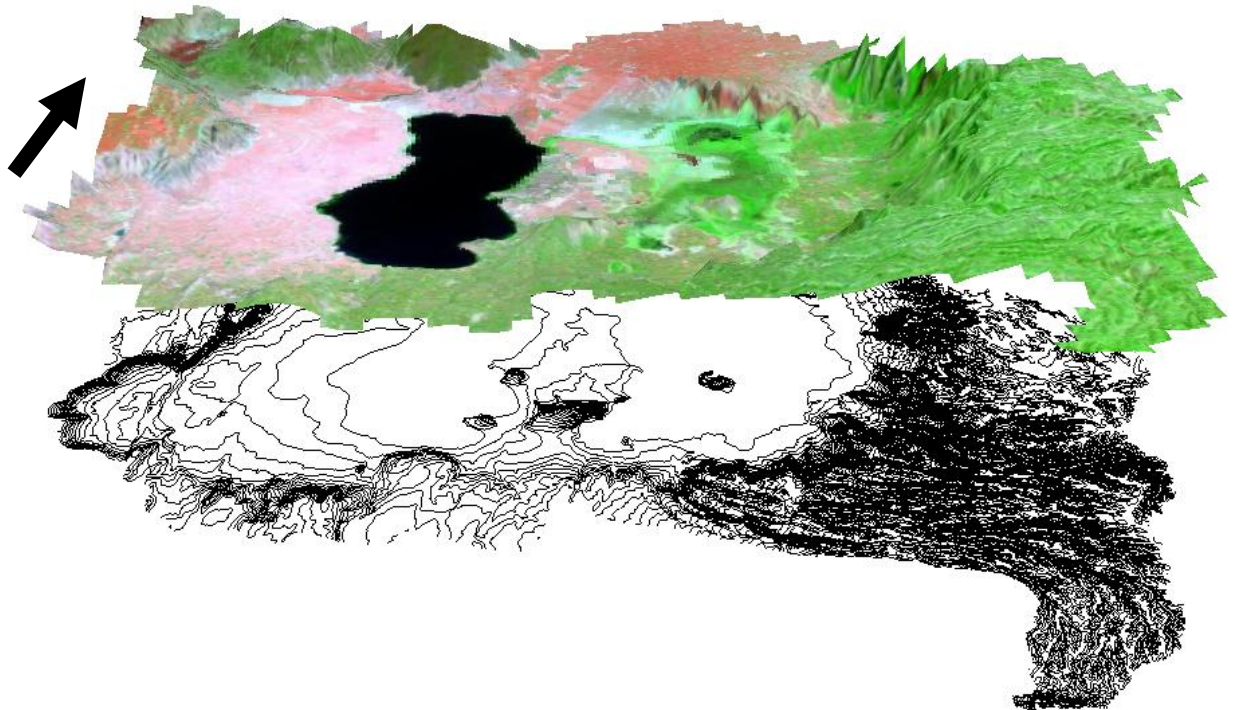


LAND DEGRADATION ASSESSMENT IN LAKE AWASSA CATCHMENT USING GIS AND MODELING



A THESIS SUBMITTED TO THE SCHOOL OF GRADUATED STUDIES
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LAND DEGRADATION ASSESSMENT IN LAKE AWASSA CATCHMENT USING GIS AND MODELING

Msc Research Thesis

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DECLARATION

I, the undersigned, declare that this is my original work, has not been presented for a degree in any other University and that all sources of material used for the thesis have been duly acknowledged.

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ABSTRACT

In countries like Ethiopia where agriculture sector has the basic contribution for gross-economy, land resource plays a major role in the level of production. *One form of land degradation is soil degradation and it is often a very slow process and may be almost invisible.* Rate and magnitude of erosion at any location is determined by the interaction of the natural and human induced parameters. Identifying the existing natural and human induced parameters control the land degradation level through GIS and Modeling enable to put on remedies that reduce the level of degradation at least to its natural level. At present, Lake Awassa catchment is exposed for land degradation problems that mainly caused from water erosion. The surface water flow in the catchment either directly end up to L. Awassa or to L. Cheleleka and its swamp vicinity. In 2004, the potential soil loss from up land of the catchment towards L. Awassa is estimated to cover 63.6% (950122.3 ton/year) and towards L. Cheleleleka is 36.4 % (544646.8 ton/year). The land cover change and inapplicability of soil conservation are responsible for intensifying the level of potential annual soil loss from uplands.

1 Introduction

1.1 Background

Land is one of the most important natural assets that ensure existence of life on earth; it is one of the main inputs in agricultural activity. In countries like Ethiopia where agriculture sector has the basic contribution for gross-economy, land resource plays a major role in the overall growth. The problem of insufficiency, improper management and access of Land resource has caused in poverty and afflictions in many poor world countries, including Ethiopia, resulting in death of millions of people.

In the study area, the presence of land degradation is evident in different ways. Occurrence of gullies on the northern, area between shashemene and Awassa all the way through Toga village, and to western and southwestern of Lake Awassa; and existence of sediment deposition (20 -35 cms), during rainy period, on the main road and on agricultural fields (Plate1,2) are some indicators. Study of such land degradation from water erosion point of view is done in this research through application of GIS and Modeling.



Plate 1: Gully formation



Plate 2: Deposition due to Sheet erosion

The land use/ land cover change in the area associated with population growth and investments that leads to enhance demand for major agricultural lands. Intensive agricultural activities and reduce the quality of land and the land become prone to degradation. Land Degradation is a natural process that occurs at some extent even though human interference is negligible.

Land degradation can be studied from physical, biological and chemical point of view of the study area and this research is based on physical impact or water erosion activities of the study area. In the research, major parameters that govern land degradation would be examined through modeling and GIS analysis tools.

Identifying the existing natural and human induced parameters control the degradation level enable to put on remedies that reduce the level of degradation at least to its natural level.

1.2 Relevance of the study

Land degradation becomes one of environmental problems in Ethiopia. It has strange impact on land and water resources. It cause reduction of fertility of the land and change chemistry of natural and man-made water reservoir. In lakes region the degradation of any part of watershed of the lake has a large impact on these water bodies. Water level rise due to siltation and change of biological resource of water bodies due to the incoming sediment that cause change in water chemistry are some of the major impact of upland catchment degradation.

Lake Awassa experience water level fluctuation in the past and some studies point out that one of many factors contributes for this event is siltation that caused by erosion process took place on upland area of the catchments. So identifying areas that are highly susceptible to land degradation enable decision makers to implement soil and water conservation in the catchment that may minimize amount of sediment entered to the lake and surrounding flat agricultural lands.

1.3 Previous works

The study area that encloses Lake Awassa is one of the most studied Lake regions of the Ethiopian rift valley lakes. The geological, hydrogeological, Pedological, engineering geological characteristics, etc of the study area have been studied by local and abroad researchers. The study conducted in the area either are in catchment scale or covered only sub area of it.

Land degradation from landslide aspect has been carried out in the Wondogenet region (Berhanu, Mohammed and Tesfaye, 2000) that showed the natural hazard in the area. The research utilized a GIS and Remote Sensing analysis techniques to delimit landslide hazard zones.

In 1998, Water Works Design and Supervision Enterprise carried out a research giving particular emphases to problems related to water level rise of Lake Awassa. During this study Land use/land cover of 1998 and 1965, soil map of the whole catchment in FAO classification had been generated. USLE model for the year 1998 used to evaluate a siltation problem. The erosivity factor in this study was a single value that did not consider the rainfall variability in the area. More over the result indicate the amount of sediment in that particular area but further analysis would have been vital to indicate which parameters have a major impose for such process.

1.4 Research Objectives

The main and specific objectives of this study is

Main objectives:

1. To map/estimate the spatial extent and level of land degradation (soil erosion) in the Awassa area by apply USLE model together with GIS
2. To understand natural and human induced parameters that aggravate the land degradation in the area through analysis of the model result

Specific objectives:

1. To indicate the utilization of GIS and Remote Sensing data processing techniques in Model input and output preparation
2. To compile a digital geo-referenced database in the Awassa Lake basin that could be used as assistance and reference of reliable information on natural resources
3. To evaluate effects of implemented various conservation management alternatives within the watershed based on the results of the model
4. To comment on measures to be taken on land degradation management on the study area based on the result of the research

The following research questions have been developed based on the main and specific objectives listed above:

1. Which area of the catchment is degraded and what parameters are controlling the distribution?
2. Which methods of GIS and Remote Sensing are important in such studies for preparing, analyzing and presenting output information?
3. What measures should be taken to minimize rate of land degradation, in general, depending on the parameters controlling the land degradation and the result of the GIS model used?

1.5 Scope of the Study

The research utilizes most of the materials utilized in the research are existing data collected from government, (WWDSE, MoW, MoA, CSA, EMP, MSA etc) non-governmental (ILRI) organizations and from peoples personal collection. Some difficulties encountered during research are finding a reliable data to use it as parameters for the model used and unwilling of some organization to provide existing data free of charge.

Approaches followed in this research include:

- Collection of the relevant data that used for generating parameters controlling land degradation
- Checking of the consistency and reliability of the data either in existing studies of the same place or other areas (in addition to field observation)
- Compilation of all information in digital format and developing of the needed model parameters through exhaustive GIS analysis
- Examine the results and finding the major parameter(s) that control the land degradation level of the specified area, and
- Suggesting the remedies that minimize the degradation level

In general, this research concentrates on the investigation of land degradation area from water erosion aspect, particularly on sheet and rills erosion. Hence, all grounds characterize the land degradation level are not covered.

2 Literature Review

2.1 Land Degradation

Land degradation can be related to both natural and human induced processes. Lal and Stewart, 1990 (cited in G. Teklehaimanot, 2003) define soil degradation as an outcome of human activities and their interaction with natural environment. They distinguished three types of degradation namely, biological, chemical, and physical. Physical land degradation includes degradation of soil structure, crusting, compaction, and erosion. Chemical degradation includes acidification, salinization, and nutrient and fertility depletion. Biological includes reduction of soil carbon and soil biodiversity processes (Lal & Greenland, 1979.). Accelerated land degradation is a biophysical process driven by socioeconomic and political causes. High population density is not necessarily related to soil degradation but what people do to the land determines the extent of degradation.

Causes of land degradation are the agents that determine the rate of degradation. These are biophysical (land use and land management, including deforestation and tillage methods), socioeconomic (e.g. land tenure, marketing, institutional support, income and human health), and political (e.g. incentives, political stability) forces that influence the effectiveness of processes and factors of land degradation. (Eswaran *et al.*, 2001).

Land degradation, a decline in land quality caused by human activities, has been a major global issue in the world. The importance of land degradation among global issues is enhanced because of its impact on world food security and quality of the environment. (Eswaran *et al.*, 2001). According to Erlich, 1988, environmental degradation from human pressure and land use has become a major problem worldwide but the effects are felt more in the developing countries than in the developed countries because of the high population growth rate and the associated rapid depletion of natural resources.

2.2 Land Degradation in Ethiopia

As Berry (2003) points out in his report about land degradation in Ethiopia with its extent and impact, Ethiopia is one of among the poorest countries and poverty and land and resource degradation appear to feed off each other. The irony is that Ethiopia is a country with high biodiversity and distinctive ecosystems and the natural resource base is critical to the economy and the livelihood of a high percentage of the population. Agriculture

accounts for 50 percent of GDP, 85 percent of foreign exchange earnings and supports, albeit insufficiently, 85 percent of the workforce. Estimates vary considerably but direct losses of productivity from land degradation are minimally 3 percent of agriculture GDP. All physical and economic evidence show that loss of land resource productivity is an important problem in Ethiopia and that with continued population growth the problem is likely to be even more important in the future (Berry 2003).

Several studies have been taken about land degradation issues at the national level in Ethiopia. As listed in Berry (2003), these include the Highlands Reclamation Study: Ethiopia (EHRS- FAO 1986); studies by the National Conservation Strategy Secretariat (Sutcliffe 1993), the Ethiopian Forestry Action Plan (1993), and Keyser and Sonneveld (2001); Effect of Soil Degradation on Agricultural Productivity in Ethiopia. The conclusion from the researches indicate that in mid 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation. Erosion rates were estimated at 130 tons/ha/yr for cropland and 35 tons/ha/yr average for all land in the high lands. Forests in general have shrunk from covering 65% of the country and 90% of the highlands to 2.2% and 5.6% respectively. Keyser and Sonneveld (2001) attempted a detailed national assessment of soil degradation on the basis of UNEP/grid DATA (cited in Berry 2003) and pointed out that:

- Soil degradation has its major impact on soils of lower fertility and where population density is high.
- On fertile soils, soil degradation tends to be compensated by fertilizer application
- Many areas, populated by a large percentage of the people are in a critical state, where fertility loss needs urgently to be compensated by new external impacts and/or soil conservation measures need to be implemented. The most vulnerable areas are in Northern Ethiopia

According to Berry (2003), the costs of land degradation in Ethiopia include:

Direct Costs -

- Costs of nutrients lost with top soil erosion (or the replacement costs of these nutrients)
- Lost production due to nutrient and soil loss
- Costs of forest removal
- Loss of livestock carrying capacity

Indirect Costs –

- Loss of environmental services
- Silting of dams and river beds
- Increasing irregularity of stream and rivers and reduced groundwater capacity

As estimates of the severity of land degradation in Ethiopia vary so do cost estimates. Almost all estimates of cost relate to the loss of soil and of nutrients from agricultural or grazing lands.

2.3 Erosion

One form of land degradation is soil degradation. Soil degradation is often a very slow process and may be almost invisible. (Cabeda, 1984, as cited in FAO, 2000) Physical degradation of the soil may be defined as the loss of the soil's structure quality and this may be observed both on the surface where thin crusts may be seen and also below the surface in or below ploughed horizon where compaction layers may be formed. With this type of degradation, the infiltration rates of the water into the soil are reduced whilst the rates of runoff and erosion increase.

Soil erosion refers to detachment and transport of soil and soil material by water, wind, ice or gravity-water and wind being the major factors. Erosion consists of detachment of soil particles from the surface; their transportation, that requires a source to carry the detached particles away (Tripathi et al., 1998). Soil erosion is a very widespread phenomenon, and is usually irreversible. Once the nutrient-rich surface soil has been lost, the ability to sustain plant growth is severely reduced, and increased runoff from the more impermeable subsoil results in a decrease in plant-available water.

Erosion can be either geological (natural erosion – steady and slow process of nature which is non-destructive) therefore which is not detrimental to man's well being and is wholly beyond his control; or it can be human induced that is caused by disturbance of nature's balance by human activities like large scale cutting of forests, leveling and cultivation, etc. A one inch soil of the surface which took a thousand years can be lost in just one year (R.P. Tripathi and H.P. Singh, 1998) and this kind of erosion which is a result of human interference, is know as accelerated erosion. This study, which is an assessment of land degradation from soil erosion point of view using modeling and GIS, deals with accelerated erosion.

2.4 Phenomena Influencing Erosion

Rate and magnitude of erosion at any location is determined by the interaction of the following major factors:

Climate: climatic variables affecting erosion are precipitation, wind velocity, temperature, humidity, and radiation receipts. Precipitation is the most forceful factor causing erosion through splash and surface runoff. The power or ‘aggressivity’ of rainfall to produce erosion is related to its amount, intensity and distribution (Jurg Krauer, 1988). Drops falling on the soil surface exert considerable force depending upon the size of the drop – the bigger the drop, the greater is the impact with which it strikes the land and consequently detaches and splashes the soil particles. These separated and displaced particles are then carried along with the runoff water. The effect of climate on natural vegetation and on soil development shows that soil and vegetation boundaries coincide in a general way with climatic boundaries. As a result, climate affects the erosion conditions of an area directly as well as through the vegetation that occurs (R.P. Tripathi et al., 1998).

Vegetation: the presence of vegetation acts as an erosion-retarded factor. Forest and grasses provide better cover than the cultivated crops. Dense vegetation cover intercepts and absorbs the force of rainfall and amount of energy (Jurg Krauer, 1988). Rate of soil loss by sheet and rill erosion on slopes of highlands, for various land uses in Ethiopia was estimated by Hurni, 1990, and updated in Bojo and Cassells, 1995.

Land Cover	Area (%)	Soil loss (t ha ⁻¹ year ⁻¹)
Grazing	47	5
Uncultivable	19	5
Cropland	13	42
Woodland/bushland	8	5
Swampy land	4	0
Former cropland	4	70
Forests	4	1
Perennial crops	2	8
Total for the highlands	100	12

Table 1: Estimated soil loss on slopes with different land cover of Ethiopia as a result of sheet and rill erosion (after Hurni, 1990, updated in Bojo and cassells, 1995)

Topography: the degree and length of a field has a very strong influence on the amount of erosion. Both these effects are probably related to an increase in the quantity, velocity and turbulence of runoff (Jurg Krauer, 1988).

Sealing and Crusting: Soil sealing is the formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling or sedimentation, which is relatively impermeable to air and water (Bergsma et al, 1996, as cited in G. Teklehaimanot, 2003). Soil sealing is due to the effect of raindrop on bare soil which results in reduction of infiltration; and increase in runoff and the potential for the soil erosion (Houghton and Charman, 1986, as cited in G. Teklehaimanot, 2003). Sealing soils often generate more surface runoff, and therefore a greater hazard for rill erosion (de Ploey, 1983, as cited in G. Teklehaimanot, 2003). Soil crust can range in thickness from a few mm to as much as 3cm. Crust can be much more compact, hard and brittle when dry than the material immediately beneath it (Bergsma et al., 1996 cited in G. Teklehaimanot, 2003). All seals are crusts but not all crusts are seals. Crusting is a sign of soil degradation caused by deteriorating conditions of plant cover and soil structure which are brought about by over cropping, overgrazing or over tillage.

Soil property: soils vary in their resistance to erosion. Part of this resistance is inherent in the soil, and is related to texture and amount of organic matter. Another part depends on soil condition and depth.

Exposition (aspect): there is a relationship between the amount of erosion of a field and the geographical direction it faces. The causes have to do with the effect of wind of rainfall inclination, of insulation in soil condition, and of the preference of grazing animals for sun or shade.

2.5 Water Erosion

Throughout Ethiopia, except in the real desert zones of the Ogaden, and Danakil plain, the landscape is subject to water erosion under the action of rainfall. The slope, nature of soil, vegetation and human activity also influence the decisive soil erosion process (Jurg Krauer, 1988).

The consequences of soil erosion and sediment deposition occur both on- and off-site. On-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in

organic matter and nutrients result in a reduction of cultivable soil depth and a decline in soil fertility. The net effect is a loss of productivity, which at first, restricts what can be grown and results in increased expenditure on fertilizers but later might lead to land abandonment (Pimentel *et al.*, 1995, as cited in FAO, 2000).

Off-site problems result from sedimentation downstream, which reduces the capacity of rivers and retention ponds, enhances the risk of flooding and muddy floods and shortens the design life of reservoirs. Sediment is also a pollutant in its own right and, through the agro-chemicals adsorbed to it, can increase the levels of nitrogen and phosphorus in water bodies and result in eutrophication (Steege *et al.*, 2001).

2.6 Forms of water erosion

As mentioned by Raymond W. Miller *et al.*, 1997, Erosion by water is classified as Raindrop splash erosion, surface flow or sheet erosion, and channelized- flow erosion.

Raindrop splash erosion: raindrops fall with an approximate speed of 914 cm/s. When raindrops strike bare soil, they beat it into flowing mud, which splashes as far as 61 cm high and 152 cm away. The soils most readily detached by raindrop splash erosion are fine sands and silt. Coarser particles are not shifted about as much because of their greater volume and weight. Most soils of finer texture, such as clays and clay loams, are not readily detached because of the strong forces of cohesion that keep them aggregated.

Surface flow erosion (sheet or laminar erosion): runoff water is responsible for much soil erosion, moving the soil particles by surface creep, saltation (movement of wet and supersaturated soil downhill by a rolling or dragging action), and valuation (results when

turbulent water causes soil particles to hop or skip in water as they move downward), and suspension (movement of smaller particles carried by moving water without touching the soil surface).

Channelized flow erosion: as water moves over the surface of the soil, some of it concentrates in low places to cut depressions or channels. Continued flow develops minor channels called rills; later, major rills and large gullies may be formed by the scouring action of increasing volumes of channeled muddy water carrying enormous amounts of sediments that will be deposited some where downstream.

According to Hurni 1985, erosion seriously reduces the productivity of the land and unfavorably affects the environment. Its results can be visualized by large gullies, or less obvious but more seriously by sheet erosion. The latter is rarely regarded by the peasants as a major problem, because they will not perceive a reduction of soil depth of few centimeters on their field within a generation. Consequently, they do not regard this kind of soil erosion by rainfall as a 'life threatening' problem.

2.7 Soil Erosion assessment

As stated above erosion is a system that its occurrence is dependent on many natural and human induced parameters. Assessing existence and effects of this process involve understanding complex interactions between rainfall, surface and subsurface hydrology, soil properties, land cover and topography. Prediction of soil loss from a given area needs spatial handling of all these information based on their contribution to the process. Such task is done using application of existing models which are developed based on the relationships of these interacting factors. There are dozen of models that used for predicting amount of soil loss from a given area.

2.7.1 Modeling Approach

Model is a simple representation or abstraction of a complex system that simplify the reality. Models differ each other based on issues such as the process they are based on (hydrology, erosion, chemical, etc), scale (spatial or temporal), input (data requirement and source, level of accuracy of data, data development utility software use, etc) and output (type, option and level of output).

Modern geographic information systems offer new opportunities for the collection, storage, analysis, and display of spatially distributed biophysical and socioeconomic data. Several soil erosion models have been modified and combined with GIS software to take advantage of these new capabilities and provide regional soil erosion assessments during the past decade (Goodchild et al., 1996). One of world wide applicable erosion models is the Universal Soil Loss Equation (USLE).

USLE model

The Universal Soil Loss Equation (USLE) is a simple multiplicative model that was derived from over 10,000 plot years of data (Wischmeier and Smith 1978). The factor values were recently updated following the analysis of thousands of new measurements (Renard et al. 1993) and a revised version of the model has been substituted in place of the original model for farm conservation planning in the United State. It considers the climatic, topographic, soil cover, land use cover, and human interaction with the landscape. The USLE and Revised Universal Soil Loss Equation (RUSLE) can be written as:

$$A = R K L S C P \dots\dots\dots \textit{Eqn 1}$$

where A is soil loss in tons per acre, R is the rainfall-erosivity factor, K is a soil erodibility factor, L is a slope length factor, S is a slope steepness factor, C is a cover-management factor, and P is a supporting practices factor. Land use and management are represented by CP and can be estimated from field observations or farm records.

3 Study Area

3.1 Location and Accessibility

Lake Awassa is situated in the Ethiopian major rift valley system surrounded by flat to slightly sloping lands, escarpments and hills. It is located 275 km south of Addis Ababa along the road to Moyale (Figure 1). The Lake Awasa Catchment covers around 1,367 km² and lies between 6° 49' - 7° 15' latitude and 38°17'- 38°44' longitude with elevation range of 2980 m.a.s.l. around Kululu ridge, near to Hogiso and 1680 m.a.s.l at the lake water level.

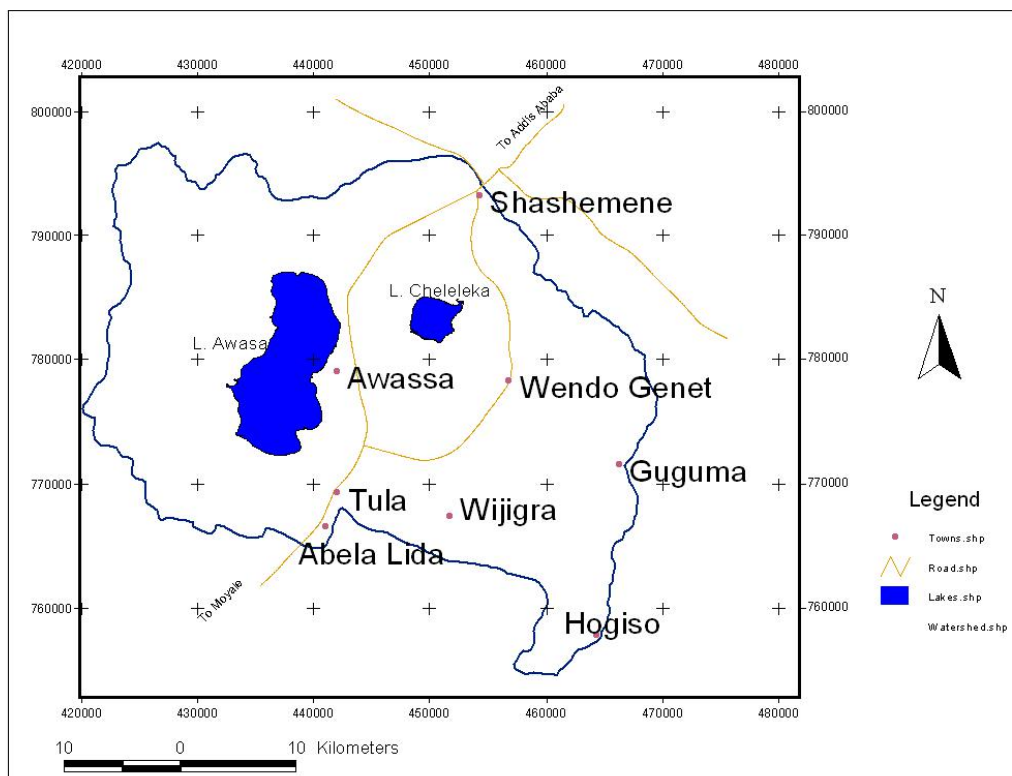


Figure 1: Location map of the study area

The L. Awassa covers around 6.9% of the total area of its basin. This lake experiences a lake level rise fluctuation during the last decades. Awassa town, current regional city of SNNPR, lies to the eastern part of the lake and susceptible to such problem.

3.2 Climate

Rainfall of Awassa Lake basin varies as one goes from the highest elevation, eastern and southeastern area of the basin, towards the lowest, western parts. The extreme east of the catchment receives 1200-1400mm per year, the caldera floor near Wondo Genet receives 1000-1200 and Awassa around 970mm. Monthly average rainfall records of stations within and nearby the basin are plotted in Figure 2. The basin's high rainfall season is during Kiremt that starts in June and ends in September and short rain season is in, Belg, which encompass March, April, and May. The area gets more than 88% of the total rainfall during the eight rainy months and the rest 12% is during the dry season (Zemenu, 2000). The moisture for precipitation originates from southwest equatorial air stream, which moves northwards with inter-tropical convergence zone (ITCZ). Variation of rainfall with elevation is illustrated in Figure 3.

