based on the relationship observed between environmental stress in one hand and the erosion hazard ($r = 0.6$), NDVI ($r = 0.77$), Human livelihood ($r = 0.76$) and rainfall variability ($r = 0.5$) on the other, it can be concluded that erosion hazard and land degradation can lead to environmental stress in the catchment.

Environmental stressed areas are found both on the escarpment and on the low lying plains.
The underlying factors causing environmental stress could be different and need further investigation using other techniques.

7.2. Recommendations

In order to reverse the situation of human induced land degradation and climate variability which in turn lead to environmental stress; the following recommendations are suggested.

- The severely degraded and stressed escarpments such as Shamena-Hurufa, Lebu-koromo, Umbulo-kejima and Lalima in the west need urgent soil and water conservation works, and since rill and gullies are common forms of erosion hazard, physical structures such as soil bunds, terraces, and area closure and plantation conservation measures are proposed. The low lying environmentally stressed areas need further study for appropriate intervention.

- Promoting indigenous plantation conservation such as acacia species and integrating local and indigenous knowledge in the participatory watershed development scheme. This helps develop the sense of ownership on the side of the community so as to make sustainable conservation works.

- Since land degradation and erosion hazard led to decline in soil depth and reduced productivity, crop and land suitability study has to be made for alternative cropping.

- There is a need for further study in the areas of geology, climate variability and human livelihood system in the catchment as the causes of environmental stress are diverse.

- In order to bring sustainable solution to the problem of land degradation and environmental stress, in addition to what was proposed; rural communities need to adopt profitable and sustainable land management practices and alternative livelihood strategies that are less demanding of the natural resources.

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Annexes

Annex. 1. Checklist for Focus Group Discussion (FGD) on farmers' perception of Environmental degradation

Preliminaries

- Field equipment **(**Camera, GPS, Stationeries**)**
- Orientation of Facilitator and Guide
- Briefing the mission to district and peasant association leaders, key informants an FGD participants
- Field work preparation

Setting objectives

- To understand the customary resources use patterns
- To identify the natural resource base for livelihoods diversification and alternatives
- To identify the causes of environmental degradation
- To understand the situation of food insecurity

Approach

- Scheduling the activities
- Trip to field site as per the schedule
- Explain purpose of the mission
- Semi-structured interview for key informants and FGD

Discussion Points

- Means of livelihood
- The land use system in the area
    - degraded areas
    - grazing grounds
    - farming system and crops cultivated
    - calendar of farming system
    - information on current crop situation, livestock situation
- Soil Erosion Problems
    - past, current, future
- Fuel wood depletion
- The causes of food insecurity
- Measures taken to reduce the problems of food insecurity and its causes
- Measures taken to reverse soil erosion/environmental degradation
    - by communities
    - government /NGOs and others
- the indicators of environmental degradation and soil depletion
- soil and water conservation works
    - What? By whom? Since when?