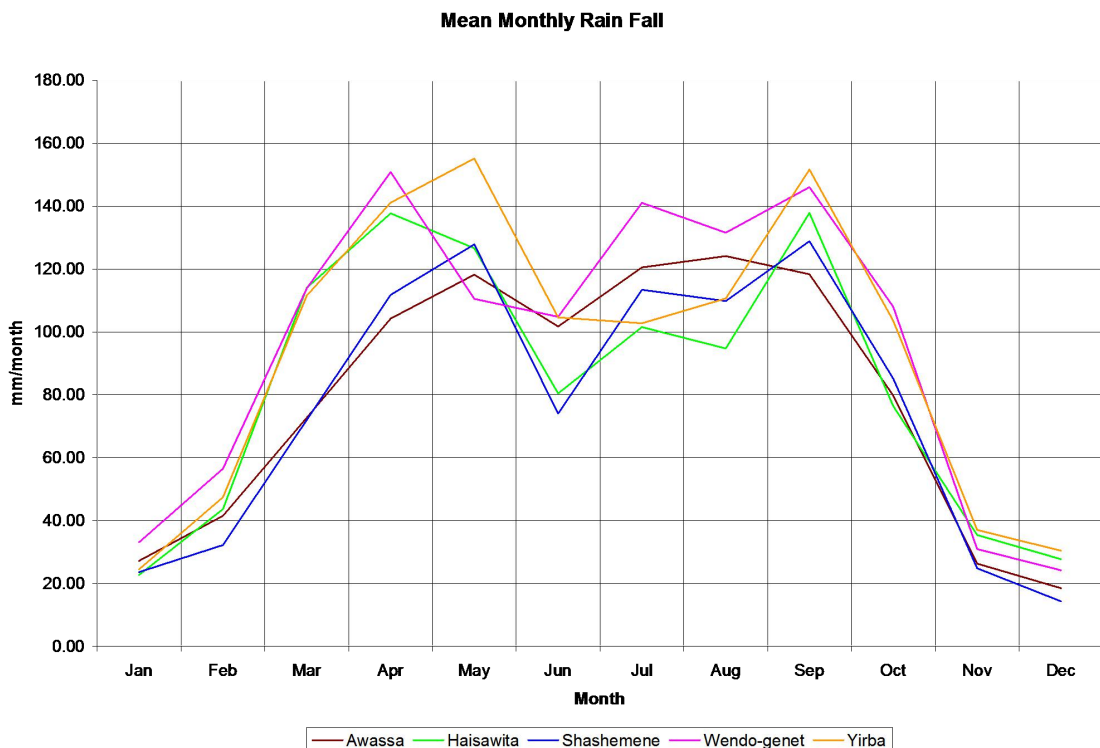


Figure 2: Mean Monthly rainfalls of stations within L. Awassa Catchment

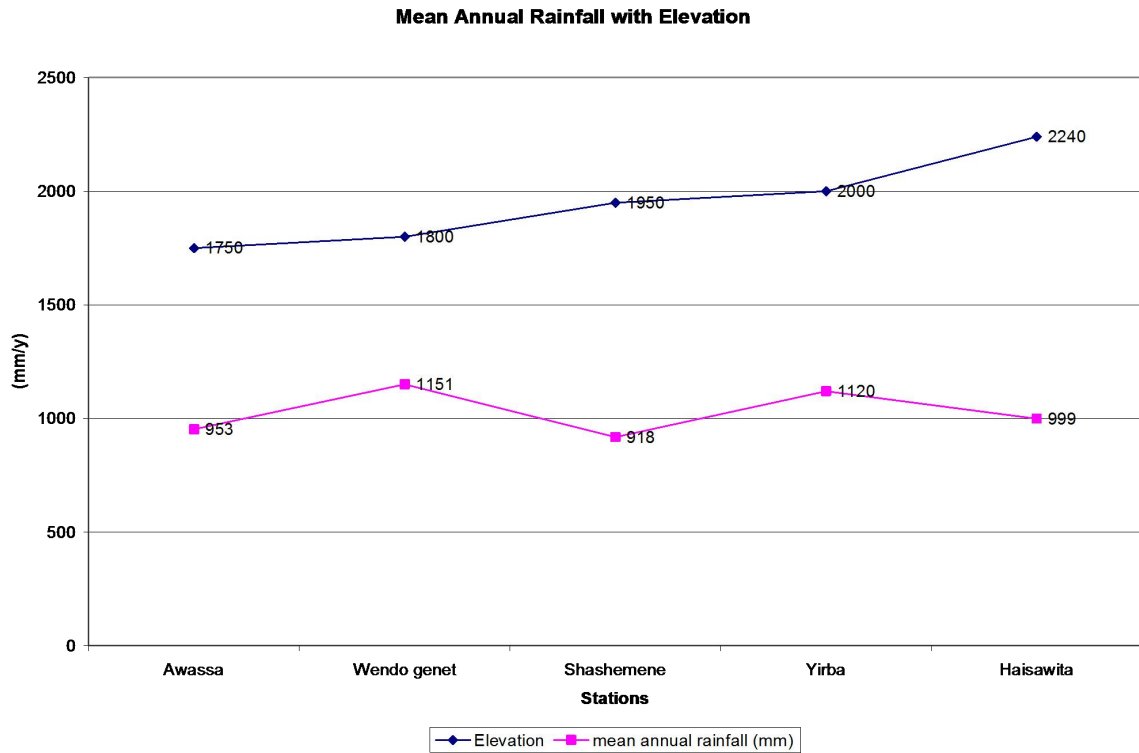


Figure 3: Mean annual rainfall distribution versus to elevation

Minimum monthly temperature of Awassa station of 25 years record shows lowest value records are in November, December, and January (9.8 °c to 10.28 °c) and the trend indicates increment during May to July, 14 °c. Maximum monthly temperature trend shows lowest records during July to August, around 23.6 °c to 24.6 °c and highest values in February and March, 29 °c to 29 °c (Figure 4). The mean monthly temperature of Awassa stations for the year 1988-2003 is plotted in Figure 5.

mean monthly temprature values (Awassa)

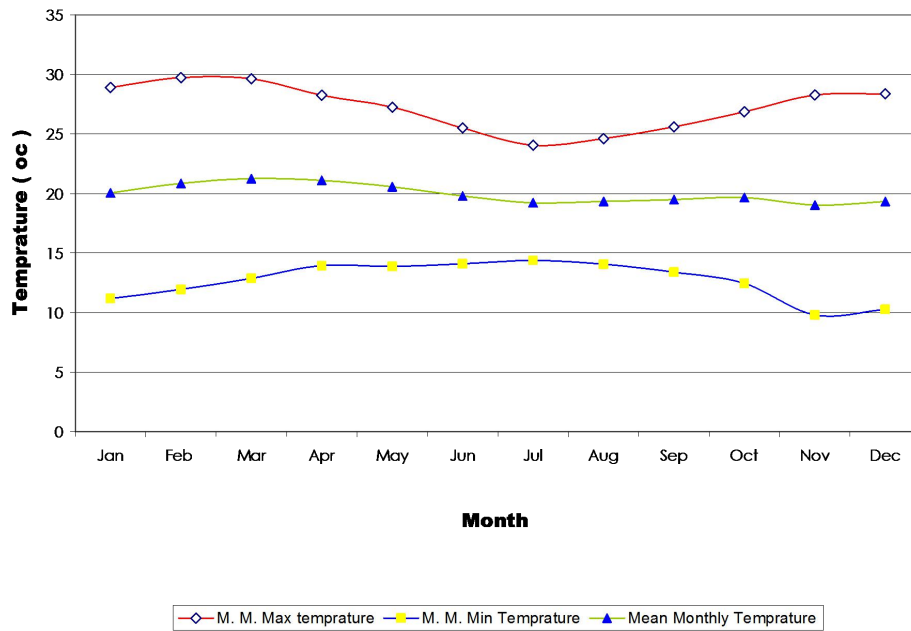


Figure 4: Mean Monthly temperature Values of Awassa Station

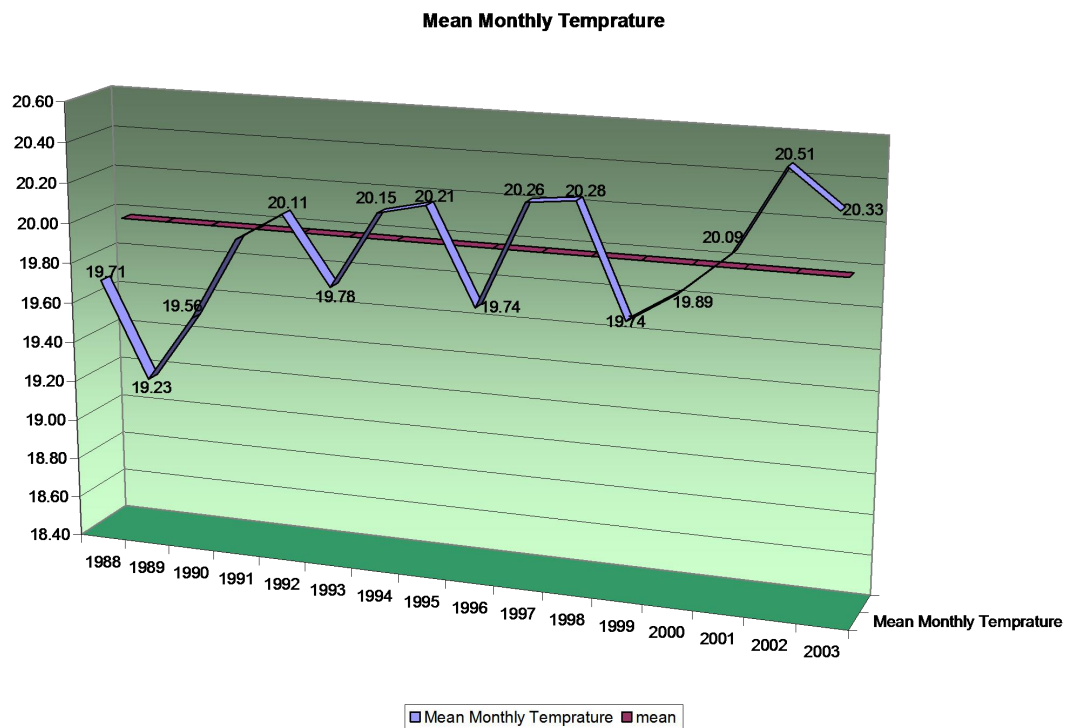


Figure 5: Mean Monthly Temperature of Awassa station for specified period

3.3 Physiography

Awassa caldera is the eastern part of the central main rift valley with a diameter of about 30-40 km. Lake Awassa and the nearby small Lake Cheleleka are situated in the central part of this volcano-tectonic depression. It was the Awassa caldera collapse that formed the two lakes and the depression was probably covered by large lake area, of which only Lake Awassa and small portion of the diminishing Lake Cheleleka remain today. In fact, Lake Cheleleka is currently drying up and changed to swamp (M Raunet 1974). The two lakes are connected by Tikur Wuha River which is the only channelized water resource of the lake Awassa. The Lake Awasa Catchment is delimited by Bilate Catchment to the south, the Ziway-Shala basin to the north and north east, and Awash River Basin to the eastern part.

The Corbetti caldera, located at the northwestern part of Awassa Caldera, forms an elliptical sunken area, 12 to 15kms across with a highest point of 2300, near to Chebbi and Urgi.

The eastern escarp of the caldera forms the edge of the eastern rift valley escarp with elevation difference of 800-1000 meters from the depression. The depression is bordered by fault escarps. The northern boundary encompasses the Weransa ridge, a straight escarp with abrupt wall about 180 meters high, which faces towards the Lake Cheleleka and swamp area.

The southern and western escarps form an arc of a circle with altitude difference of 200 to 400 meters and with steep and gullied sides.

Figure 6 shows the digital elevation model of the study area in South to North orientation using vertical exaggeration of 3x. MICRODEM 7.02 program is used for preparing such display that could help us to visualize the overall geomorphic feature of the study area. The ASCII format of Digital Elevation Model (DEM) is used as input for generating the 3D scene of the study area.

Figure 7 illustrate the color composite of TM band 7, 4, and 3 which is draped on elevation grid. The vegetation distribution is clearly observed on the eastern and southeastern area. This is caused because of band 4, which is used as green band in a color composite image. Vegetations have high reflectance in this band.

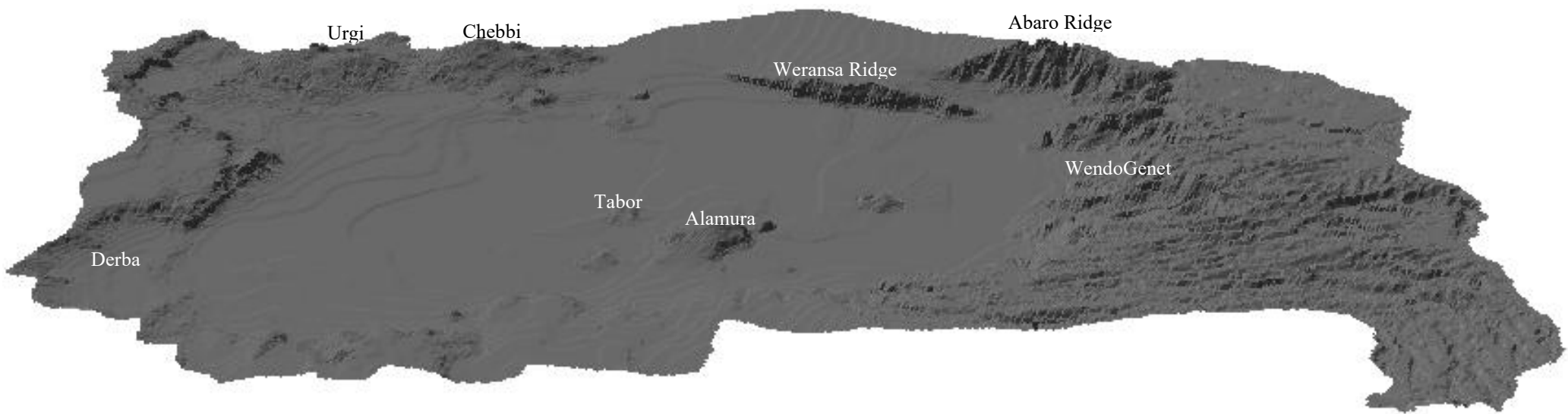


Figure 6: South to North view of the lake Awassa catchment

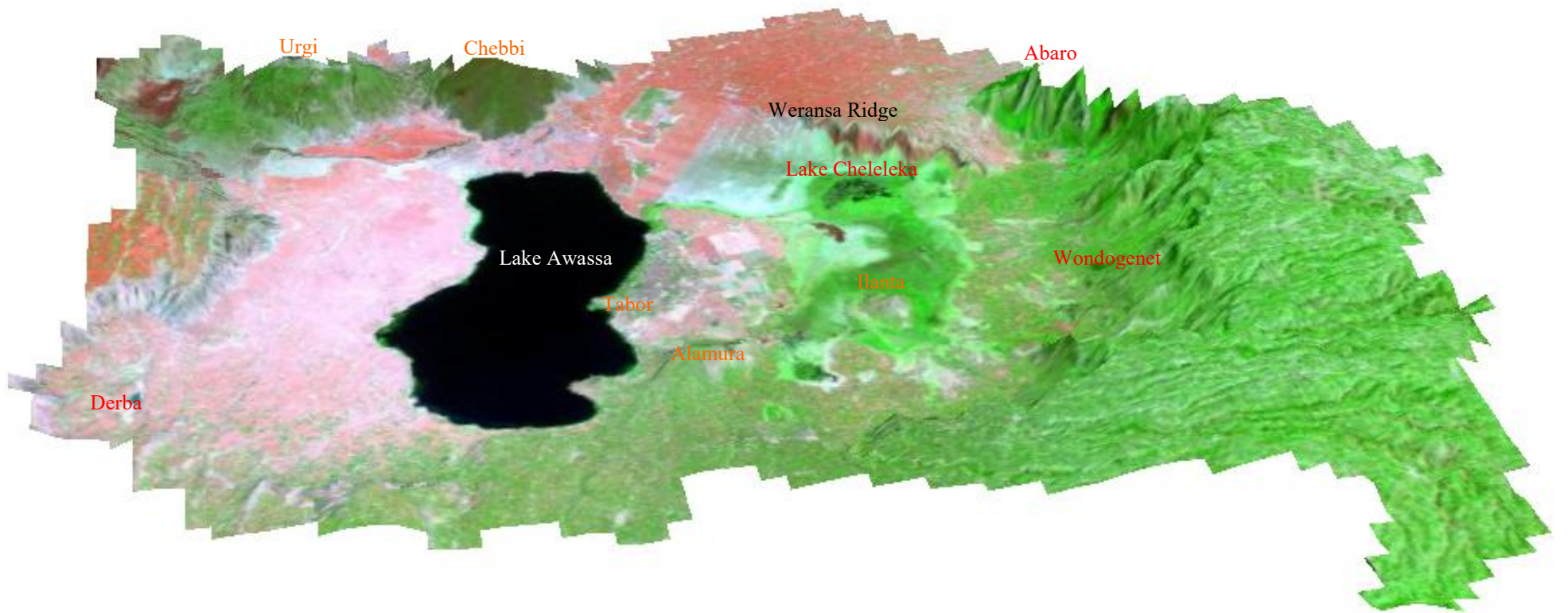


Figure 7: 3D view of TM color composite (TM 743) of the study area

3.4 Geology

Geology of a given area controls all hydrogeological characteristics such as surface water flow or ground water movement. In addition to these, it is one of the major factors that control the formation and type of soil that occur in the area which in return supports the existence and type of biosphere present in the area.

3.4.1 Lithostratigraphy

The lithology of the Lake Awassa catchment area dominated by volcanic and volcano-lacustrine sediments (M. Raunet 1994, Zenaw Tadesse 2003, Zemenu Geremew 2000). The geological units present in the study area are recent lacustrine and alluvial deposits, scoria cones, rhyolitic lava flows and associated ignimbrites, tuffs and volcanic ash.

The closed basin of the nested Awassa-Corbetti caldera complex is a giant elliptical depression 30-40 kms wide. The volcanoes in Awassa caldera are the great CORBETTI caldera complex to the north and the series of small monogenic cones east of Lake Awassa. The Corbetti caldera forms a more or less elliptical sunken area, 12 to 15 kms across (M. Raunet, 1994). The Corbetti caldera, which found North West of Awassa Lake, is a nested caldera within Awassa caldera. The Corbetti caldera has two volcanic centers of urgi and chebbi. The urgi centre is a source for the formation of pumice in the vicinity and chebbi is a centre for the formation of obsidian, which covers the Chebbi Mountain (Zenaw Tadesse, 2003).

Much of the central part of the catchment is covered by recent volcano-lacustrine sedimentary deposit. The wide, very gently area between Lake Awassa and the Cheleleka swamp is sprinkled with isolated cones that form the only elements in the land relief, sticking out of the volcano-lacustrine plain. Some of these hills are very distinct breached cones (THABOR, 1739 m, and GUMBI, 1850m, in the swamp) with very straight flanks. Such monogenic cones consist of layered tuffs combined with unwelded basaltic scoria (M. Raunet, 1994).

According to Zemenu Geremew the stratigraphy is categorized into five groups based on their geochronology (Figure 8 and Figure 9) and this category map is modified from

Zemenu 2000 based on attribute level editing of the geological unit map adopted from Zenaw Teddese 2000. From younger to older the stratigraphy are listed as follows:

Volcano-Lacustrine Deposits: are the only non-volcanic formations in the area. The deposits cover all the swampy area of Lake Cheleleka to the east including the foot of western escarps and north east of Lake Awassa. This unit also characterized the western side and a few flat areas, northern and southern tips of Lake Awassa.

Recent Acidic Volcanics: Corbetti caldera and its vicinity defined as this group. Pumice falls and ashes of Urgi, including the western side of Lake Awassa, and obsidian flow of chebbi volcanic complex that characterized by recent obsidian flows are a geological units grouped in these category.

Recent Basaltic Flows, Basaltic Hayaloclastites and Scoria Cones: small monogenic cones that scattered in volcano lacustrine deposit of flat land of the catchment forming the only relief are categorized in this group. Scoria, sometimes associated with scoracious basalt is the main lithological unit identified in this group.

Old alkaline silicic rocks: west and east of the caldera walls are where rocks of this group extensively exposed. Welded tuff, pumiceous deposits, surge deposits and rhyolite ridges of Wendogent area are some of lithological units define in this category.

Basalts And Ignimbrites Of The Plateau Trap Series: oldest rocks, such as fine grained mugerite. At the eastern side of caldera wall, these rocks exposed locally at the quarry site close to the base and overlain by thick welded tuff.

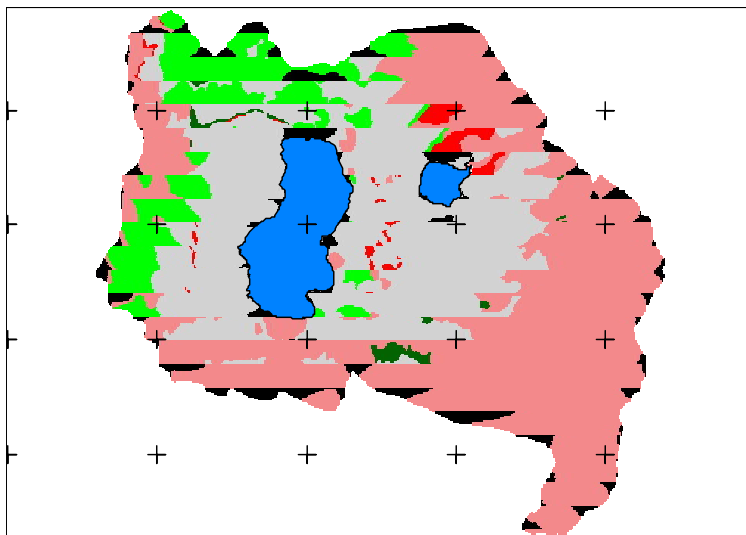


Figure 8: Geochronological distribution of lithology of the study area (modified from Zemenu 2000)

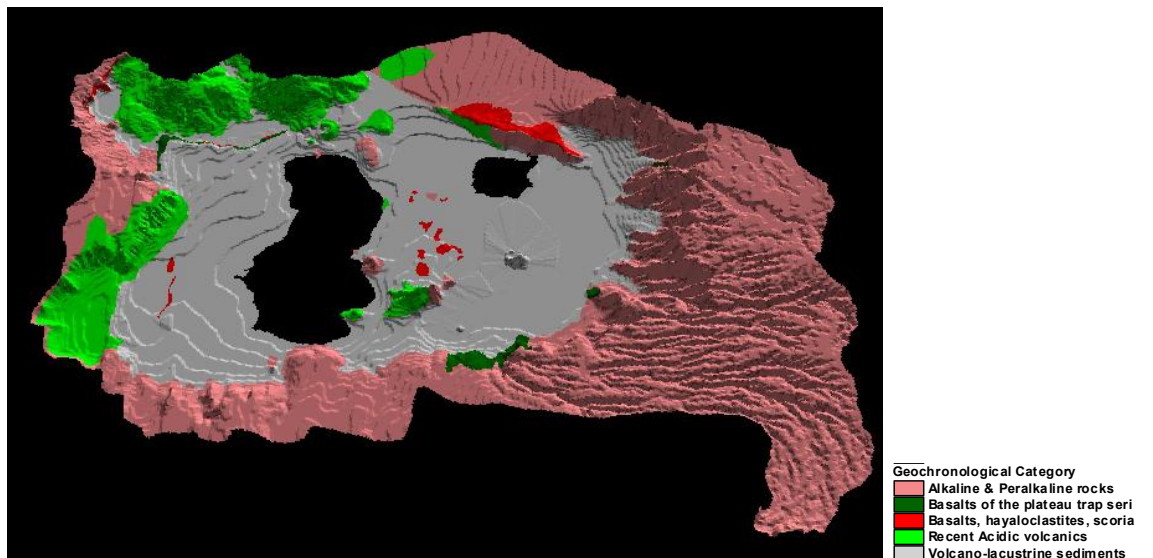


Figure 9: 3D map of geochronological units

3.4.2 Geological structures

There are a number of rift system faults with north and northeast trend along which the length of Lake Awassa is oriented. These faults are extension (normal faults) forming step faults. They are mainly dominant to the south and south west of the lake. The volcanic collapse structure (caldera) forms nearly circular structure around Lake Awassa basin. This collapse shifts some of the MER fault systems showing that the collapse has taken place subsequent to the rifting. In the Awassa caldera a line of young faults affect the rift floor. These faults, the Wonji fault Belt, shattered the rift floor into several relatively small horst and graben. Lakes or swamps occupy the more depressed areas (Zenaw and Taddess, 2003).

Ground cracks are observed in the Muleti sub-catchment southwest of Lake Awassa. The approximately NNE-SSW striking cracks could convey water from the sub-catchment to the lake when intercepted by East-west running faults. From degradation point of view this tectonic formed cracks are a cause for many gully formations in the area. Figure 10 shows some of the ground crack observed in Muleti area and prepared by Ayalew et.al 2004.

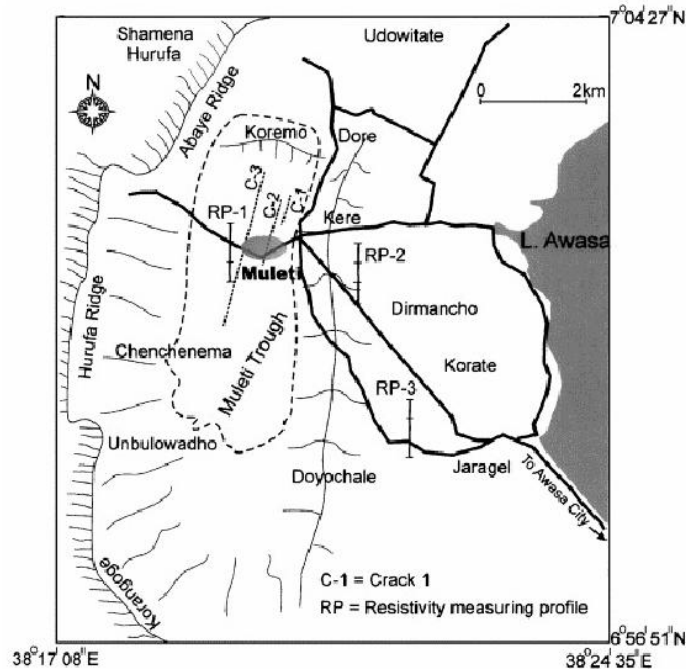


Figure 10: Map showing the location of recent cracks, After Ayalew et al 2004 (Cited in Yemane 2004)

According to Ayalew et.al 2004, (cited in Yemane 2004) the cracks have varying dimensions ranging from 2.5 to 12 meter wide and 150 m to 2.4 km length. The cracks have been described by Ayalew, et al. as having similar strike direction to the general trend of the Ethiopian Rift Valley and have neither vertical offsets nor horizontal displacements. Ground Cracks, Figure (10), 1, 2, have been created in 1996, 1997 and crack 3 in 1996 but widened 1998 respectively one after the other when the region was inundated by massive flood after above normal precipitation and developed in length and width gradually since April 1996.



Plate 3: Some of the recent ground cracks (1996-1998) on lake Awassa catchment (Muleti area)

One small pond located some 8.9 kms southwest of Lake Awassa near Derba village (Figure 11) is assumed to have dried out due to such tectonically-activated ground cracks. According to the information we collected from local people, the pond was created during the 1970's but disappeared since 2001/2002 within short period of time following a small earthquake. During field visits, the pond was dry and covered with grass.

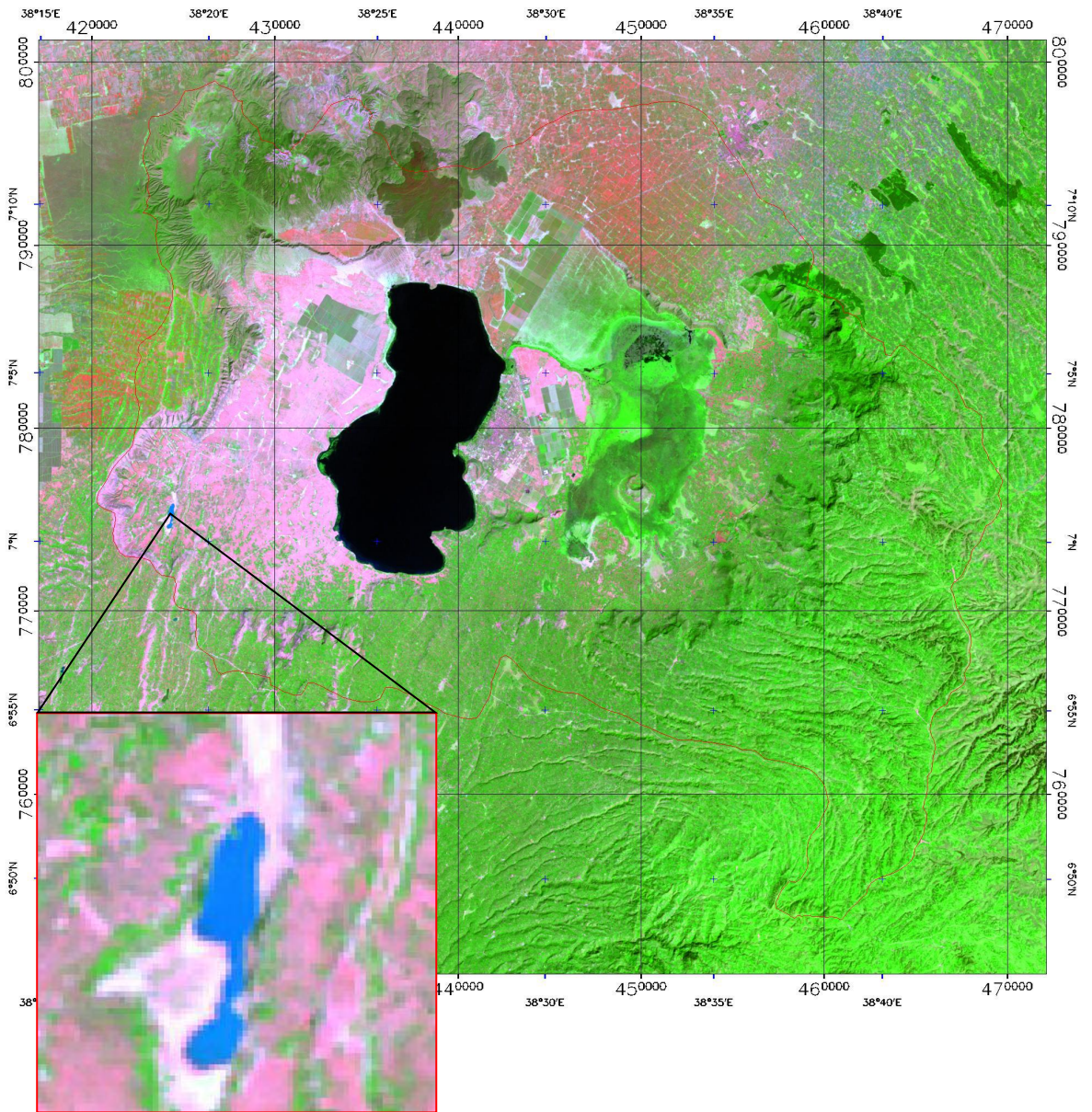


Figure 11: Derba Pond near Muleti in 1999 before it disappeared, FCC of TM 743.

3.5 Soil

Soil is one of the major environmental factors that control the erosion rate of an area. Soil of the study area in its catchment level is studied in different level of detail by IRAT (1974), UNDP and FAO (1984), WWDSE (2001).

According to FAO/UNDP (1984) the soil of lacustrine and fluvio-lacustrine plains of Lake Awassa characterized as silty loam to sandy loam texture on fluvio-lacustrine plains with 0-2% slope range, a clay loam to sandy loam on colluvial margins with 2-8% slope range and a loam to sandy loam texture marshy depressions. Soils developed on undulating sideslopes and piedmont zones where strongly influenced by colluvial processes but retaining distinct residual deposits are characterized as silty loam to sandy loam on undulating side slopes ranging 2-8 percent and clay loam to sandy loam on lower hills with slope range 8-16%.

Soil map of the catchment is prepared by the Water Works Design and Supervision Enterprise during the study of Lake Awassa water level, lake Awassa study and design project. The map shows the major soil types identified in the area according to the FAO soil classification based on their different relief intensity and slope: Andosols, Cambisols, Vertic luvisols, Vertic cambisols, Leptosols, Gleysols, Alisols, and Regosols. The blue print copy of the map was converted to digital form by digitizing using Cartalinx software (Figure 12).

Different soil has different tolerance for water and wind erosion depending on texture, structure, organic nature, and the amount and kinds of salts present (R.P Trpathi et.al 1998). The soil map is used as one input for evaluating soil erosion through USLE model.

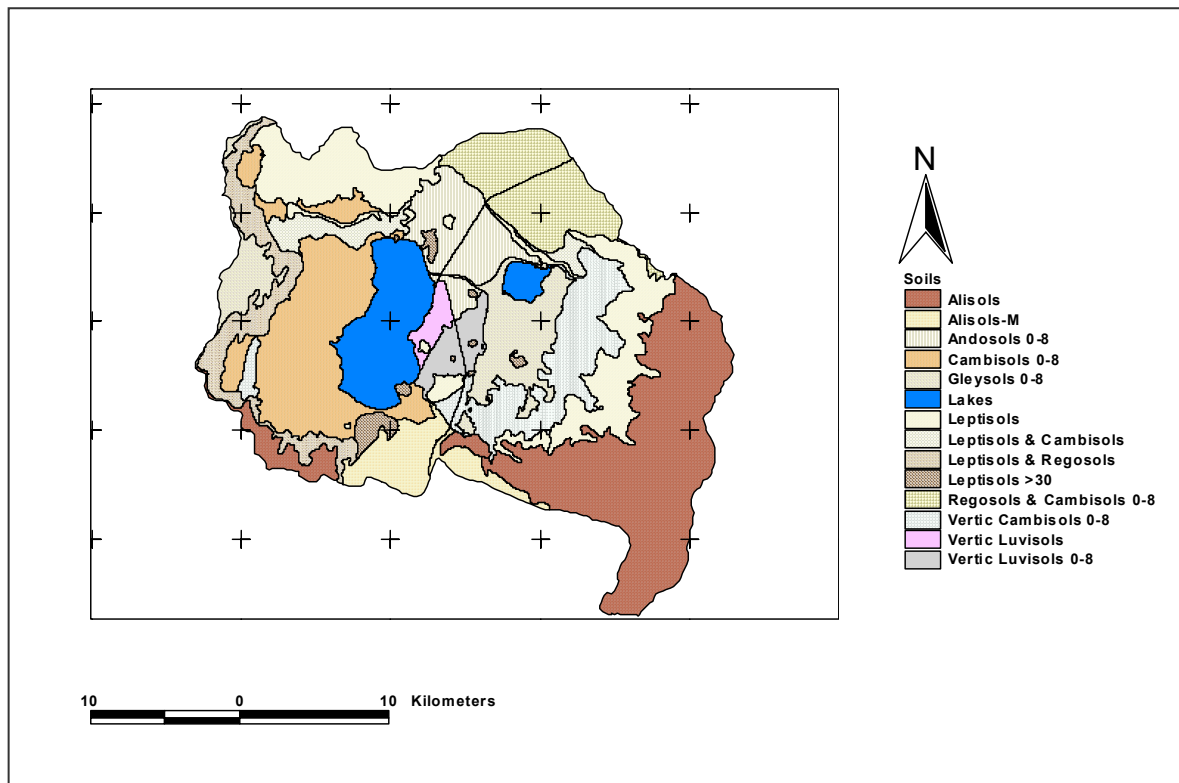


Figure 12: soil map of Lake Awassa catchment (adopted from WWDSE 2001)

3.6 Drainage

3.6.1 Rivers

Drainage density of the study area concentrates towards the east and south eastern side. This face of the catchment is wettest and highly vegetated as compared to any other part. As of Dessie Nedaw, 1997 (cited in Zemenu Geremew, 2000) the drainage density of the study area is 0.725 and this shows the basin is poorly drained.

As in Figure 13, drainage map of the area, illustrated some of the rivers of southeastern side such as R. Lango, R. Wesha, and R. Werka drain L. Shallo. However, most of the rivers from this side such as R. Shenkora, R. Gomesho, R. Wedesa, and R. Kerama run from the highly elevated area of the catchment and drain the swampy area with out reaching to the lakes.

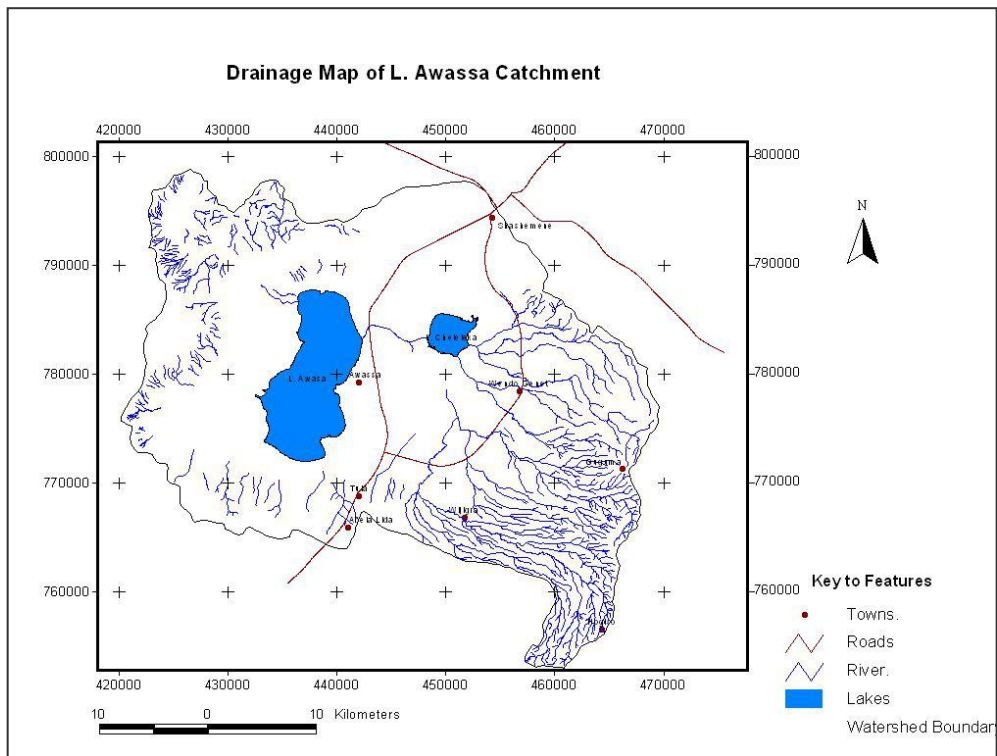


Figure 13: Drainage map of the study area

All these rivers and the swampy area are part of the Tikurwuha river catchment, which covers 625km² (52%) of the total L. Awassa catchment (Zenaw Tessema, 2003). Tikurwuha River, flows from L. Shallo to L. Awassa. Seasonal courses, western and southern area, around some part of the escarp of Awassa caldera are a means of runoff during rainy season directly towards L. Awassa and Shallo. During rainy season the runoff from these sides, including the northern side, is notable and rich in sediment. Plate 4 shows overland flow towards L. Awassa during rainy day. This is un-channeled runoff which is affluent in sediment, passing most of the agricultural fields and roads and draining to Lake Awassa flood plain.



Plate 4:

Overland flow near Muleti area

Most of the rivers of west and south western sides of the basin are not gauged. Tikurwuha River, a channel connecting L. Cheleleka and L. Awassa, is gauged at Tikurwuha and Dato villages. Other gauged rivers, near WendoGenet area, are Washa and Warka rivers near WendoGenet. The daily discharge of all the rivers collected from Ministry of Water Resource (MoR) and analyzed to see monthly average flow (Figure 14).

Following the rainfall trend (Figure 2), the runoff is higher in between August and December the runoff is maximum during this period and minimum runoff amount is recorded between February and May. All gauged rivers are perennial even if they have low discharge in dry period.

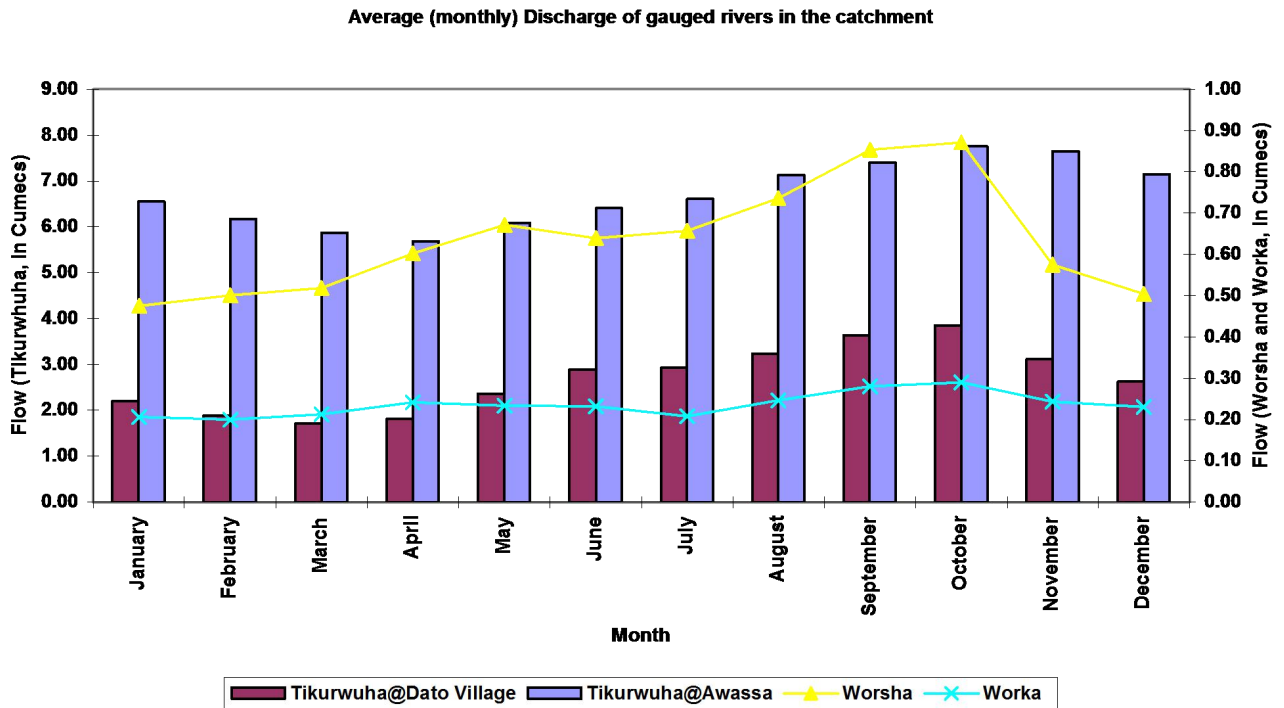
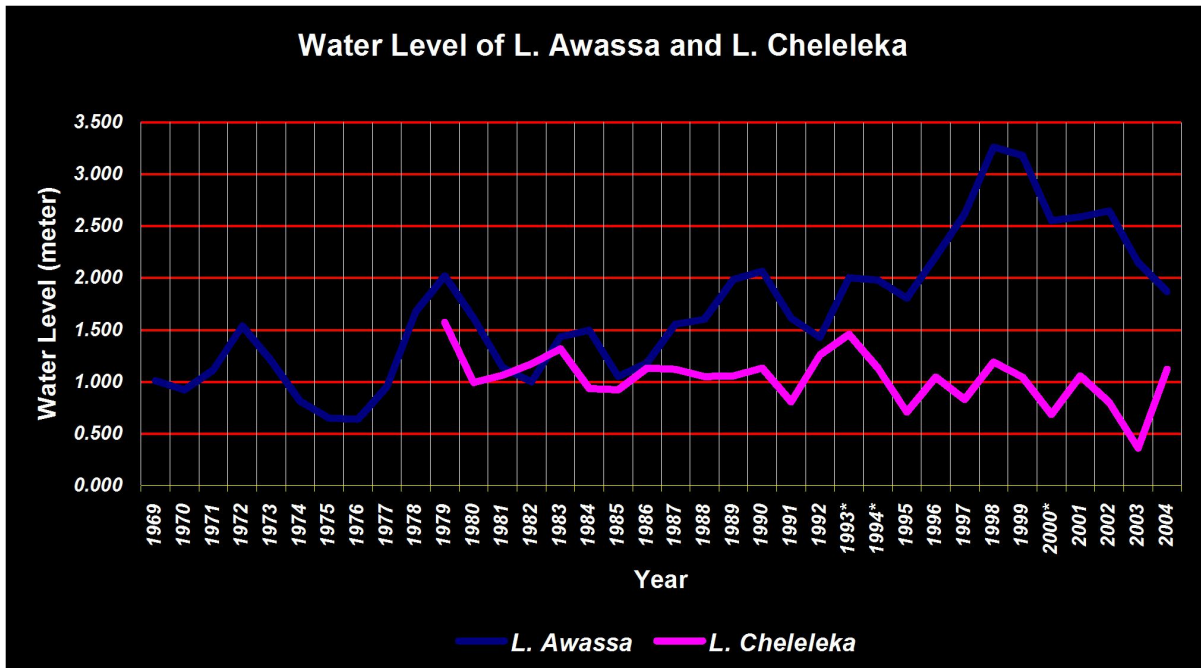


Figure 14: Monthly average discharge of gauged rivers in the catchment

3.6.2 Lakes

The two lakes, L. Awassa and the small L. Shallo, which currently has dried up to a swampy area, are situated in the central part of the depression. Water levels of the two Lakes are presented for the specified year (Figure 15). Awassa lake level had been rising since early sixties at increasing rate, in effect enormous areas around the lake shore are flooded; many buildings, properties and infrastructures are ruined and also people living around the lake are displaced. The lake level rise has two trends. The first type of fluctuation, observed also at Lake Cheleleka has nearly similar increment and decrement rate in a specified year interval but the second one which is observed between 1995 and 1998 and unique for L. Awassa is abnormal rate of increase of water level amplitude. According to Zenaw Tessema (2000), regardless of the seasonal fluctuations, the lake has been rising at an average rate of 76 mm per year between 1966 and 1999. Awassa lake level rise as compared to monthly average discharge of Tikurwuha river is illustrated in Figure 16.



* Full Data missing during the specified year

Figure 15: Water level of L. Awassa and L. Cheleleka in the

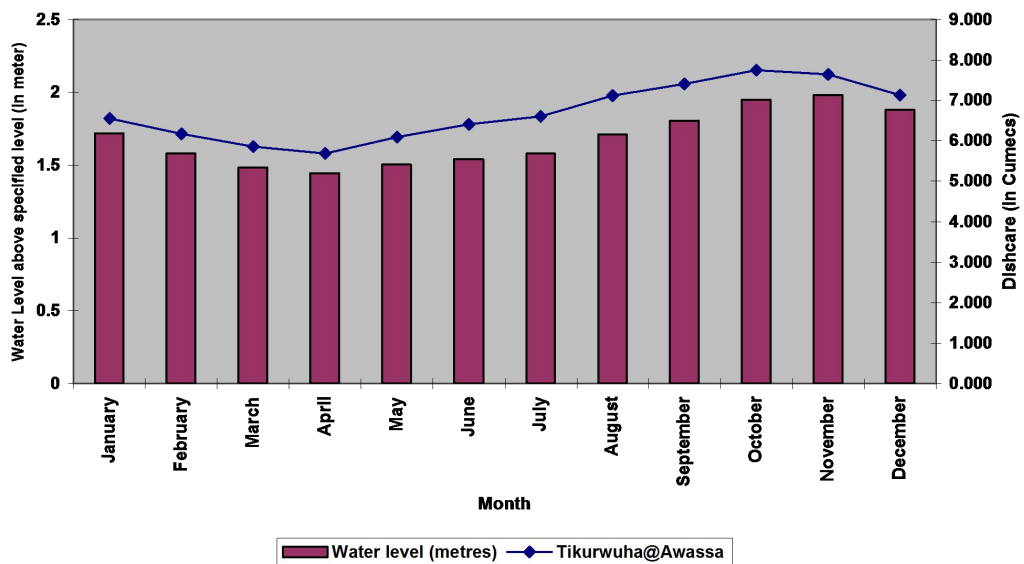


Figure 16: Monthly Awassa Lake Level as compared to monthly Discharge of Tikurwhuha near to Awassa Town.

According to Mohr 1970 (cited in Zenaw 2000), Lakes Awassa and Shallo, situated in Awassa caldera, were united as a single lake in the last Century. The surface area of Lake Cheleleka was about 12km² in 1972 but currently it has completely disappeared as a result

of siltation (Topic 5.2). The lake floor, which once was covered by water, is now filled by sediment transported from the eastern highland.

3.7 Landuse

Land use land cover map of 1965, 1998 digitized from blue print version of W.W.D.S.E (2001), and that of 2004 is adopted from Yemane 2004 using the softcopy picture (geo-referencing and screen digitization technique). Figure 17, 18, 19 show these maps respectively.

The northern mountainous part of the study area that consists of obsidian flow and characterized by dense bush land cover. The eastern escarpment and the plateaus are moderately vegetated, and the floor of the escarpment is covered with mixed type vegetation. Scarcity of vegetation is observed in the poorly drained western part of the catchment and the problem increase in the high lands of this side.

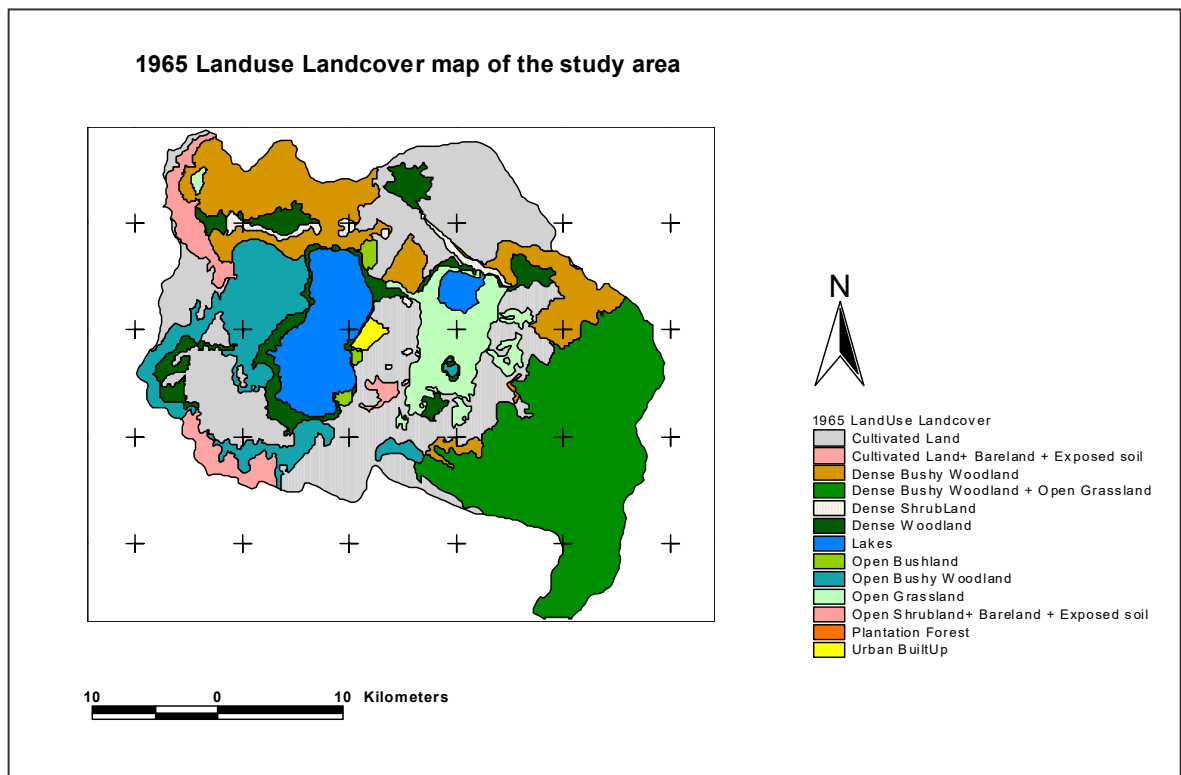


Figure 17: 1965 land use map of Lake Awassa catchment (adopted from WWDSE, 2001)

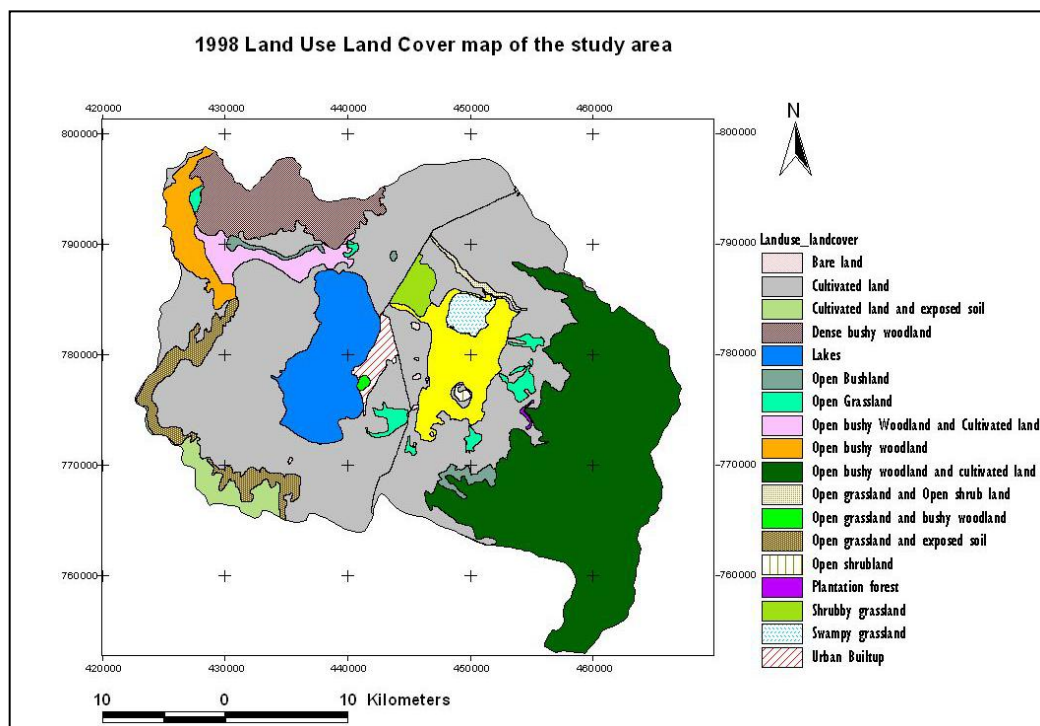
According to Zenaw 2000, the land use and soil study of the area have revealed that considerable land use changes have been identified in the past 35 years. Population growth in and around the catchment has brought depletion of natural vegetation cover and

facilitate change of woodlands to farmland. The large part of the catchment is under cultivation and the soils are highly susceptible to erosion.