Annex 2. Ancillary Information on Satellite Images

Landsat5 TM

IMAGE_ID P168R55_5T19860121

PATH 168

ROW 55

DATE 01/21/86

FILE_FORMAT GEOTIFF

DATA_FORMAT BYTE

PLATFORM LANDSAT5

SENSOR TM

PROJECTION UTM37

DATUM WGS84

UNITS METERS

X_START 3.8041800000E+05

Y_START 9.0319350000E+05

X_INCREMENT 2.8500000000E+01

Y_INCREMENT -2.8500000000E+01

Landsat7 ETM+

IMAGE_ID P168R55_7T20051203

PATH 168

ROW 55

DATE 03/12/05

FILE_FORMAT GEOTIFF

DATA_FORMAT BYTE

PLATFORM LANDSAT7

SENSOR ETM+

PROJECTION UTM37

DATUM WGS84

UNITS METERS

SUN_AZIMUTH: 127.25800769

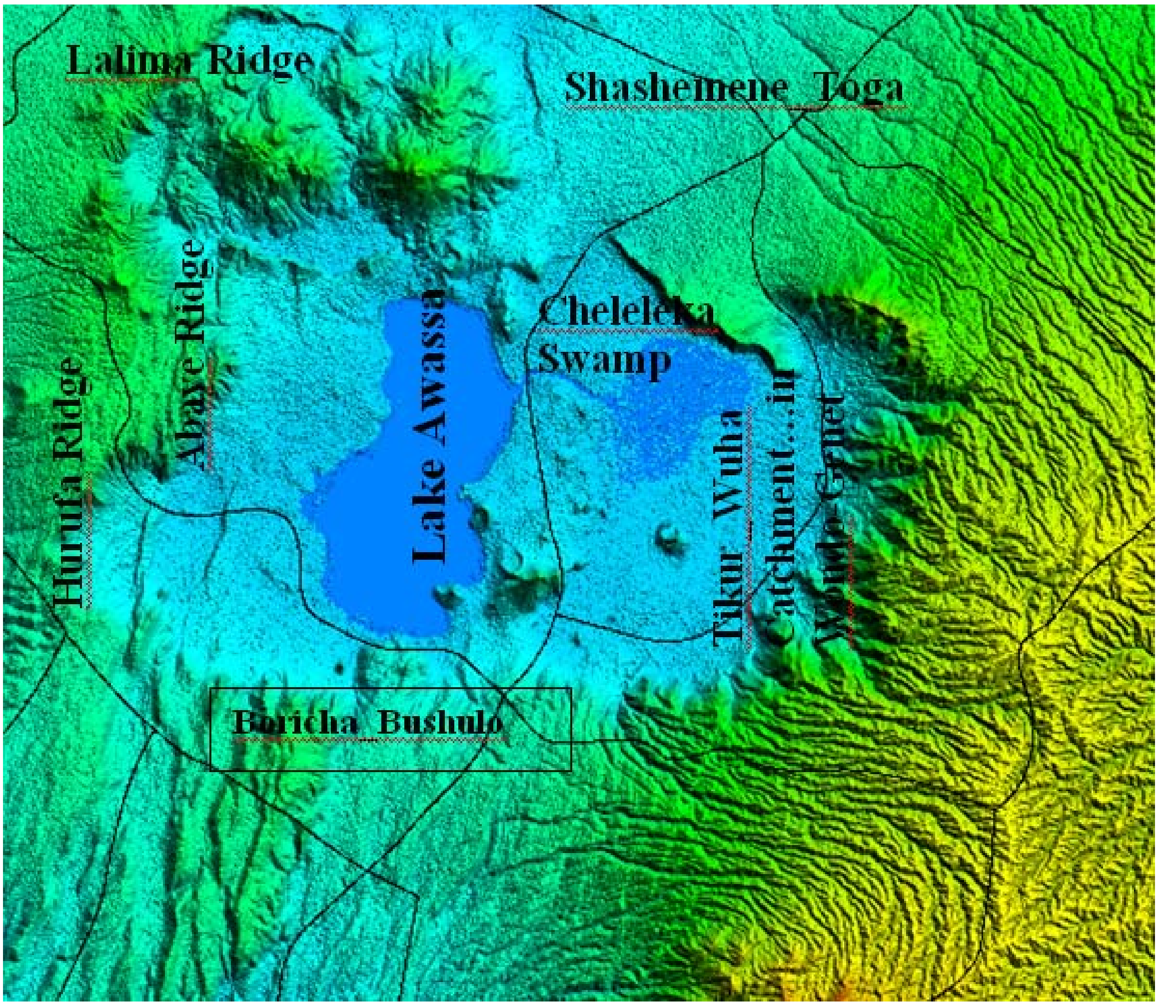
SUN_ELEVATION: 51.3001928

CLOUD COVER: 0

Annex 3. Band Designation of Landsat TM and ETM+

Spectral Bands	Uses
1. Blue-green	Useful for distinguishing soil from vegetation and deciduous from coniferous.
2. Green	Emphasizes peak vegetation, which is useful in assessing plant vigor.
3. Red	Discriminates vegetation slopes.
4. Reflected IR	Emphasizes biomass content and shore lines.
5. Reflected IR	Discriminate moisture content of soil and vegetation; Penetrate thin clouds.
6. Thermal IR	Useful for thermal mapping and estimated soil moisture.
7. Reflected IR	Useful for mapping hydro thermally altered rocks associated with mineral deposit.

Annex 4. 3D view of Lake Awassa Catchment



Declaration

I, the undersigned, declare that this thesis is my original work presented as part of the requirement for Masters Degree in Remote Sensing and GIS at Addis Ababa University. I further declare that this work has not been presented for a degree in any other university, and all sources of material used in this thesis were duly acknowledged.

Name: Tigneh Eshete G/Kidan

Signature: ______________________

Place and Date of Submission: Addis Ababa University, June 2005