Land use/ land cover map of 1965, 1998 digitized from blue print version of WWDSE (2001), and that of 2004 is adopted from Yemane (2004) using the softcopy picture (geo-referencing and screen digitization technique). Figures 17, 18, 19 show these maps respectively.

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Figure 18: 1998 land use map of Lake Awassa catchment (adopted from W.W.D.S.E, 2001)

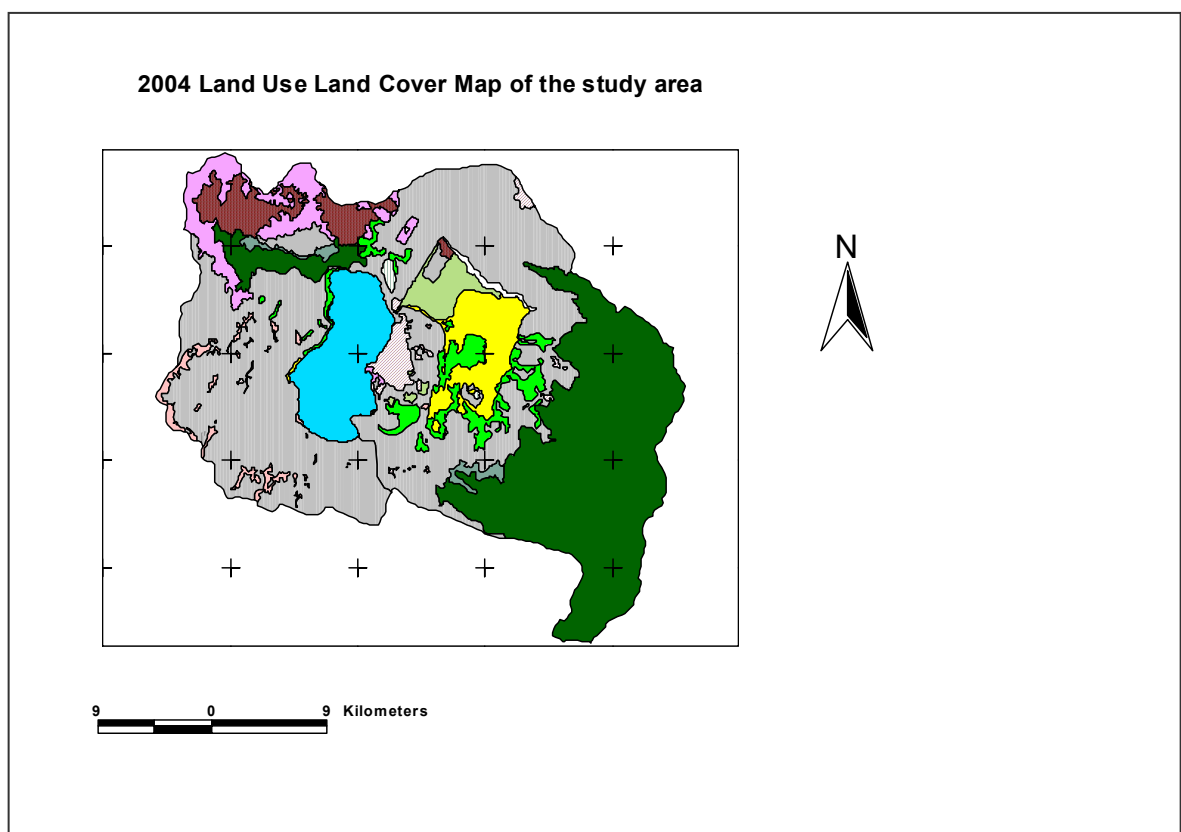


Figure 19: 2004 land use map of Lake Awassa catchment (adopted from Yemane, 2004)

3.8 Socio-economic

Most of the study area is situated in the SNNPR, while the northern part of the catchment, near Shashemene, is enclosed in the Oromiya Region state. Part of the study area which is in the SNNPR region, exists in Sidama Zone wherein Awassa Zuria, parts of Shebedino and Borchha Werdas are included.

According to SNNPR-CSA data and explanation of official, the population number in Awassa and the nearby towns increased in a remarkable rate in the last decade. Being the central city for the Southern Nation Nationalities and People regional government, the existence of many governmental and non-governmental bureau in the city, enhancement of investment (especially in educational sector) are some factors for population increment in the city and its vicinity.

4 GIS Data Analysis

The geographical (or spatial) data represent phenomena from the real world in terms of their position with respect to a known coordinate system, their attributes that are unrelated to position, and their spatial interrelation with each other which describes how they are linked together (known as topology and describes space and spatial properties) (P. A. Burrough and A. McDonnel, 1998). According to Aronoff (1989), Geographic Information Systems (GIS) are designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis. Bernhardsen (1999) describes GIS as a system that embraces:

- techniques to input geographical information, converting the information to digital form
- techniques for storing such information in compact format on storage devices
- methods for automated analysis of geographical data, to search for patterns, combine different kinds of data, make measurements, find optimum sites or routes, and a host of other tasks

- methods to predict the outcome of various scenarios
- techniques for display of data in the form of maps, images, and other kinds of displays
- capabilities of output of results in the form of numbers and tables

A GIS data could be either in Vector or Raster model. The vector data model uses points and their x, y-coordinates to construct spatial features. Vector based features are treated as discrete geometric objects over the space. The process of developing the vector data model consists of several steps. First, spatial features are represented as simple geometric objects of points, lines and areas. Second, for some GIS applications, the spatial relationships between features must be expressed explicitly. Third, a logical structure of data files must be in place so that the computer can efficiently process data for spatial features and their spatial relationships. The raster data model uses a regular grid to cover the characteristics of a spatial phenomenon at the cell location. The variation of the spatial phenomenon is reflected by the changes in the cell value, for example, Satellite image with different Digital Number values of pixels. (Kang-Tsung Change, 2001)

4.1 Data acquisition

Building an accurate GIS database of spatial entities is a demanding task. Three basic ways of creating a digital geographic database are: acquire data in digital form from a data supplier, digitize existing analogue data, and carry out one's own digital survey. In all cases, the data must be geometrically registered to a generally accepted and properly defined coordinate system. Whether in analogue or digital form, the data need to be converted to the internal database structure of the GIS being used. With existing digital data sets, this often involves using a standard exchange format between the supplier and client GIS systems. Where the original data are in analogue form the coordinates of the entities are recorded digitally using devices such as digitizers and scanners. Once data have been captured, they must be checked for dislocation and value errors. Attribute values must also be linked to the entity database, which involves building links to relational tables or spreadsheets (Burroughs and McDonnell, 1998).

Creating a GIS database is a complex operation that may involve data capture, verification, and structuring processes. Raw geographical data of important parameters used in a Model was available in many different analogue or digital forms, such as maps, tables.

In the study, data generation from primary and existing data is worked out using GIS and other Database Management software. CartaLinx digitizing software is used to convert analogue data (maps in paper form) to digital format and for editing a topology. Arcview is used widely to edit, analyze spatial and attribute information. Land use / land cover maps of the area, soil map of the area, contour map, drainage map, towns, geologic map of the area are generated either tablet or screen digitization of hardcopy or scanned map sources. The following topics confer how some of useful primary and derivative GIS data layers were generated.

4.2 Spatial Data Analysis

The power of a GIS lies in its ability to analyze spatial and attribute data together. Spatial data analysis includes all GIS analysis techniques applied on the georeferenced geographical data. Some of these are buffering, interpolation, overlay, etc. The most applicable spatial data analysis in the research is interpolation and applied overlay analysis.

Interpolation: is the procedure of predicting the value of attributes at un-sampled sites from measurements made at point locations within the same area or region (Burrough et al., 1998). It is necessary when the data we have do not cover the dominant of interest completely. Interpolation in the study is used to convert data from point observation to continuous fields so that spatial patterns sampled by these measurements can be compared with the spatial patterns of other spatial entities.

Map overlay: is GIS spatial operation that includes arithmetic (addition, subtraction, multiplication, or division) and logical (based on a specified set of criteria) operations that performed on GIS data layers. The data layers can be either in raster or vector data model format. Depending on the type of data format, the type of operation may vary. Overlay operations are usually performed more efficiently in raster-based systems.

The following topics describe about how some of the useful primary and derivative GIS data layers were generated.

4.3 Topographic Data

Topography plays an important role in the distribution and flux of water and energy within natural landscapes. The digital representation of the topography is called a digital elevation model (DEM). The most common DEM data structure is the raster or grid structure. This

normally consists of a matrix of square grid cells with the mean cell elevation stored in a two-dimension array. Location of a cell in geographic space is implicit from the row and column location of the cell within the array, provided that the boundary coordinates (georeferences) of the array are known. Grid DEMs are widely used because of their simplicity, processing ease, and computational efficiency. DEMs are used in water resources projects to identify drainage features such as ridges, valley bottoms, channel networks, and surface drainage patterns, and to quantify sub-catchment and channel properties such as size, length, and slope. The accuracy of this topographic information is a function of both the quality and resolution of the DEM, and of the DEM processing algorithms used to extract this information, (Garberecht and Martz cited in Maidment and Djokic, 2000).

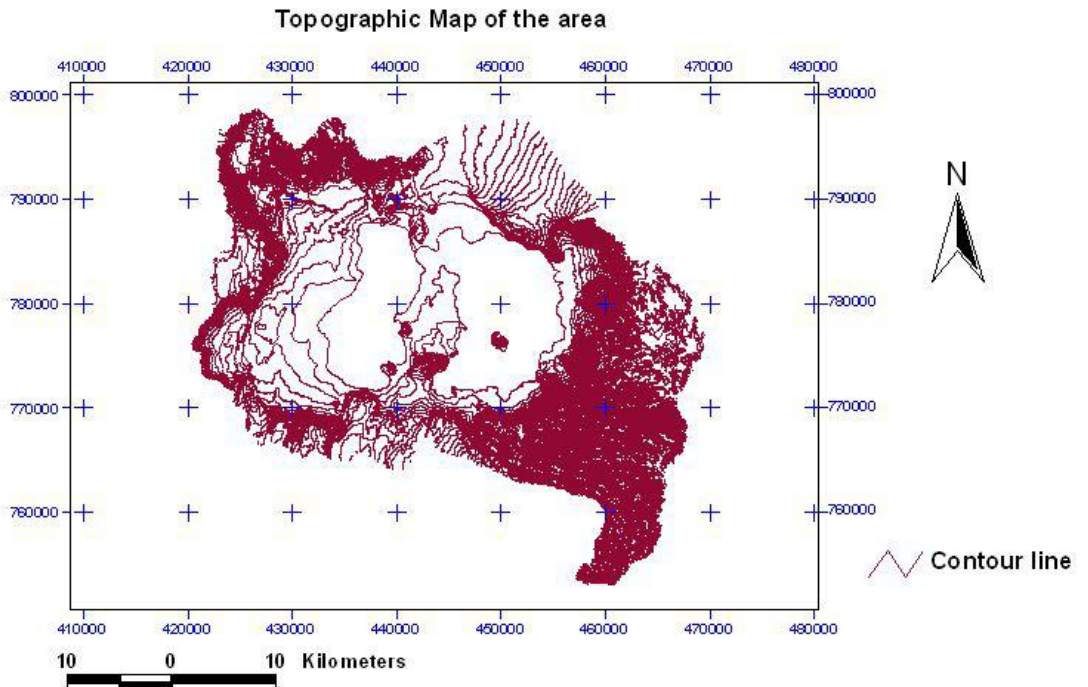
A topographic map of the study area includes four sheets with a scale of 1:50,000. These adjacent sheets are selected to cover all the watershed area of Lake Awassa. The basin coverage plotted on the map on the sheet and later digitized to generate a polygon shape file that is used as Area of interest (AOI) in different applications. Name of the sheets used in this study are listed below with their Sheet code and coverage coordinates.

<u>Sheet Name</u>	<u>Sheet Code</u>	<u>Coverage (Upper/Lower) Corners</u>
Awassa	0738 C4	38°15'E 7°15'N/38°30'E 7°00'N
Shashemene	0738 C4	38°30'E 7°15'N/38°45'E 7°00'N
Leku	0638 A2	38°15'E 7°00'N/38°30'E 6°45'N
Wijjgra	0638 A2	38°30'E 7°00'N/38°45'E 6°45'N

4.4 Generation of Digital Elevation Model (DEM)

A known Digitizing Software CartaLinx was used as digitizer software. From each topographic sheet, entities such as contour, road, towns, and other objects were digitized after the maps were geo-referenced to a UTM coordinate system, Zone 37. The contour lines, which represent lines of points of equal altitude, are the main input for producing the landscape information of the study area. After generating the arc file using CartaLinx, the exported tool used to convert the contour file from CartaLinx to Arcview shape file format (Figure 20).

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e, was utilized to generate DEM from contour shape file via its basic extension tools such as 3D analyst, Spatial Analyst, XTools, and Grid Analyst. Generation of DEM is summarized as follow:

A file that contains altitude contour information is opened in Arcview view environment as a theme. The shape file converted to grid theme (raster data) using elevation data as value for each pixel. The size of the pixel is defined as 50 m x 50 m.

Figure 20: Digitized Line contour

Figure 21: Grid Line contour

A Grid Analyst tool used to convert the grid contour theme to xyz text value which includes three columns, i.e. the coordinates (x –UTM easting, y-UTM northing) and value (elevation data). Generated text file opened in Microsoft Access as a database table, edited for field names and export as dbase file format (*.dbf).

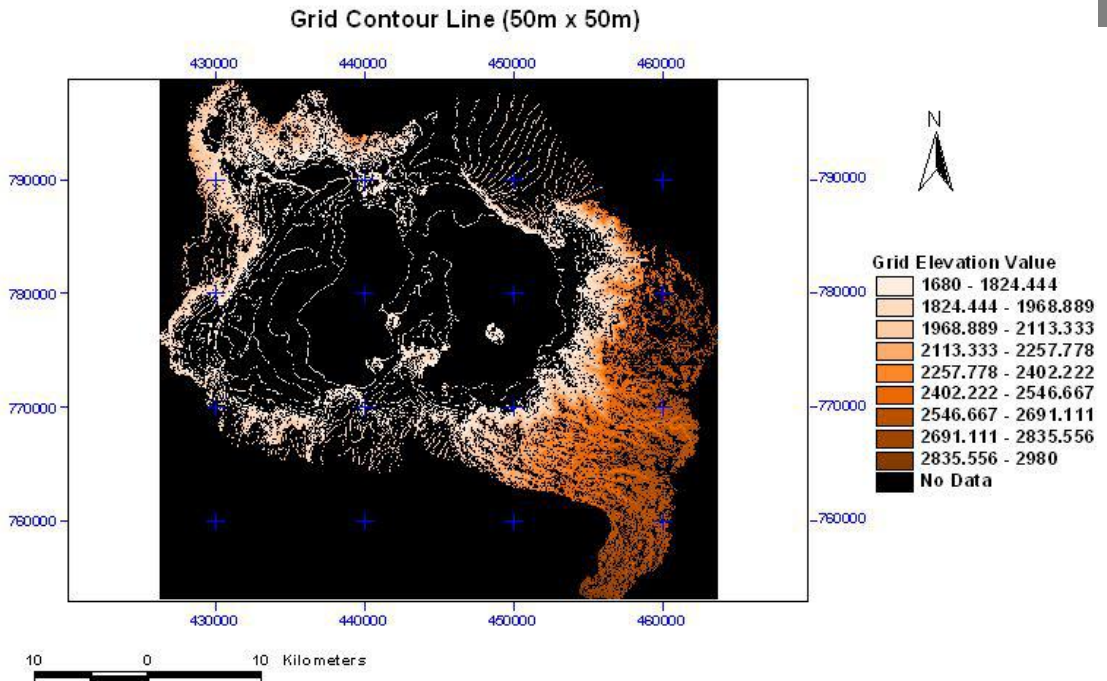
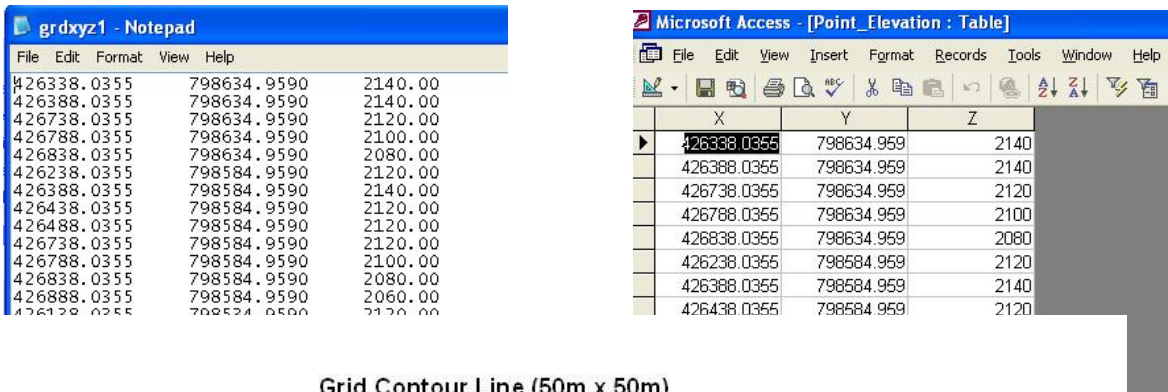
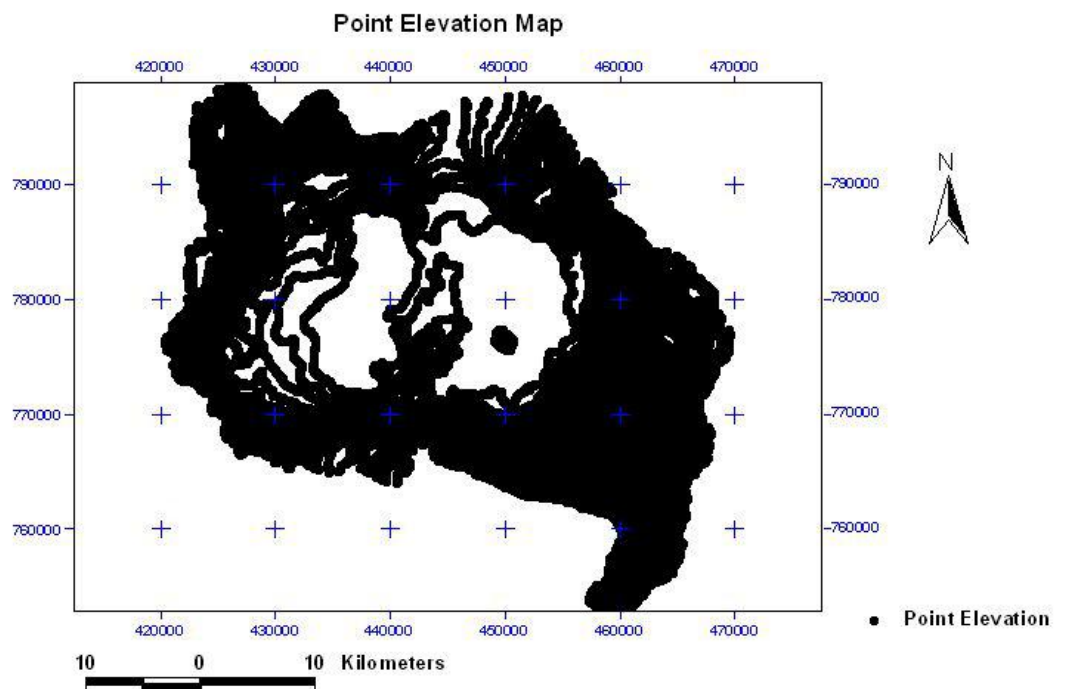


Figure 22: Text elevation data generated from grid line contour (left) and Access elevation database used for generating dbase table

The dbase file opened in Arcview using its table object. The table opens as shape file using x and y as its geographic location information. A new Point shape file is created by converting the event theme to shape file.



tion shape file generated from elevation dbase table opened in Arcview table object

The Arcview Spatial Analyst tool is used for interpolating a point elevation data to generate surface grid elevation theme that hold elevation data with 50m x 50m pixel size.

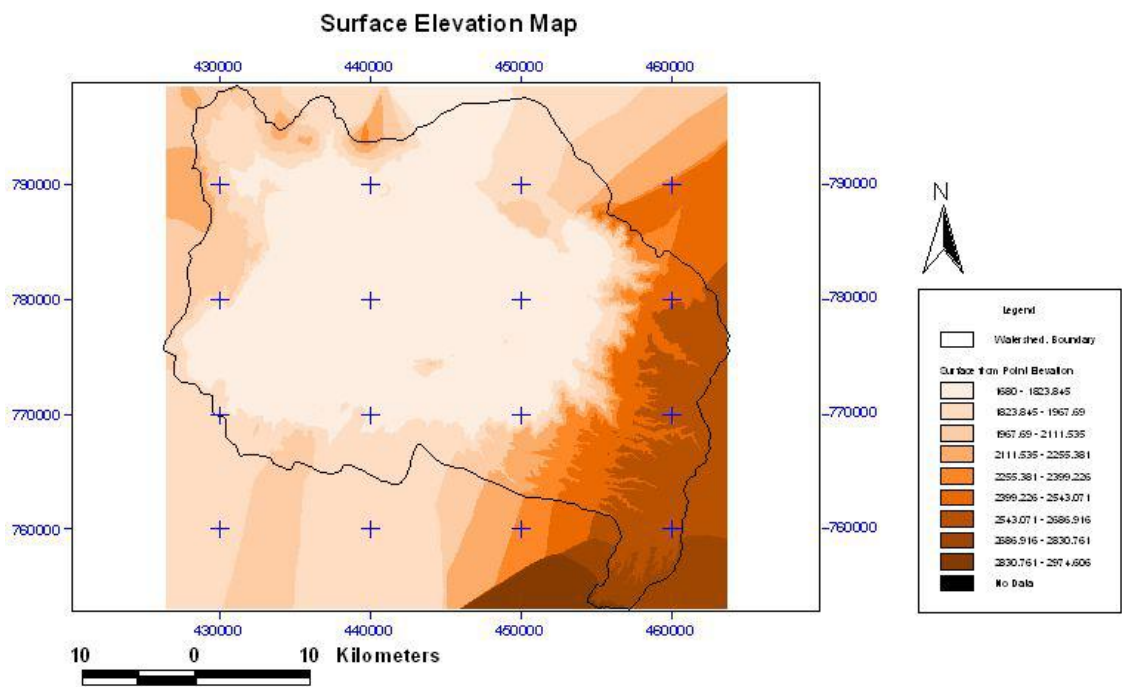


Figure 24: DEM generated from interpolation of Point elevation theme

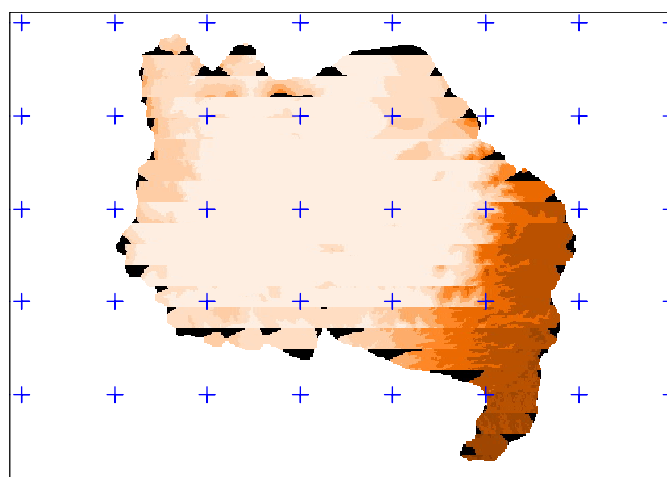


Figure 25: DEM clipped to Study area extent

Finally, Grid Analyst tool used to extract pixels only included in the study area (L. Awassa catchment). During this process, all pixels out of the study area are assigned to have values of no data.

DEM of the study area is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in the landscape. In principle it describes the elevation of any point in the study area in digital format and hence it contains information of the so-called ‘skeleton’ lines which are lines of slope reversals (drainage, crests) and breaks of slope.

4.4.1 DEM derivative data

DEM is currently become an important input for generating automated extraction of terrain features such as slopes, aspects, hill shading, etc. there are also many applications of a DEM and its derivatives in hydrology.

4.4.2 Slope and aspect

After obtaining an interpolated raster DEM, other terrain properties can be extracted using filtering techniques (Meijerink, *et al.*, 1994). First, gradients in x and y directions are derived, transforming the scalar DEM into a vector field. Each pixel becomes a vector with two components, the partial derivatives in x and y directions. Since x and y are discrete (the raster row and columns), differences are used to approximate the partial derivatives and this can be achieved by convolution (linear filtering) with kernels:

$$\begin{matrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{matrix}$$

(Difference in x direction)

$$\begin{matrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{matrix}$$

(Difference in y direction)

To get properly scaled gradient values, the pixel size must be taken into account. The convolution result must be divided by 2 x pixel size. The result of such convolution on a 3 x 3 DEM window will be placed at an output position that corresponds to the center of input window. Therefore, the output systematically shifts half a pixel, horizontally and vertically.

After creating gradients, say GX and GY, the absolute gradient can be used as a slope map:

$$\text{Slope} = \sqrt{(GX \times GX + GY \times GY)} \dots\dots\dots \text{Eqn 2}$$

An aspect map (angle of slope direction, or azimuth) can be obtained by:

$$\text{Slope Azimuth} = \arctan (GY/GX) \dots\dots\dots \text{Eqn 3}$$

3D views of a given area (Figure 6) which are a pseudo relief image and used for visual illustration are also generated from the DEM of the study area using MICRODEM software by taking different sun azimuth and sun elevation.

In Soil erosion analysis, topography is one of main characteristic that control rate of soil loss on a specified plot of land. The DEM is a basic source for generating such topographic factors like slope, slope length, etc. While applying USLE model on the Lake Awassa catchment, the

4.4.3 Automated extraction of catchment hydrologic properties from DEM data

The application of DEM is widening to watershed related fields. In this study, some of catchment hydrologic properties, vital for understanding the surface water movement in the catchment and delineating automated depositional areas where upland eroded soils accumulated are generated using Hydrologic-modeling extension of Arcview.

During this analysis new DEM high resolution pixel size (20 x 20) is generated from point elevation data of the area (Figure 23) by applying the same procedure in the last topics. All information such as cell size (20 x 20m), number of rows and columns (2292r, 2474c), marginal UTM coordinates, etc adjusted in DEM grid theme property.

Water bodies within DEM of the catchment, i.e. Lake Awassa and L. Cheleleka first assigned to have no data using a clip grid command of grid tool extension of Arcview GIS and the resulting Dem named as **Clip_DEM** (Figure 26).

Before further calculations done, potential data errors in the DEM should be corrected. In some cases, the DEM contains false sinks, i.e., one or more cells, surrounded by cells of higher elevation. These false sinks, effectively create a discontinuity in the modeled flow and corrected using the Hydrology function command ‘Fill Sink.’ The ‘Fill sink’ command alters the elevation of each sink so that it is equal to the elevation of its lowest neighbor.

In ArcView with the Hydrologic Modeling extension activated, the false sinks fill in using the 'Hydro/Fill' command with the **Clip_DEM** grid active. The resultant grid was named as **Fill_DEM**.

Using 'Hydro/Flow Direction,' a flow direction grid was created and, with the flow direction grid active, automated stream network generated from Flow Direction grid using Hydro/Stream Network as Line shape command. Unlike highly elevated and sloppy areas where slope gradient change is higher, the synthetic stream lines on flat planes have no significant information about the stream itself.

To delineate depositional areas (flat lands), automated sub-watershed generated by applying Hydro/watershed command. Each sub watershed indicates flow towards the synthetic stream lines with in the specified sub-watershed. Flat areas, without defined sub watershed clipped and identified as depositional area.

The result shows that the drainage is radial type and all the flow is towards Lake Awassa. However, water from eastern and southeastern of the catchment part first accumulates in Lake Cheleleka and on swampy area below this lake and finally travels to Lake Awassa.

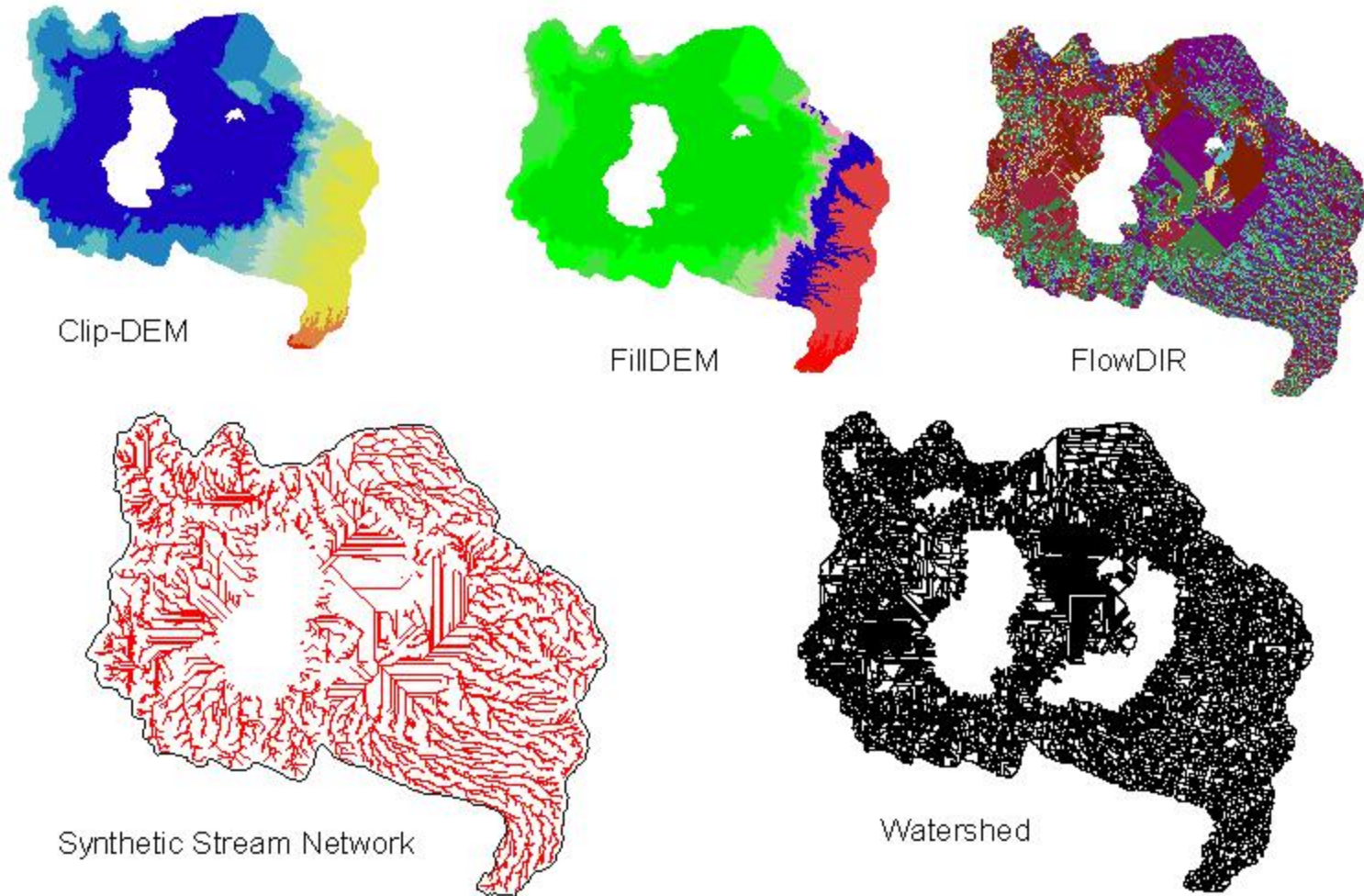


Figure 26: automated catchment Hydrological properties generated from DEM

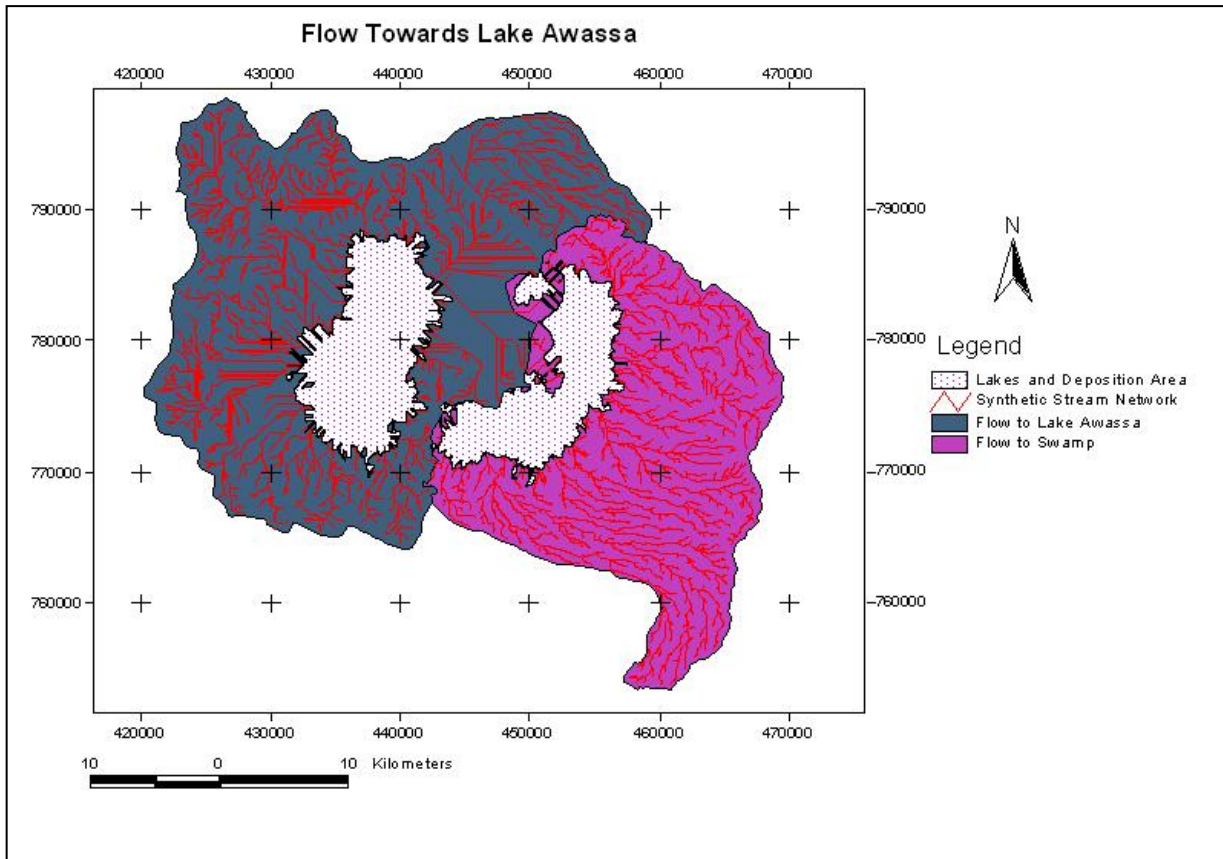


Figure 27: Surface Water Flow Generated from DEM

The result map (Figure 27) indicates that flat areas around Lake Awassa and Lake Cheleleka area where deposition is took place. Further analysis of the stream line and subwatershed coverage used to digitize area flow towards the lake and the Cheleleka swamp.

4.5 Climatic Data

Climatic data are point data in nature. Raw data are tabular information collected from meteorological stations, with known geographic coordinate system. In this study Rainfall records of stations in and near the catchment which are useful to generate Rainfall Erosivity, has been stored in spreadsheet file.

The geographical location in UTM coordinate (Easting and Northing) of each station is stored with the attribute information as two fields. Rainfall erosivity, as new field within the database, calculated from adopted formula The table opened in GIS media and station data saved as

point shape file. The Rainfall Erosivity map of the area, which is surface information, is generated by interpolating the point data.

4.6 Soil maps, Geological maps, Land use Land cover maps

Data collection and adapting it to different application is a tedious and costly stage of GIS system. Data could be in different appearance including tabular, text, existing maps, etc. After digitizing all hardcopy format input parameters into digital computer files analysis on attribute and spatial level is done to get a final input for the model. For instance, soil erodibility map of USLE model generated from soil map as follow.

Digitized soil map activated and attribute of the shape file opened

In attribute table after turn on the table for editing by *Table/Start Editing* (Figure 28, Left) command, a new field having a number format with float (4 digit after decimal) (Figure 28, Right) was added to existing table using *Edit/Add Field* command and Field definition dialog box.

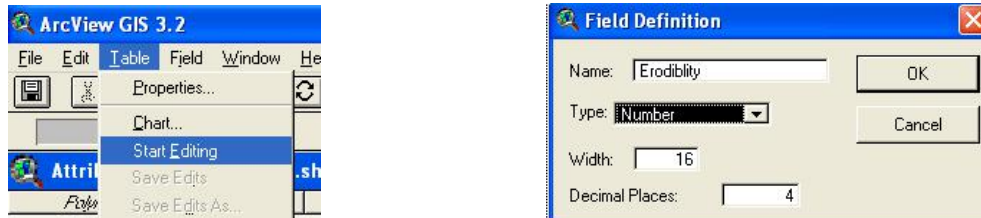


Figure 28: A dialogue box showing how to start table editing (left) and adding new field (Right) in Arcview GIS

The value of erodibility of each soil type is added in a new field and at the final stage of table editing the table is saved using *Table/Stop* editing Command (Figure 29)

Textuserid	Hectares	Erodibility
Cambisols 0-8	3190.004	0.38
Leptisols + stone h	8354.591	0.32
Cambisols 0-8	639.777	0.38
Cambisols 0-8	1001.058	0.38

Figure 29: Editing the new field for each soil type (records)

Finally, to have erodibility map of the study area the soil shape file should be converted to grid format. Hence, the shape file activated and *Theme/Convert to Grid* command launched. The grid size is assigned to 50m X 50m and erodibility field was used as value of each pixel (Figure 37).

The Landuse/Landcover factor map (Figure 41) is generated using the same Procedure listed above.

Generally, in the research most of GIS data input system and spatial analysis tools and data presentation system are used to handle information, spatial distributed parameters.

5 Remote Sensing Data Analysis

According to Lillisand and Kiefer (2000), remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. Currently the application of remote sensing is getting wider in many scientific fields. Area coverage, capability of sensing information within higher spectral resolution, ability of covering remote area, advancement of processing and storage of computers, development of newly easy to use software for processing digital data for information extraction has high input for remote sensing demand.

Remote sensing utilizes energy, electromagnetic wave, as a means of acquiring information from the object under investigation (earth features soil, water, vegetation, cloud, ice, etc). Depending on the source of light energy used for detection, either natural solar energy (sun) or man made EMR; the type of the type of remote sensing system is categorized as *Passive* or *Active* remote sensing. In order to interpret remotely data it is not necessary to know a great deal about the physics of generation and propagation of electromagnetic radiation (EMR). But it is crucial to know the response of objects when they interaction with a specified wavelength of EMR. Remotely sensing devices (Satellites, Aircrafts, Hand cameras, etc), from different platforms (Space, Air, Earth) detect this energy response (backscattered light energy) and stored in digital form with a specified radiometric resolution having a grey level (black to white). For a single object we can have different response depending of the wavelength that the detector working on and the plot that show the wavelength with reflected EMR from this object is called a spectral reflectance curve for that particular feature. A spectral reflectance curve of common earth features is shown in figure (30). All features show their own signature in different wavelength and this signature used to identify one from the other.

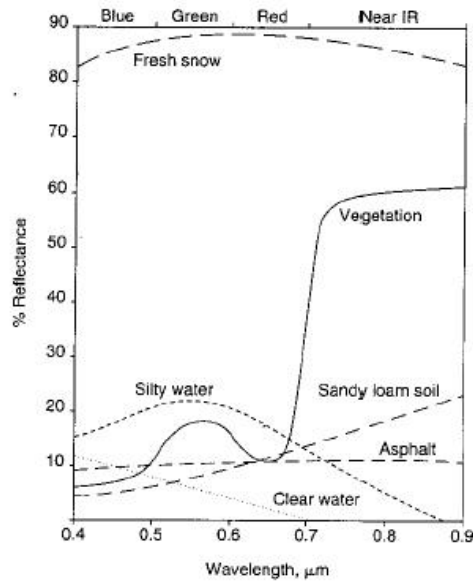


Figure 30: Spectral response curve of common earth features in visible and near infrared regions

In the study, raw data, satellite images of various years, are georeferenced to a single coordinate system (UTM 37, datum Adindan) using ENVI 3.5 image processing software. First Landsat TM 2000 image is georeferenced with Topography sheet taken from Ethiopian Map Authority as base map. In this process 18 Ground Control Points (GCP), features which are both visible on topographic sheets and raw images such as river and road junctions, are used. Images from other years were georeferenced based on the corrected TM 2000 image by applying Image to Image rectification procedure of ENVI 3.5.

Image enhancement is the technique applied on raw digital data to increase the interpretability of features in a given area. The type of image enhancement selected depending on the interest of the analyst for the specified purpose. Image enhancement can be done either on a single or multiple images.

5.1 Vegetation Cover Assessment

Vegetation appearance in a given area depends on the agro-climatical conditions of that specified area. Climate (rainfall, temperature) and soil (fertile soil with good moisture and nutrients) determine the existence of natural vegetation in the area. Appearance of vegetation

on an area can be investigated using remote sensing images by applying image analysis techniques which are useful to magnify vegetation appearance based on its response in different bands.

In the visible wavelengths, the pigmentation of the leaves is the dominant factor. Chlorophyll is especially important and it has very low reflectance in the blue and red regions of the visible spectrum. When the plant is under stress and chlorophyll production is decreased, much higher reflectance can be detected by sensors. The internal structure of the leaves controls the level of reflectance of near IR, where about half of the incident energy is reflected, nearly half is transmitted, and very little is absorbed by the leaf. The total moisture content of the vegetation controls the mid IR reflectance, with much of the incident energy being absorbed by the water in the leaf, the remainder being reflected. Some of image processing techniques applied to visualize the appearance of vegetation in the study area are discussed below.

5.1.1 Normalized Difference Vegetation Index (NDVI)

Image division or spectral band ratioing is one of the most common mathematical operations applied to multi-spectral image data. Ratio images are calculated as the division of DN values in one spectral band(s) by the corresponding pixel value in another band(s).

Various forms of ratio combinations in the wavelength range 0.7-1.1 μm (near IR) to those in the 0.6-0.7 μm range (red) have been developed for vegetation monitoring. Simple vegetation index (VI) is sensitive indicators of the presence and condition of green vegetation ($\text{VI} = \text{NearIR} - \text{Red}$)

The most commonly used index is the Normalized Difference Vegetation Index (NDVI). It is one of band ratioing type that enhances or discriminate vegetation from other features of a given area. Images of near infrared and red are used in this analysis. The abrupt change of reflectance of reflectance signature of vegetation cover from red to infrared spectrum, enable us to use image of this portion to discriminate vegetation from other surface cover types which may have relatively identical characteristic in other range.

The NDVI is calculated as:

$$\text{NDVI} = (\text{NR} - \text{R}) / (\text{NR} + \text{R})$$

Where **NR**- image of near infrared

R - image of Red

In general, vegetation yields high positive NDVI values. Clouds, water, and snow yield negative values due to larger red reflectance than near IR. The NDVI values for rock and bare soil are near Zero due to their similar reflectance in both bands. Therefore, in a NDVI image (figure 31) the lighter tones are associated with dense coverage of health vegetation.

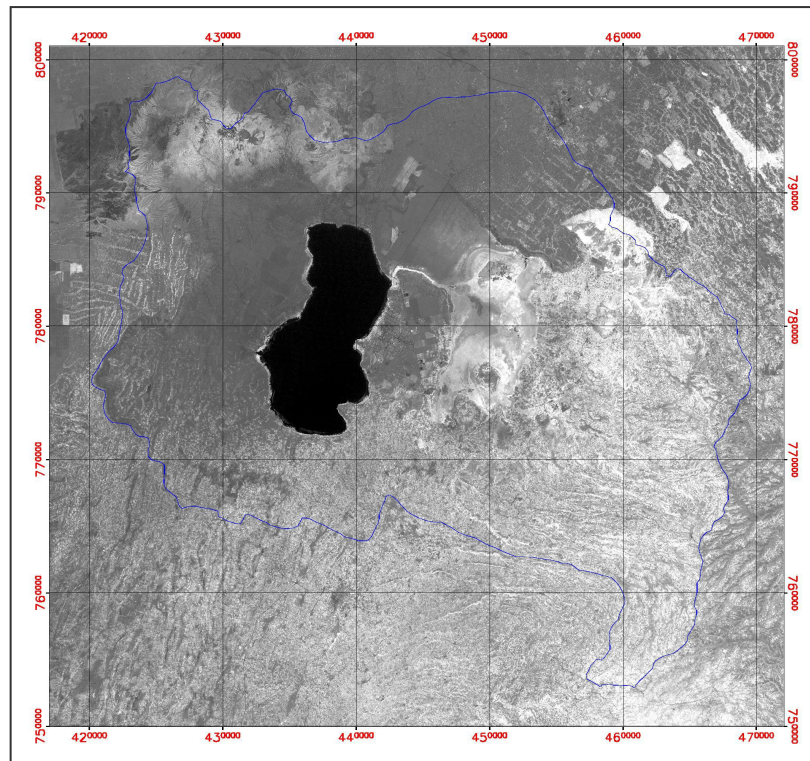


Figure 31: NDVI of LandSat 2000

The NDVI image designates that the eastern (Wendogenet area), swampy area, north western (highlands of Corbetti caldera) and southeastern part of the catchment is covered by vegetation with different degree of light brightness.

5.1.2 Tasseled Cap Transformation on Landsat TM

Tasseled Cap transformation is based on Gram-Schmidt sequential orthogonalization techniques that produced an orthogonal transformation of original six non-thermal bands of Landsat TM data. Four separate images namely Brightness, Greenness, Wetness, and Haze can be created based on the application of Tasseled Cap transformation. The formula used for producing Greenness image is:

$$\text{Greenness} = -0.24717\text{TM1} - 0.16263\text{TM2} - 0.40639\text{TM3} + 0.85468\text{TM4} + 0.05493\text{TM5} - 0.11749\text{TM7}$$

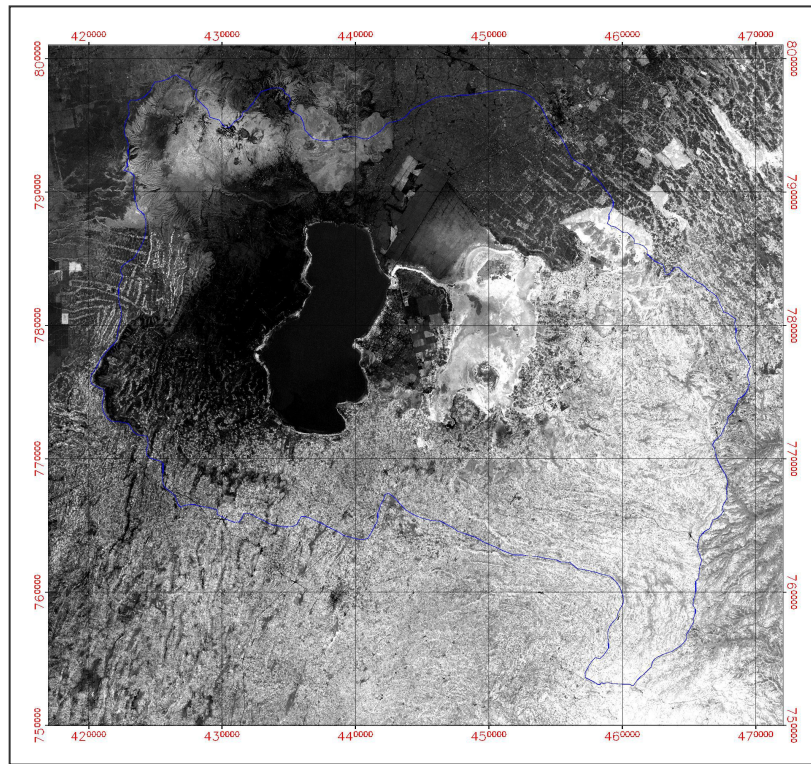


Figure 32: Tasseled Cap transformation (Greenness) of Landsat 2000 calculated in Envi Band Math

In similar fashion as in NDVI image, Greenness image (Figure 32) confirms the same sides of the catchment show the appearance of vegetation.

Color composite is assigning different bands of Landsat images or their composite (processed images) to Red, Green, and Blue color. This often used to discriminate a specific object from other land cover features.

5.1.3 False Color Composition (FCC)

To identify the appearance of vegetation in lake Awassa catchment False color composition of band ratio of band 3 and band 4 of TM 2000 images, Greenness image calculated from TM 2000 images, and band 3 are used as RGB. Band 3/4 shows low brightness of vegetation, Greenness indicate vegetation appearance as light color and in band 3 the brightness value of vegetation is low due to absorption in red wave length. Here only in green color we have high input contribution comparing to red and blue. As a result, in the composite image vegetations appear as bright green (Figure 33).

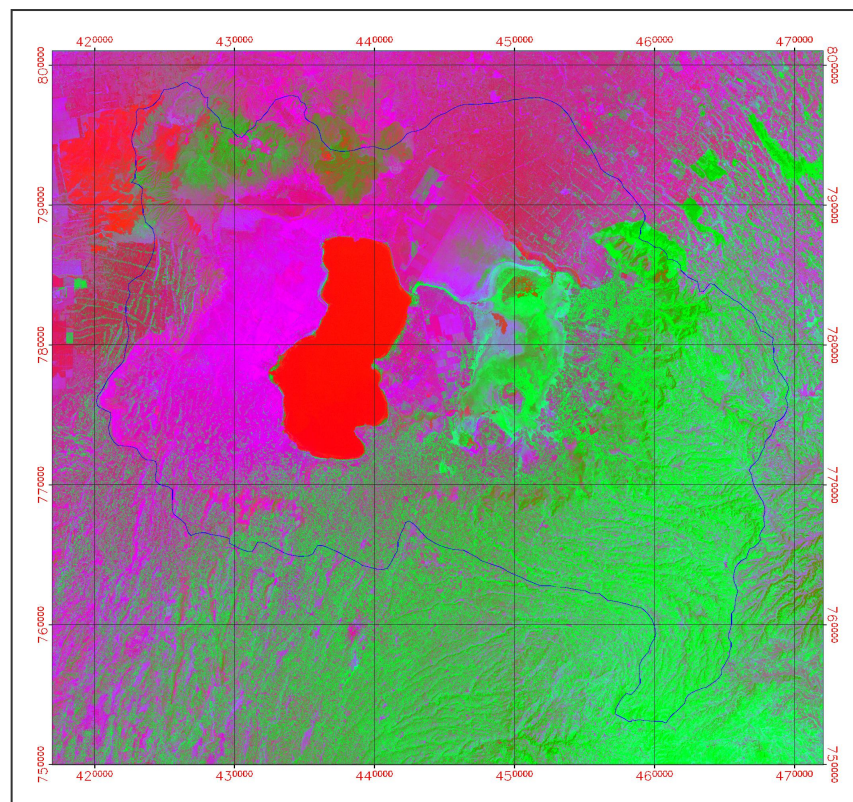


Figure 33: FCC of Band Ratio $\frac{3}{4}$, Greenness, and Band 3

5.2 Water Surface change of Lake Cheleleka

False Color Composition of different years Landsat 1973, Spot 1993, and Landsat 2000 to see major changes took place due to degradation related to upland erosion. Lake surface declination of Lake Cheleleka is one of the major change observed in the image. Lake Cheleleka shows a decreasing in size and the lake changes to swamp with remarkable grass cover. Area of the lake surface calculated using digitizing the lake surface on images of all the year.

The lake surface area, analyzed from Landsat 1973 is 1167.4 hectare, spot 1993, it decline to 487.934 and that of Landsat 2000 is appears to be only 267.8 hectares. This change has brought by deposition of sediments transported from uplands as a results of Water erosion. Since in the color composition (RGB) Infrared channel (vegetation shows high reflectance) is used as green, the green surface indicates vegetation cover (swampy Grass). The Lake bounded by Weransa ridge to the north and it feed Tukur Wuha River to the west.

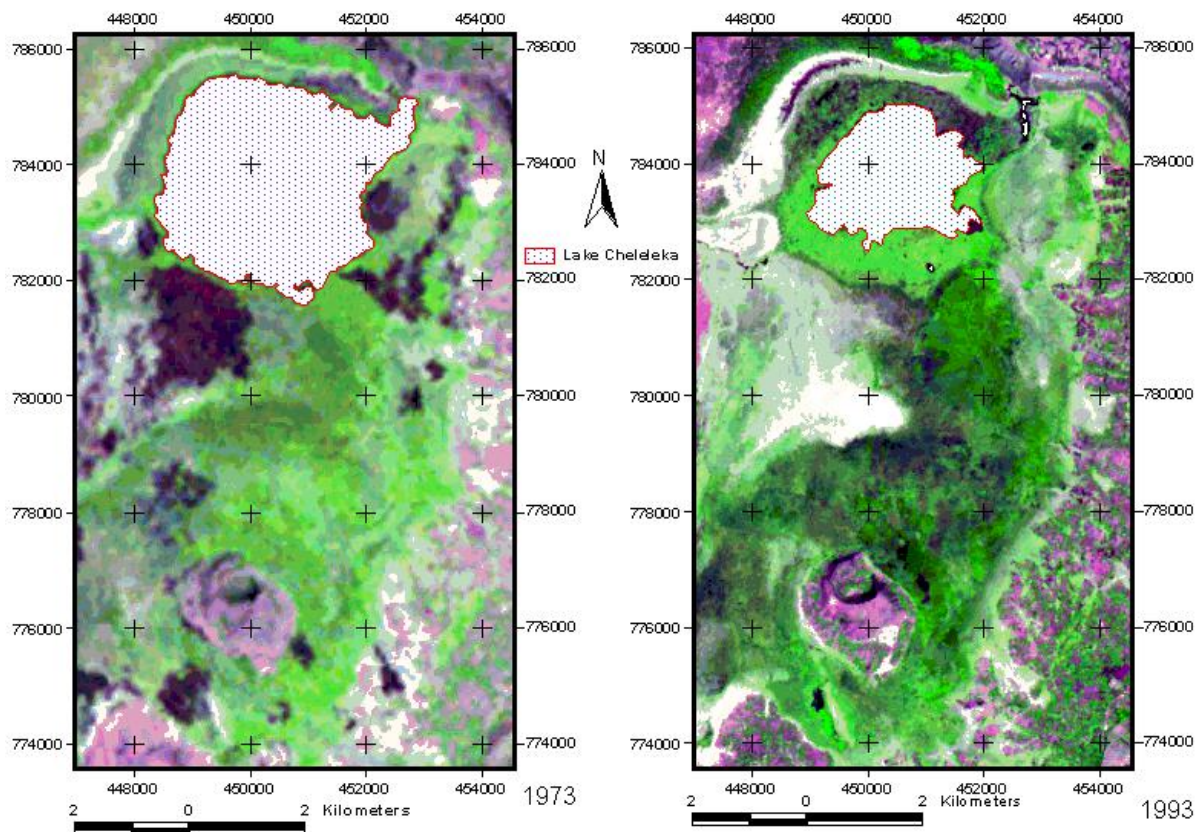


Figure 34: Surface coverage of Lake Cheleleka in 1973 (FCC MSS 475), left, in 1993 (FCC SPOT 132), right.

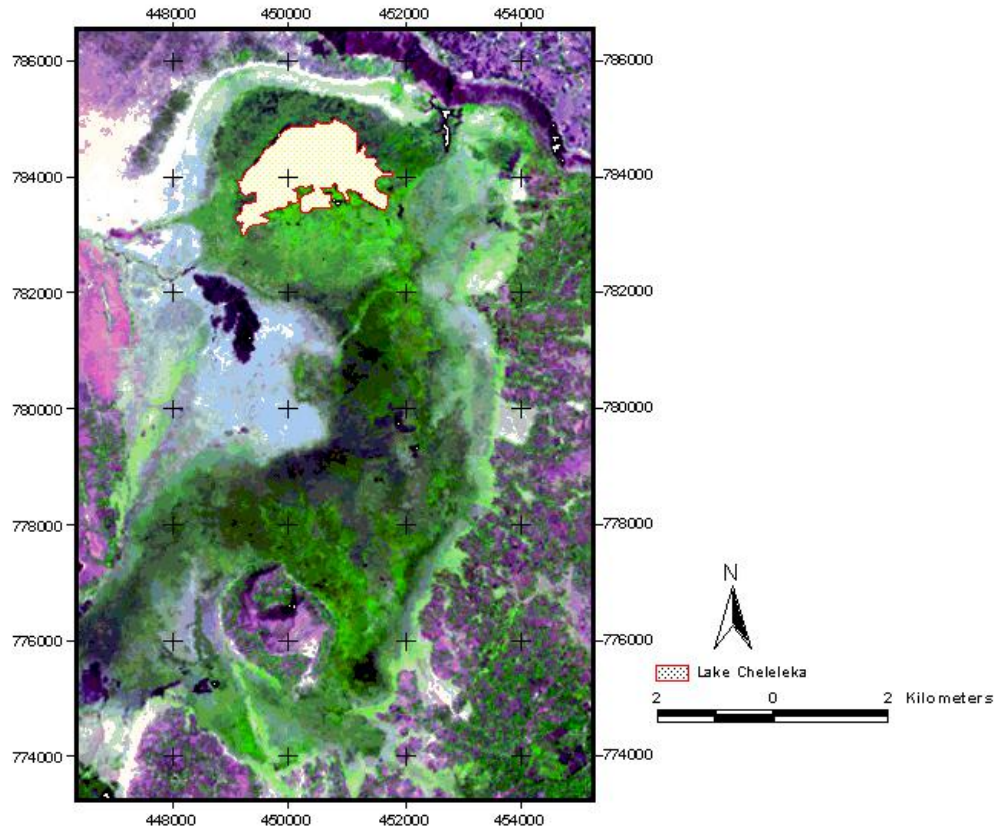


Figure 35: Surface Coverage of Lake Cheleleka in 2000 (FCC LandSat 243)

6 USLE Erosion Model

6.1 Introduction

Erosion risk assessment using modeling is one of the bases in developing effective soil and water conservation plans to reduce soil erosion or level of land degradation. Especially countries like Ethiopia, where the agricultural activity is believed to be the base for a means of developing channel, we should be concerned and closely observe the outcome of the interaction of this activity to its environmental impact related to land degradation.

In the study area, agricultural activities are widely practiced in the last few decades in an increasing rate; we can even say the major land use change in the area is as a result of advancement of agricultural activity. According to WWDSE (2001), dense woodland and bushy woodland, which covered about 27,995 ha in 1965 in the lake catchment, is now changed to open bush land, open grass land, cultivated land and others by 70 % i.e. the remaining dense bushy woodland in 1998 is only 30 %. This implies that the erosion processes observed in the study area are not natural but are a result of impact of human interference.

In this research, the USLE soil erosion model is applied to predict amount of annual rate of erosion in L. Awassa catchment. The model encompasses six parameters which are directly linked to variables (climate, topography, vegetation cover, management practices) that affect soil erosions.

Geographic Information System is imperative in such studies to generate such physically distributed parameters, integration of the layers using the principle of the model and put across the outcomes in the form of map and attributes. In our country, the availability of data, in digital or even in well-organized permanent paper collection is one of the biggest constraints for application of modeling and in quantification of erosion or other related processes.

6.2 The USLE model

The advantage of using models of any kind is to get a clear idea of interaction between the elements of a given system. One of several models that is based on mathematical relationships between various environmental and climatic effects, landscape features and soil erosion rates

is the Universal Soil Loss Equation (USLE). This soil loss prediction equation was developed in the late 1950's, at the Runoff and Soil Loss Data Laboratory of the United States Agricultural Research Service, by Wischmeier and Smith. It was designed to be geographically universal in applicability and therefore called Universal Soil Loss Equation. The equation estimates sheet and rill erosion, where forest management and agricultural activities expose the soil surface to rainfall impact and runoff. It does not estimate gully, landslide or soil creep erosion (Krauer, 1988)

The average annual soil loss is dependent on the following factors:

Rainfall erosivity	R factor
Soil credibility	K factor
Slope gradient	S factor
Slope length	L factor
Land cover	C factor
Land management	P factor

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

$$A = RKSLCP \dots\dots\dots \text{Eqn 4}$$

The model was modified and adapted to Ethiopian conditions based on recommendations of the Soil Conservation Research Project (SCRCP) by Hurni (1985). It is this latter version, which will be employed in this work.

6.3 Model Input Parameter Generation

6.3.1 Rainfall erosivity (R) Factor

Rainfall erosivity Factor is a property of rainfall and can quantitatively evaluate the potential capacity of rain to cause erosion in given circumstances. It measures the combined effect of rainfall and its associated runoff.

Through their kinetic energy, raindrops produce, essentially on previously moistened aggregates, a mechanical effect at the point of impact and they detach the fine particles on the very surface of the soil, carry them away in suspension or seal the topsoil. Intensity, drop size distribution, drop fall velocity, effect of wind, thunderstorm, and precipitation are the main characteristics of natural rainfall that influence its erosive potential. Rainfall intensity relates the total amount of rainfall to its duration. This characteristic is very important in the rainfall erosion process. When the intensity exceeds the maximum infiltration rate of the soil surface, runoff results and a portion of the rainfall is lost (Krauer, 1988).

While climate does not tend towards sharp breaks in the study area, the distinction between highland and lowland is still clear. In general, orographic lift over the highlands promote rainfall, the highlands therefore tend to be well watered and relatively humid. There is also a distinct relationship between temperature and altitude, such that the highlands are cooler and evapotranspiration is correspondingly less than the lowlands.

Rainfall is one of the climatologically elements that has a comparatively fair length of record in the study area. The relatively highlands on the scarp slope in the east and southeast are the wettest areas in the sub-basin. The amount of rainfall decreases from west to east. The scarp slopes of Wondo-Genet have better natural vegetation cover and more rainfall than the lowlands around Lake Awassa.

Multiple correlation and stepwise multiple regression analysis of rainfall data of 157 meteorological stations all over Ethiopia did not reveal any strong relations between annual precipitation, altitude and location (Hellden, 1987). Therefore the monthly precipitation records were used to establish the linear regression ($r^2 = 1.00$) describing the R factor as a function of mean annual precipitation,

$$R = -8.12 + (0.562 \times P) \dots\dots\dots \text{Eqn 5}$$

Where P - mean annual precipitation [mm] (Hellden 1987)

The resulting equation was applied to mean annual precipitation (1384 mm) of the meteorological stations near and within the Lake Awassa catchment is presented below. The Rainfall erosivity factor, R, is calculated based on the above equation.

Erosivity, R factor of calculated for each stations within and near to L. Awassa catchment						
Station No.	Name	X(m)	Y(m)	Elevation	Mean Annual Rainfall (mm)	Erosivity (R factor)
1	Awassa	442235	779921	1750	953	527
2	Wendo genet	456960	778399	1800	1151	639
3	Shashemene	455869	795581	1950	918	508
4	Yirba	433423	765478	2000	1120	621
5	Haisawita	451228	763012	2240	999	553
6	Aje	428559	807012	1860	1272	707

Table 2: Erosivity factor calculated from Annual rainfall of the stations within and near to the Lake Awassa catchment

Point data, Erosivity factors calculated for all stations, converted to surface data using interpolation method in ArcView GIS. This gives 50 x 50 grid pixel value of erosivity factor for all point in the catchment. The surface Erosivity map is presented in figure 39 .

Erosivity value in the catchment is higher on the highlands following its high amount of annual rainfall gain.

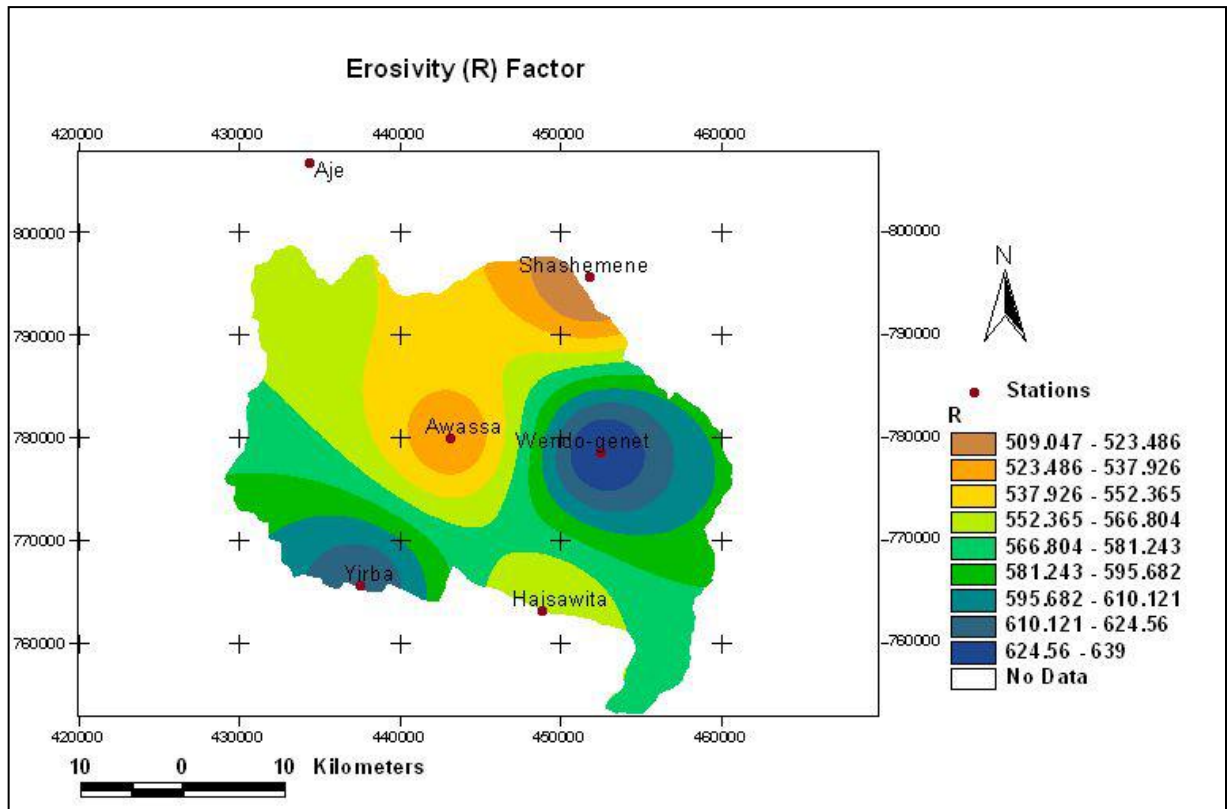


Figure 36: Rainfall Erosivity map of Lake Awassa catchment

6.3.2 Soil Erodibility (K) Factor

While erosivity refers to the aggressiveness of the climate, the term erodibility refers to the liability of the soil to “suffer” erosion due to the forces causing detachment and transport of soil particles (Lal R., 1977). Some soils erode more readily than others. Soil properties that influence soil erodibility by water are either the principal characteristics that affect the infiltration rate and permeability, or those that resist dispersion, splashing, abrasion and transporting forces of the rainfall and runoff. All this differences, caused by properties of the soil itself, is referred to as the soil erodibility, K (J. Krauer, 1988).

The erodibility factor, K value is ease with which a soil can be eroded. Values range from 1.0 (most eroded) to 0.01 (almost nonerosive). Soils high in silt and very fine sand are more easily eroded and than other soils. Organic matter, larger structural aggregates and rapid soil permeability all lessen the soil K factor (Raymond W. Miller and Roy L. Donahue, 1997).

In this study K value is assigned for all soil types in the study area using GIS attribute table level editing. K value assigned by WWDSE for each soil type in the catchment area is used to generate soil erodibility map. K value is calculated based on the landscape, soil type and cover nature of the study area. This is done in attribute table of the soil map of the area by inserting a new field (**K_Factor**) and adding the k value for each record (soil polygon) based on the WWDSE 2001 report.

The resulting shape file changed to grid file using Theme/Convert to Grid command of Arcview with a cell size of 50 x 50 meter and the cell value is based on **K_Factor** field. Figure 37 shows the resulting grid (erodibility surface map)

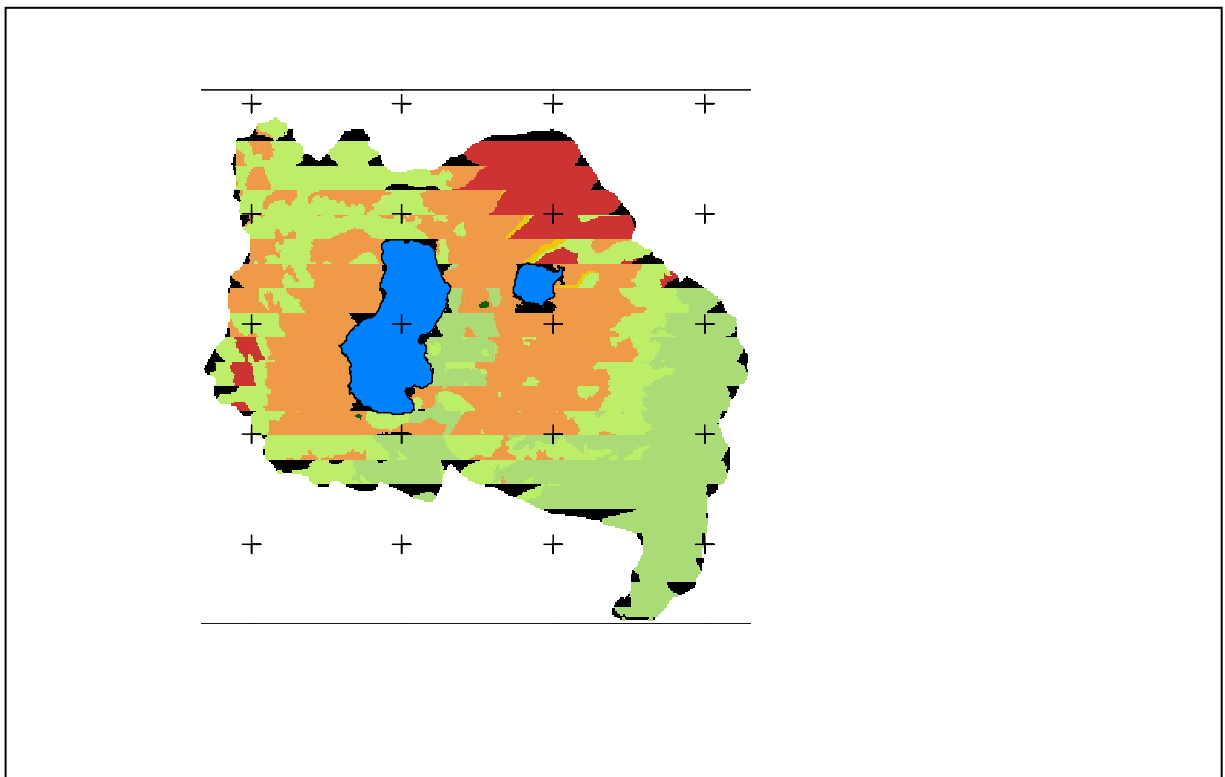


Figure 37: soil erodibility factor of the study area

6.3.3 Slope Gradient (S) Factor

Slope steepness affects both runoff and soil loss. Slope accelerates erosion as it increases the velocity of the flowing water. Slope gradient factor is assigned to the specified range of slope gradient from slope percent grid of the study area which is generated using Arcview Model builder extension. The slope gradient rank and the slope gradient factor adapted for Ethiopia, Hurni, 1985 is used.

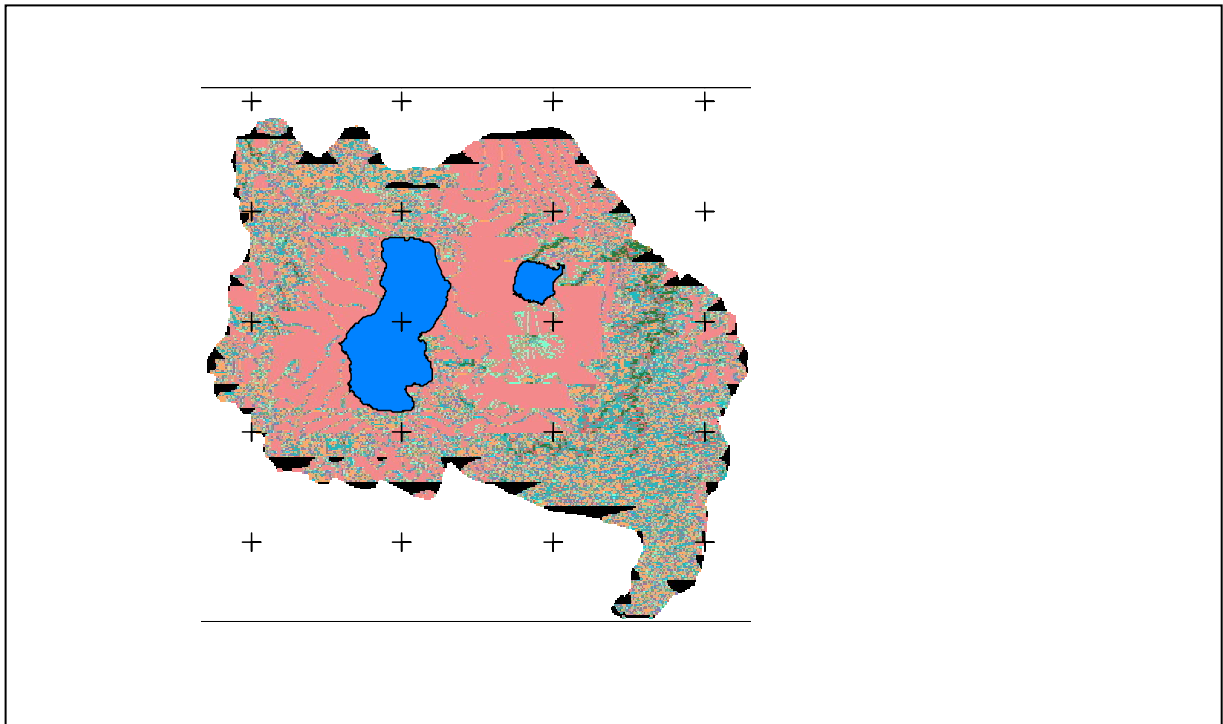


Figure 38: Slope length factor

S-Factor	Slope gradient (%)
0.1	< 1
0.12	1 – 2
0.2	2 – 4
0.35	4 – 6
0.6	6 – 8
1	8 – 13
2	13 – 25
3.2	25 – 40
4.2	40 – 55
5.5	55 – 100
10	> 100

Table 3: Slope gradient factor (Hurni, 1985)

6.3.4 Slope Length (L) Factor

Slope length is the distance from the point of origin of overland flow to the point where either the slope decrease enough that deposition begins or the runoff water enters a well defined channel. Longer slopes increase erosion because water accumulated and increase in speed, collecting more cutting sediment and doing proportionally more damage.

Slope-Length factor of the area is generated using Arcview GIS Terrain analysis extension. Automated Slope-Length factor calculation is more accurate as the resolution of DEM increases. As previously indicated the DEM is prepared from a Topographic sheet of 1:50000 scale with 20 meters vertical resolution.

Arcview Avenue script code, slfactor.ave associated with Terrain Analysis/SL Factor command is used to generate a slope length factor parameter for the USLE. . The code was created and modified by Frank Schmidt in 2001 and 2002, respectively, and it was written based on SL-Factor for USLE based on Literature by Moore & Wilson 1992.

The formula used in the calculation of SL-factor indicates that the SL factor is mainly depends on slope length and sine of angle of the slope. Following this the result, shows that regions with high slope but short length could have higher slope length factor. Due to this reason the eastern side of the catchment where the slope is steep, escarps area, the slope length factor is high. Weransa ridge and other similar landscape in the area have because of their high slope. The formula in the code used to calculate the SL-factor is:

$$LSGrid = (((flowaccGrid/22.13)^{0.4}) * 1.4 * (((slopeGrid.sin)/0.0896)^{1.3})) \dots \dots \dots Eqn 6$$

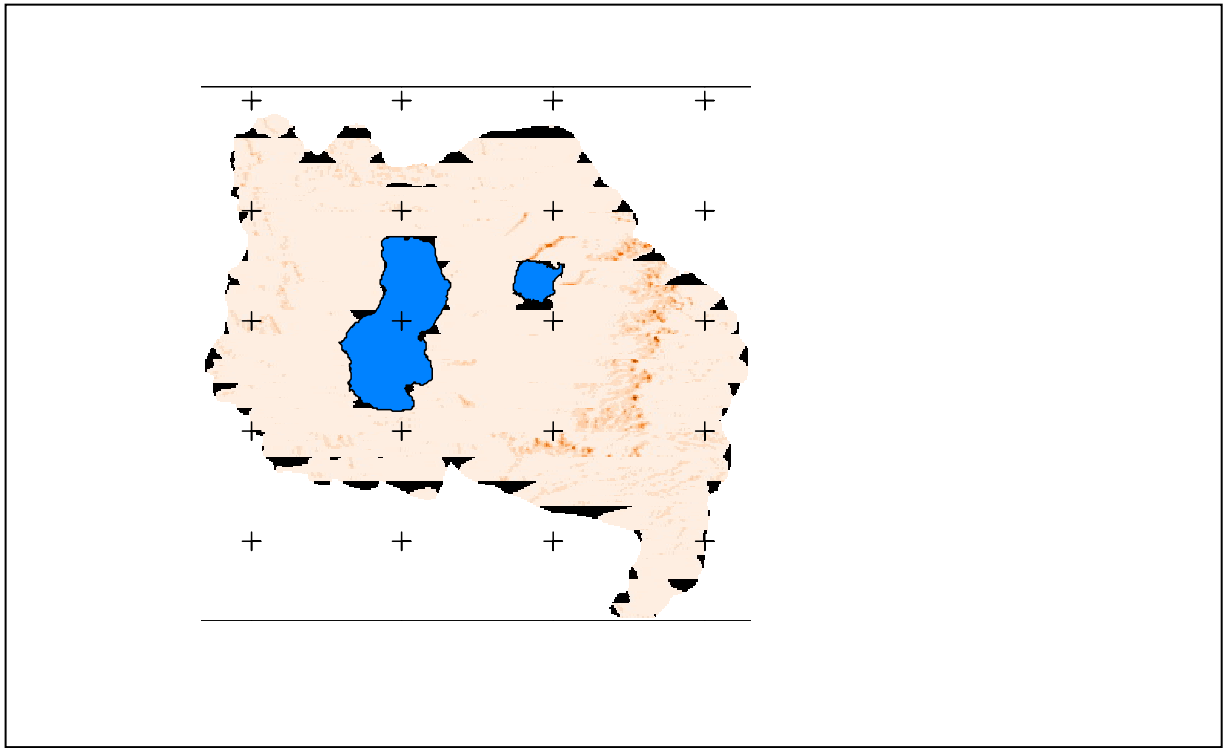


Figure 39: slope length factor of the study area

6.3.5 Land cover (C) Factor

The cropping factor C is the ratio of soil loss for given conditions to soil loss from cultivated continuous fallow on identical soil, and slope and under the same rainfall. The type of Land cover (crop type) and tillage make the greatest difference in the amount of erosion that occurs in a given area. Pasture and hay crops are effective in reducing erosion to a very low level. The more of the soil that is left uncovered during, before or after tillage, the greater the risk of soil erosion by either wind or water (Wilbur W. Frye).

The Landuse land cover map of 2004 (Figure 21) is used to generate the cover factor for USLE model. Major land cover types described in this map are cultivated land, Open bushy woodland and cultivated land, open grassland, open bushy woodland, and dense bushy woodland. Peasant farmers and government organization are carrying out farming activities around Lake Awassa Sub-basin. The coverage of each land use system in percentage is listed in table 4.

LANDCOVER	Area (Hectar)	Area (Km ²)	Coverage (%)
Bareland	1981.53	19.82	1.4
Cultivated Land	58226.32	582.26	42.4
Dense Bushy Woodland	4982.96	49.83	3.6
Lakes	9286.45	92.86	6.8
Open BushLand	1106.97	11.07	0.8
Open Bushy WoodLand	6150.53	61.51	4.5
Open Bushy Woodland & Cultivated Land	37947.70	379.48	27.6
Open GrassLand	5534.47	55.34	4.0
Open Grassland & Open Shurbland	987.17	9.87	0.7
Open ShrubLand	316.32	3.16	0.2
Shrubby Grassland	2652.39	26.52	1.9
Swampy Grassland	5806.70	58.07	4.2
Urban BuiltUp	2294.74	22.95	1.7

Table 4 : coverage each Landuse of 2004 from total catchment area

Figure (40) shows areas assigned as agricultural fields and some farmlands owned by organizations such as Ethiopian seed Enterprise, institute of Agriculture Research. Other part of the cultivated land is run by private owners and peasants.

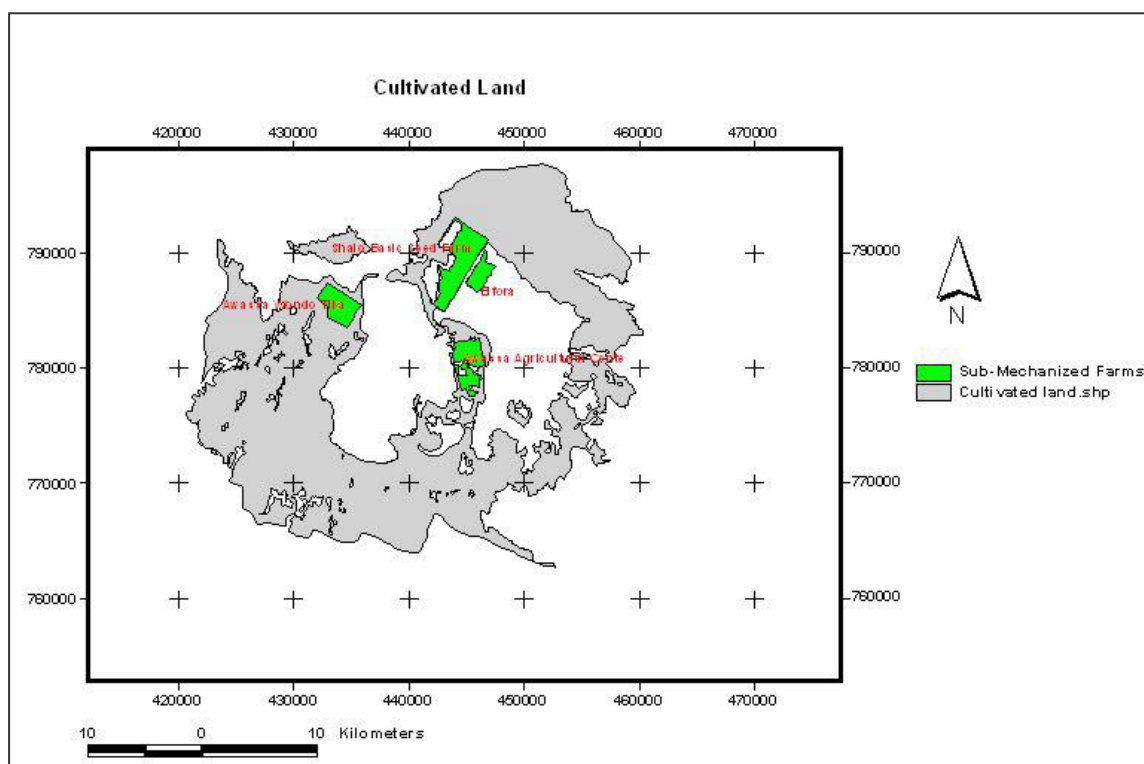


Figure 40: cultivated land in the study area and some areas run by Semi-mechanized farm

According to Ethiopian Seed Enterprise the main crop production and Institute of Agriculture research, the area is characterized as Weina Dega agro-ecological region (IAR, Research Report 3/88) and in the area dominantly known for production of maize and Haricot bean, and the minor crops include potato, pepper, Enset etc. The enterprise distributes certified seeds to selected peasants and other private investors in the study area and follow up the production steps. The crop pattern of the study are is listed in table 5.

S.No.	Crop type	Land preparation	Planting	Harvesting
1	Maize	Feb. - Mar	April	Nov. - Dec
2	Haricot bean	Feb.-Mar	March	June
3	Haricot bean	June	July	October
4	Potato	January - February	February	June
5	Potato	June - July	July	Nov.-Dec.

Table 5: Cropping calendar of the Lake Awassa sub basin (WWDSE)

The C-factor is assigned for each land cover based on previously studies of land degradation (Hurni, 1985, EARO, 2003,). Table z shows the C factor for various land covers of the dstudy area. Cultivated land of the study area (near to wendogenet) is covered usually by Coffee, banana, sugarcane, and Enset. The low land area is also dominated by Maize, Enset and around flood plane the lake farmers produce vegetables.

The last three years production records of Ethiopian Basic seed enterprise and other semi-mechanized farms owned organization shows that the production is dominated by maize and Haricot bean, management factor is relatively better than individual farmers. Tillage in such farms is done using Machineries and according to Ethiopian Basic seeds Enterprise experts, mulch application and crop rotation tried on their farm land.

LANDCOVER	C-Factor
Bareland	0.4
Cultivated Land (high land)	0.01
Cultivated Land (low land)	0.1
Dense Bushy Woodland	0.01
Lakes	-
Open BushLand	0.038
Open Bushy WoodLand	0.01
Open Bushy Woodland & Cultivated Land	0.01
Open GrassLand	0.013
Open Grassland & Open Shurbland	0.0255
Open ShrubLand	0.038
Shrubby Grassland	0.05
Swampy Grassland	0.01
Urban BuiltUp	-

Table 6:C –factor for land covers in the study area

Some of the land covers, example bushy woodland & cultivated land assigned to have c factor by taking the average of the two land cove types (Woodland and Cultivated land).

The land use land cover type of the area is converted to its c-factor map and a grid map of 50 X 50 m is prepared using C-factor as pixel value. Figure 41 shows the c- factor of the study area.

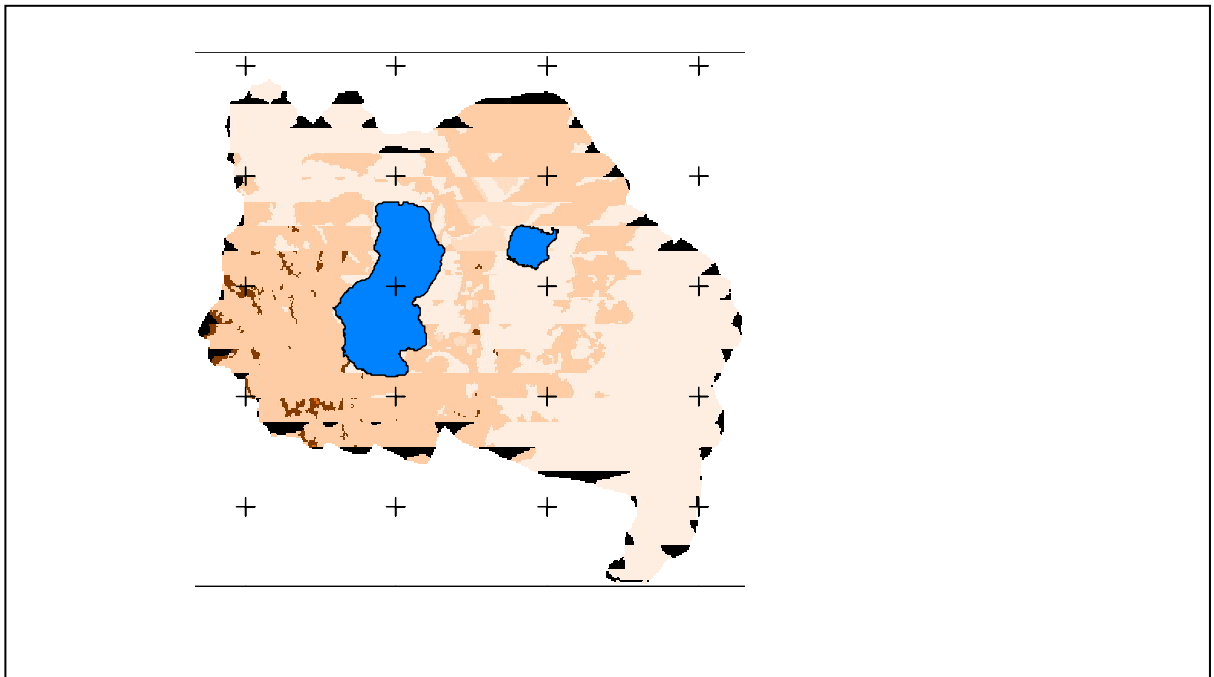


Figure 41: Land cover factor, C of the study area

6.3.6 Support Practice (P) Factor

The conservation practice factor is the ratio of soil loss for a given practice to that for up and down the slope farming. P value varies depend on a range of practices applied on the farm such as contouring, strip cropping, and terracing.

According to agriculture experts form Ethiopian Basic Seed enterprise, a government organization that is specialized in the hybrid of basic seeds in its certified quality and distribute it to local farmers and private organizations involved in agricultural investment in the study area, soil and water conservation is poor in the catchment. Data from SNNPR-CSA reveal that no remarkable land in the area is covered by soil and water conservation program.

The southern and southwestern side of the lake is highly cultivated. Natural cover in the area is almost none. Small mountains and hills in the area are highly cultivated and some of them are used as a quarry site for supply of construction material to the town and its vicinity. The flood plain of the lake is used for agricultural activities and according to some information from agricultural input supplier farming activities in this area are supported by fertilizer input without buffering (plate 5-7).



Plate 5: Agricultural activities adjacent to Lake Awassa (south)



Plate 6: Hillside agriculture and extraction of construction materials (south of Lake Awassa)



Plate 7: Maize farm land preparation (0.75m between each row) (Shallo Farm)

Mulch application was tried on maize agriculture field of Shallo farm, Ethiopian basic seed enterprise, but local people use it as fire wood immediately after harvesting. As the experts pointed out this is one of the reasons that the soil is poor in organic matter. This activity is also common on farm lands owned by peasants in the catchment.

P values for contouring activity is calculated using slope gradient map of the study area based on Morgan, 1995.

Slope map of the study area generated from DEM of the study area. The slope map clipped by a shape file that generated from 2004 Landuse land cover and show only areas where agricultural activities going on (*Open Bushy Woodland & Cultivated Land and Cultivated Land*).

The slope map grouped into five classes (class 1- 0-5, class2 5-7, class3 7-9 class4 9-11 and class5 >11°). Depending on the slope classes the P-value is assigned into new field **P_val** to each class as 0.7, 0.8, 0.85, 0.9, and 0.95 respectively. New shape File is created from this slope class map of cultivated area with its P-value by the name **P_Val_1**. Similarly, new region which indicate non agricultural areas is created from slope map using clip tools of Grid tools extension. This area assigned to have a value of 0.85 for conservation support practice value. The resulting file saved as shape file namely **P_Val_2**.

The grass land on the swampy area and on lower slope is also considered to have 0.5 P value. This area also saved as **P_val_3**.

The three shape files area combined using XTools/merge theme command and a single shape file generated for the catchment. The resultant shape file is converted to grid theme with Pixel value representing management factor. Figure 42 shows the management practice surface map of the study area

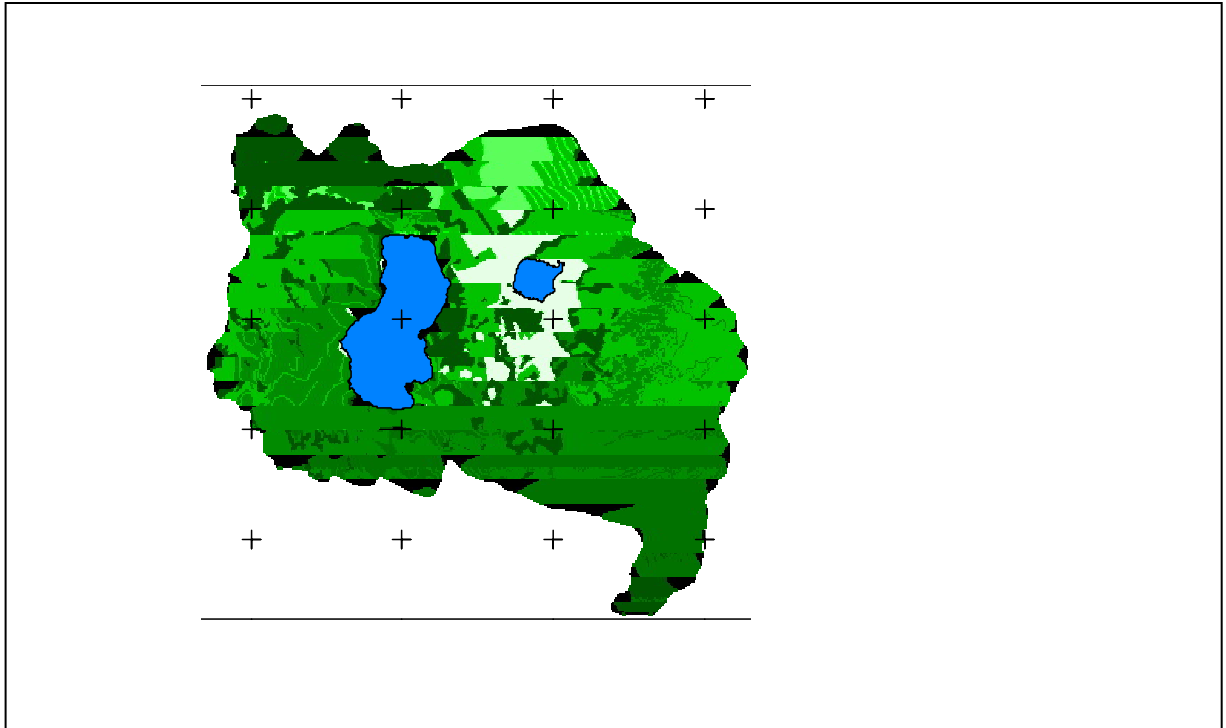


Figure 42: Conservation Practice (p) Factor map of the catchment

6.4 Mean Annual Soil Loss

The final assessment of the mean annual soil loss rates is calculated using overlay analysis method of GIS spatial analysis. The soil loss is calculated from all layer of parameters generated in previous topic. These are Rainfall erosivity, Soil erodibility, Slope-Length, Land cover, and conservation practice (figure 43).

Each layer was organized in a grid format with a cell size of 50 x 50 meters. The layers were combined by multiplying each cell of identical position from all existing surface information based on the relationship defined by the USLE model. Including the 'no data' cells there are 917 rows and 989 columns. Hence, overlay of all these cells (917 X 989) is done by multiplying one theme with the other to generate the final map that shows the annual soil loss rate of the catchment on each 50m plate area.

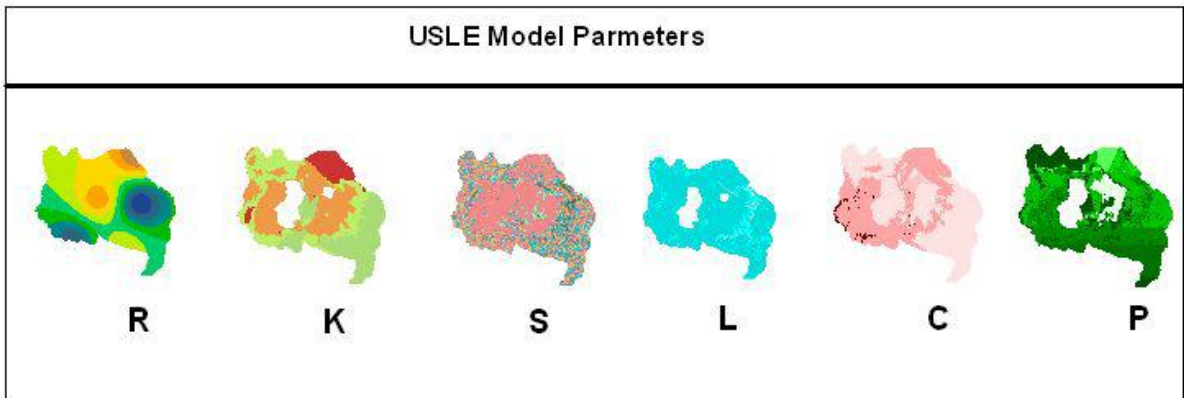


Figure 43: parameters of universal soil loss equations

The resultant map shown in Figure 44, depicts the magnitude of mean annual soil rate with its distribution in the catchment.

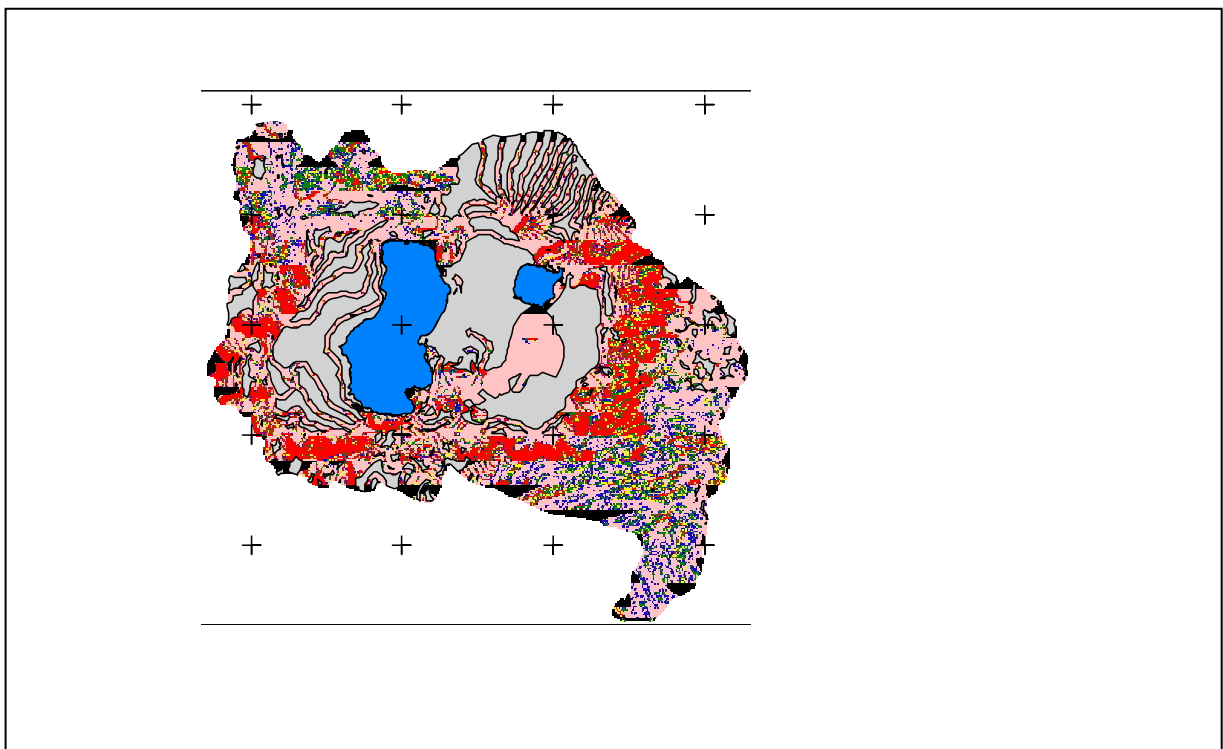


Figure 44: Mean Annual Sheet Erosion soil loss of the catchment surface map

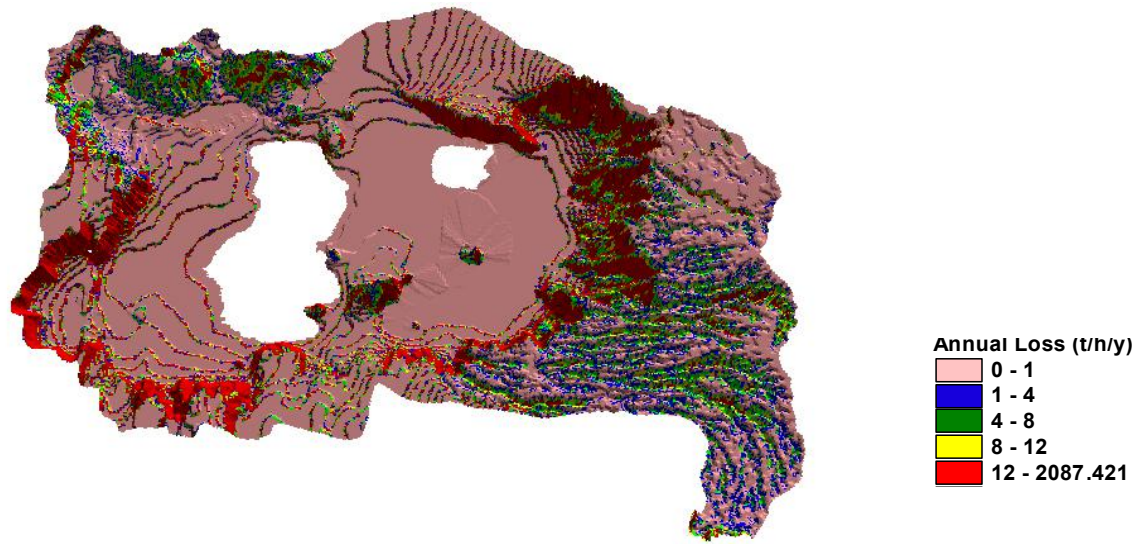


Figure 45: 3D view Distribution of Soil Loss rate

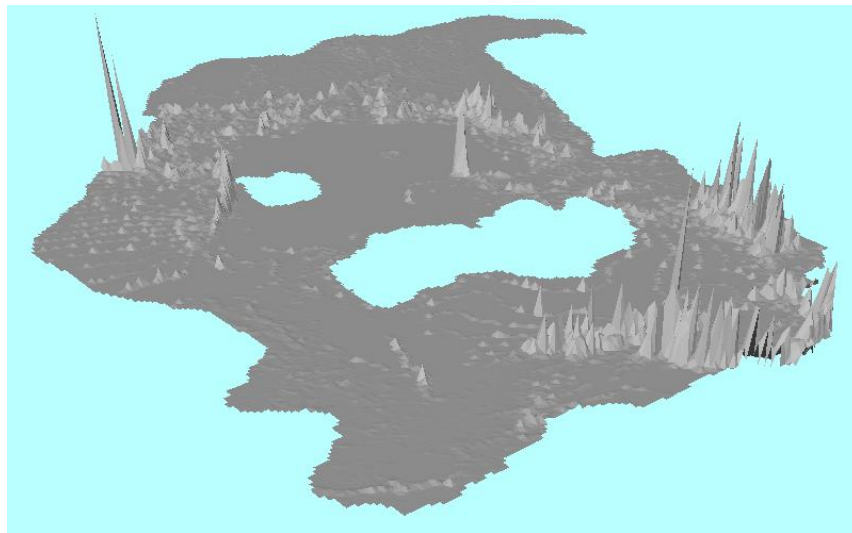


Figure 46: Sheet erosion distribution and its magnitude

The result indicates that most of the study area is under 8 ton/hectare/year annual soil loss rate (Figure 46). Nevertheless, the elevated western and southwestern part of the area cover above these values and dominated by high soil loss rate.

Most of the northern side (Corbetti Caldera) is delineated as area less than 10 ton/hectare/year but as the model output indicates the northeastern part of the catchment, the area between

Weransa Ridge and Abaro ridge, has high rate of erosion compared to the lower land in the vicinity and western ridges near Wondogenet area.

South of Awassa Lake (Dulecha Ridge) where high human interference is seen on the slope side of the small hills, the model output shows that the rate of erosion is higher. Similarly, the model identified all the small cones adjacent to the lake side (Tabor, Alamura, Kike, Ilanta, Tamura) as higher potential rate of erosion.

The flat land of the study area, having 0 slope gradient, have a result of 0 mean annual soil loss; but that may not be true in reality. High resolution Digital elevation map of the area (< 20 m) is necessary to get a better result on the flat land.

7 Results and Discussion

7.1 Soil Loss Distribution

Water erosion is a natural process that occurs whether there is or no human interaction. USLE model considers both factors, viz manmade and natural. Climate (Rainfall erosivity), Soil (Soil erodibility), Topography (Slope gradient and Slope length) are more of nature-controlled but to a peasant-scale farm it could be modified by man through terracing and other conservation methods). The land cover type (cropping and land use system) and soil conservation management practices (conservation support practices) are linked with human activity and its interaction with nature. For example, in the study area, the land use system is changing from early 1960's to current condition. Deforestation, expanding agricultural activities area major changes in the area. This by itself can cause remarkable change on the erosion process.

Distribution of rate of soil loss in the area is a function of the spatial distribution of all factors controlling the erosion processes. Depending on the individual parameters, contribution to this process and the magnitude (the resultant of interaction of all factors calculated by USLE equation) vary within the catchment.

To understand the most important input parameter(s) that govern the annual rate of soil loss from a specified area, it is vital to see the distribution and amount of these rates with respect to the magnitude and the relationship with existing human or natural controlling factors. Re-classification of Annual soil loss into sub classes is done to see their magnitude and spatial distribution.

Soil Erosion Class	Potential Soil Loss (tons/hectare/year)
Very Low	<1
Low	1 - 4
Moderate	4 - 8
High	8 - 12
Severe	>12

Table 7: Soil erosion Classes

Parameters of USLE are examined based on value greater than 8 t/h/y.

7.1.1 Erosivity and Annual Soil Loss

Rainfall erosivity and Annual soil loss map shows positive correlation. Isoerodent map, which is overlain on Annual soil loss erosion map, indicate that annual soil rate greater 8 t/h/y which cover 28076.7 hectare of the catchment are included with in erosivity greater than 560. This is 79.6 % of total annual soil loss area covered by above 8 t/h/y. Figure 47 shows isoerodent map and soil loss distribution. This factor totally depend on regional distribution of the climate and cannot be modified and used for minimizing soil loss rate.

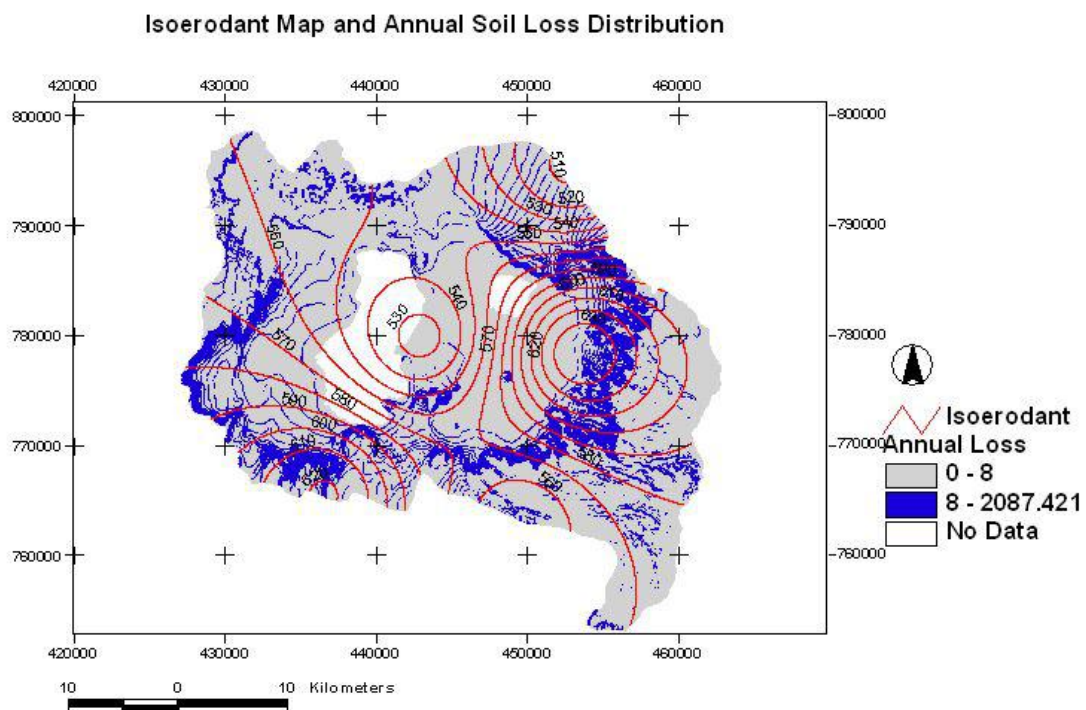


Figure 47: Erosivity versus to Isoerodent Map

7.1.2 Erodibility and Annual soil loss

Together with air and water, soils have a fundamental role in our environment. They perform a wide range of key functions related to our natural environment as well as economic functions and as an element of landscape.

Erodibility factor is taken from WWDSE soil map of 1998. soil in the are are classified based on their inherent characteristics and their geomorphic appearance. The K value that is

mentioned in WWDSE 2001 report and based on the description the erodibility map is prepared as a map and used in USLE model as one of model inputs.

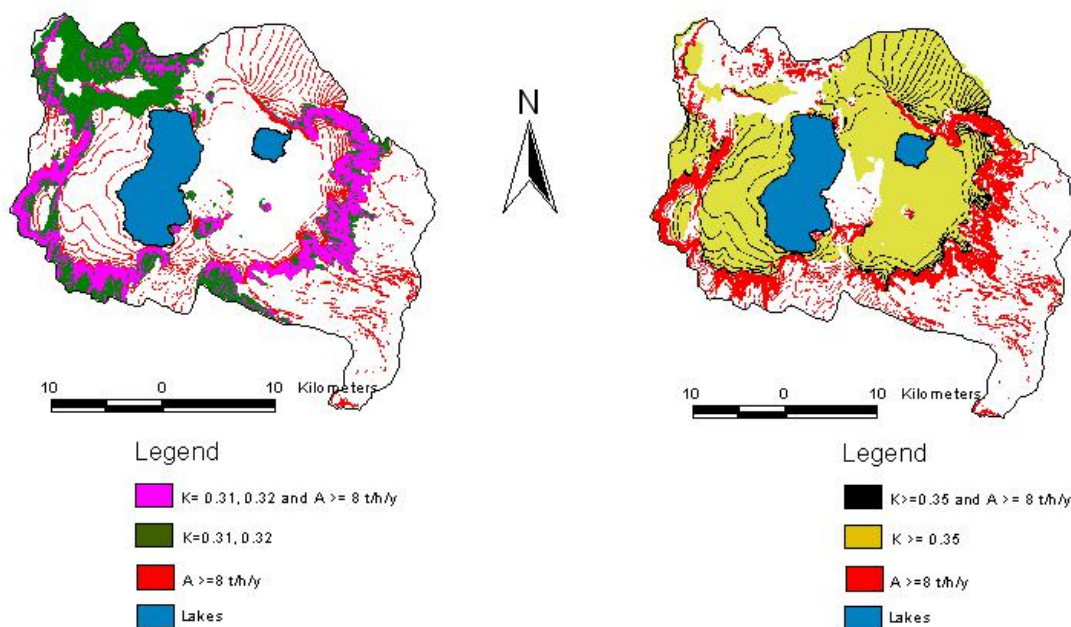


Figure 48: Distribution of Erodibility and annual soil loss rate above 8 t/h/y

High values of K value are given for Leptisols on escarp (k = 0.35), Cambisol, Vertic Cambisols, and Andosols which developed on 0-8 slope gradient (k = 0.38) and Regosols + Cambisols developed on 0-8 slope gradient (k = 0.44) that cover the northern area between Shashemene and Toga with low soil depth overlying the unconsolidated pumice volcanic deposit that is highly susceptible for almost all soil erosion types dominantly gully erosion. As Figure 57 indicates, the distribution of the highly degraded area as compared to soils of high erodibility factor, the overlapping area is small, only 32.5 % of the total high degraded area marked by the model fall in high erodible soils. Soil having 0.31 and 0.32 erodibility factor, such as Leptisole and Leptisole + Cambisol developed on 0- 30 slope gradient; and Cambisols + Alfisols and Leptisol + Regosol cover 58.2 % annual soil loss rate. The rest of area in high degraded region is covered by soils which have k value less than 0.30.

7.1.3 Slope Gradient and Annual Soil Loss

Slope controls the speed of downward moving water in a given land plot. To see the impact of this factor, first the slope gradient that fall in high and severe degraded annual soil loss classes

(> 8 t/h/y) model result is clipped and histogram is calculated to see the S-factor distribution in this region.

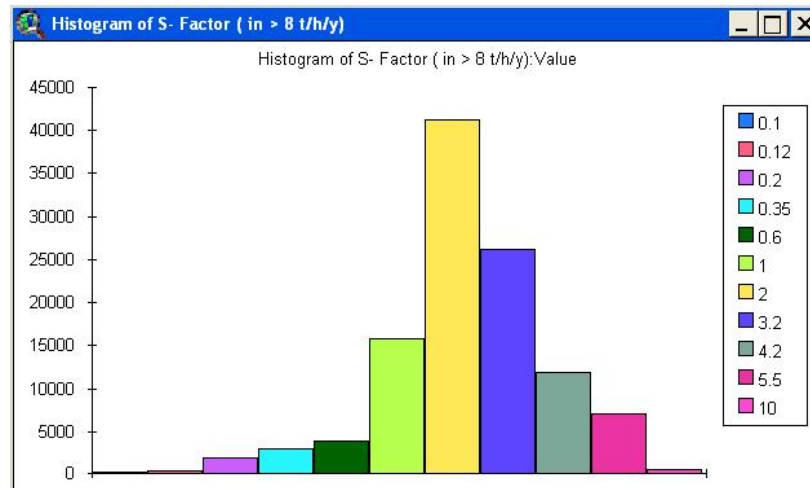


Figure 49: Histogram of Distribution of S-Factor in annual soil loss > 8 t/h/y class

Calculating area coverage (%) of annual soil loss classes in high and severe classes falling in the slope gradient ranges suggested by Hurni (1985) indicate that 86.1% of the total area of highly degraded area categorized in 8-55 slope gradient percent and with 13-25 being a dominant class (Table 8).

Slope gradient (%)	< 1	1 – 2	2 – 4	4 – 6	6 – 8	8 – 13	13 – 25	25 – 40	40 – 55	55 – 100	> 100
S-Factor	0.1	0.12	0.2	0.35	0.6	1	2	3.2	4.2	5.5	10
Area Coverage in High and Severe Classes (%)	0.2	0.4	1.3	2.1	2.7	12.0	38.9	24.4	10.8	6.7	0.5

Table 8: Distribution of Annual soil loss within Hurni (1985) soil gradient ranges

7.1.4 Slope Length and Annual Soil Loss

Slope length factor is calculated using automated DEM processing, Arcview avenue program, cited in Terrain analysis extension. The slope length effect on the results of the model varies with topography and in the degraded areas slope gradient value is concentrated to a range of 0.129 – 7.212 (Figure 50).

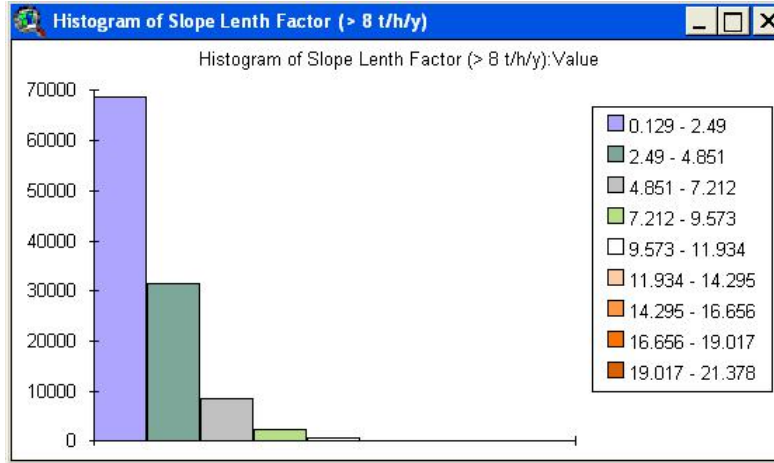


Figure 50: Histogram showing frequency of Slope length factor in > 8 t/h/y class

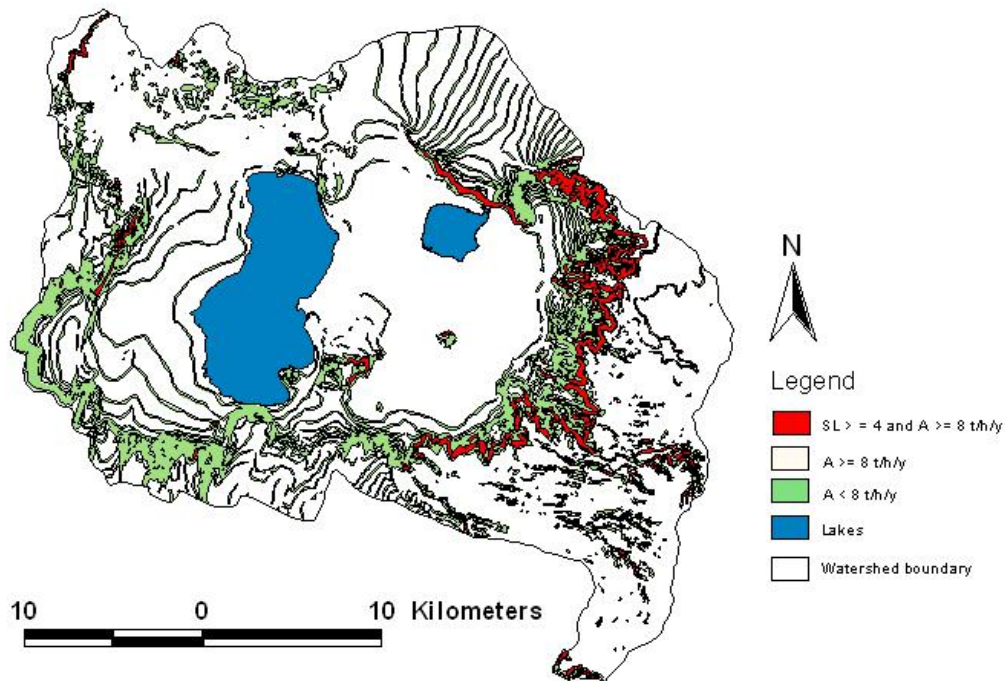


Figure 51: Distribution of High Slope Length Factor within High Annual Soil Loss Rate Region

Analysis of regions with high potential annual soil loss rates indicates that the escarpments of windward areas and all sloping other escarpments (eg. Weransa ridge) with steep slope have high SL factor (≥ 4) and they fall in high degraded areas, particularly on the eastern side of the catchment where the slope steepness is highest (Figure 51). This indicates that even if other factors such as land cover and soil erodibility might be small inputs in this area, high SL factor and high slope gradient factor have a major influence on Annual soil loss rate.

7.1.5 Land use and Annual soil loss

Landuse system is directly linked to socio-economic status of populations living in and around the study area. People living near the lake, especially rural areas, depend on fishing and irrigation agriculture practices. Agriculture is a dominant economic support for the population living in the area. Landcover map of 2004 map (Figure 21) shows that the dominant land cover type of the study area is cultivated land (42.4 %) together with open bushy woodland & cultivated land (27.6 %), which cover about 70 % of the total area.

Analysis of land degradation distribution in each landuse/landcover system is done. This is used to understand which are the most degraded landuse/landcover types.

As seen in Table 9 and Figure 52, the annual soil loss rate greater than 8 t/h.y, grouped as degraded areas, fall in Cultivated land (44.9%) and Open Bushy Woodland & Cultivated Land (32.6%) and the rest distributed to other Land use classes. About 80 % of Open Bush Land, Open Grassland & Open Shurbland, and Bareland classes are indicated by the model as areas of high degradation. Open Grassland & open Shurbland (cover Weransa ridge), Open Bush Land and Surbland may have high rate of erosion not because of their C-factor which is low but open Bare Land class may have high degradation due to its high C-Value (0.4).

Mean Annual Soil Loss Rate Class (ton/hectare/year)	Area Coverage in Hectare												
	Cultivated Land	Open Bushy Woodland & Cultivated Land	Dense Bushy Woodland	Open Bush Land	Open Bushy Woodland	Open Grassland	Open Grassland & Open Shrubland	Open Scrubland	Shrubby Grassland	Swampy Grassland	Bareland	Total	Area Coverage %
0	20632.5	1291.8	197.7	41.9	260.4	2743.8	0.0	1.6	2080.4	2202.4	206.7	29659.2	24.5
0-4	20696.7	22782.2	2634.2	289.2	3750.3	2079.8	42.1	176.9	438.0	2343.3	126.8	55359.6	45.7
4-8	2154.0	4360.4	1064.7	33.1	1010.8	222.0	16.2	41.0	34.8	11.9	37.0	8985.8	7.4
>8	12181.7	8838.8	1004.2	1692.3	982.6	420.5	386.7	81.6	70.2	34.1	1417.2	27109.8	9.5
Degraded Land (>8 ton/hectare/year)	12181.7	8838.8	1004.2	1692.3	982.6	420.5	386.7	81.6	70.2	34.1	1417.2	27109.8	
Percentage of Degraded Area from Total Cover of the specified Land Use	21.9	23.7	20.5	82.3	16.4	7.7	86.9	27.1	2.7	0.7	79.3	22.4	

Table 9: Annual Soil Loss Rate Distribution in different land use systems.

Coverage of Degraded Area (> 8 t/h/y) within the Specified area

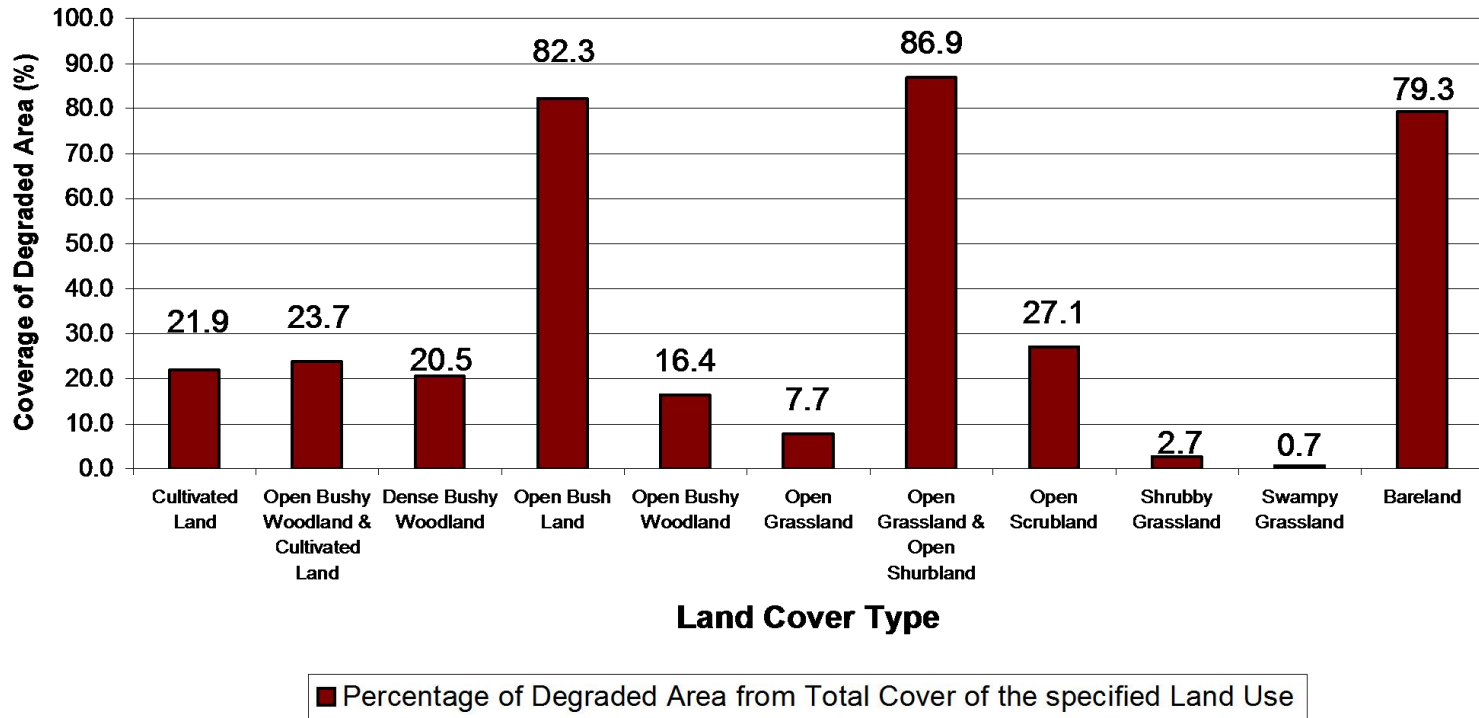


Figure 52: Landuse and cover (2004) and Annual soil loss rate distribution

7.1.6 Conservation Support Practices and Annual Soil Loss

As discussed in the previous chapter, Conservation support practices factor, P value was assigned assuming that on agricultural fields contour ploughing is done depending on slope of this landuse class p value assigned (Morgan, 1995). Grassland on swampy area which is a flat land assumed to have P value of 0.5 and since there is no major soil conservation activities in the catchment all non- agricultural land assign to have p value of 0.85 (Hurni, 1985).

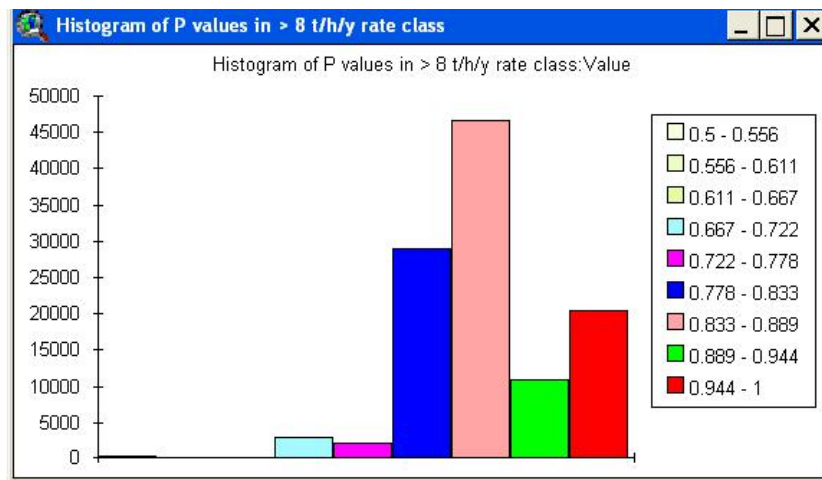


Figure 53: Histogram showing frequency of P value in > 8 t/h/y class

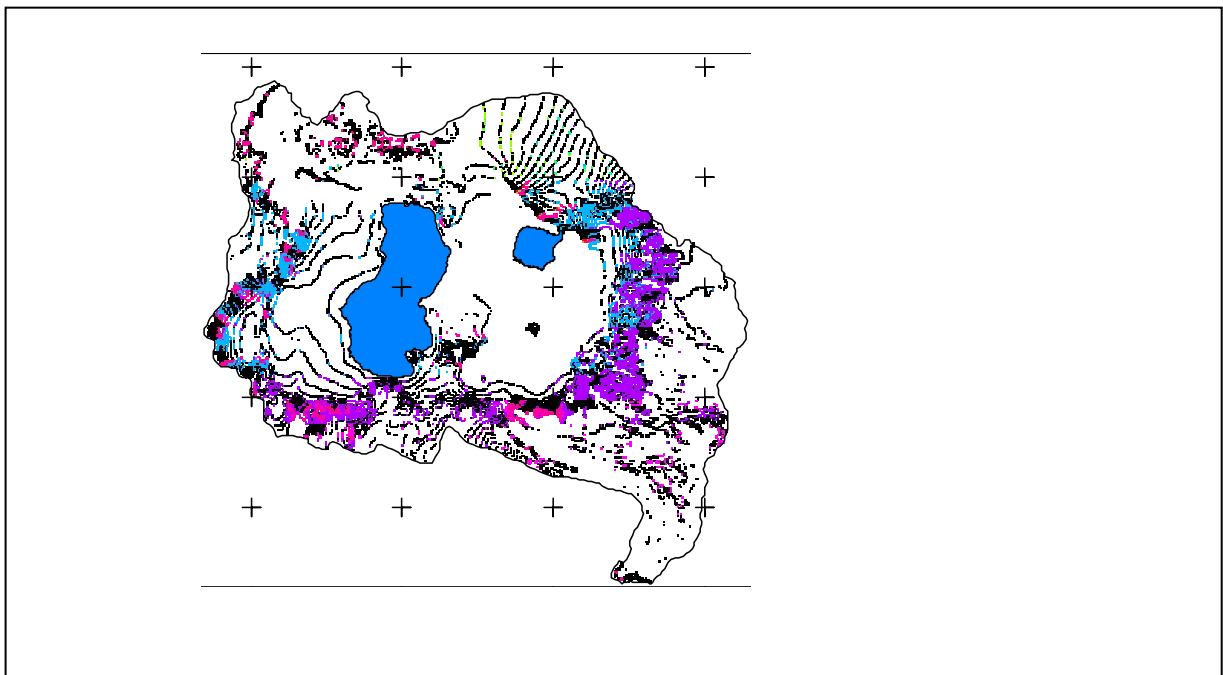


Figure 54: P values spatial distribution in > 8t/h/y class

Areas with P values between 0.778 – 0.833 are in high degraded area. This are agricultural fields with slope between 5 ° - 11° and are more degraded than other agricultural fields. This region covers 87 % of the total area, which is characterized as degradation greater than 8 t/h/y class. Non agricultural fields with no conservation practices also cover 18 % of this class.

7.2 Sedimentation and Annual soil loss rate

As mentioned under topic 4.4.3, the catchment is delineated as depositional and erosion area (Figure 28). Assuming the maximum eroded soil from upland areas accumulates on lower lands or on depositional areas such as on Cheleleka swamp and around Lake Awassa.

The delineated subcatchment areas are used to calculate the potential total amount of eroded sediments took place due to sheets and rills erosion. All pixels representing the annual soil loss rate and overlapping these areas clipped independently and their total is added and multiplied by area of a pixel. The potential total sediment that reached to the depositional area is assumed to be this value.

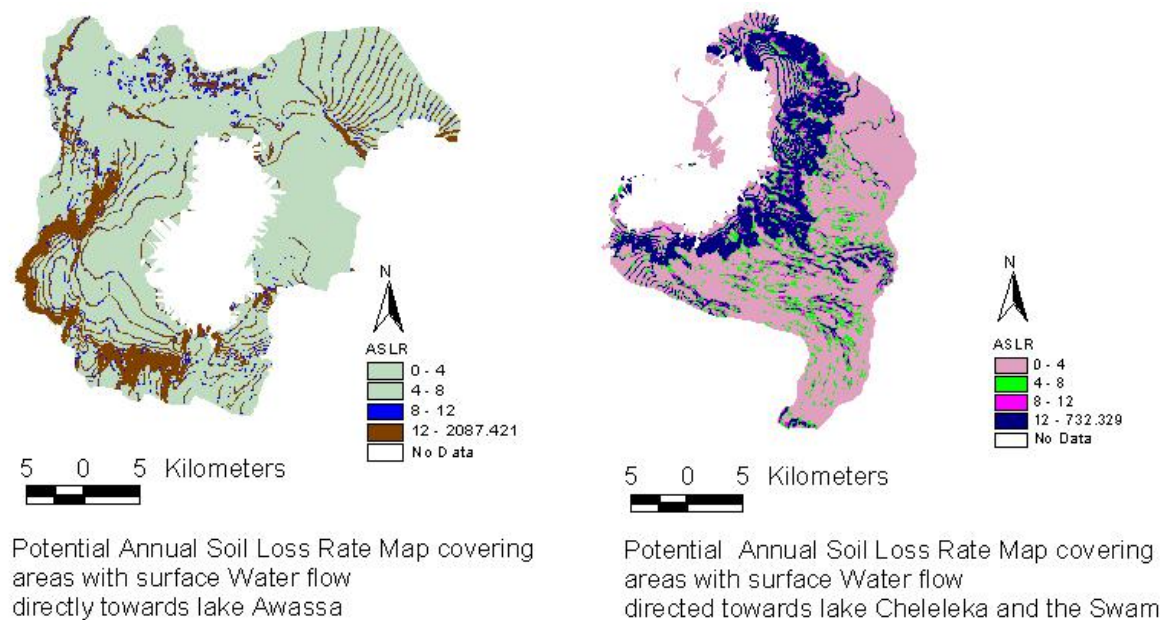


Figure 55: Annual soil loss rate and flow pattern of 2004, flow to Lake Awassa and its surrounding (left) and flow to Lake Cheleleka and the swampy area

The southern, western, northern and northeastern parts of the catchment areas are characterized as direct surface water flow towards the lake Awassa. The amount of annual soil

loss rates calculated from all pixels covering this area is assumed to be a sediment input into and around this lake. Similarly, the hydrologic modeling algorithm distinguishes the eastern and southeastern parts of the catchment areas as areas having a surface flow direction towards the swamp and the lake Cheleleka area. Hence, the annual soil loss rate covering this area is assumed to be the maximum sediment input towards this area in the specified year (Figure 63). To do this, first the annual soil loss map is clipped using the flow coverage shape files and the resulting grid is converted to point text file containing x (center of a pixel X-utm value), y (center of a pixel Y-utm value), and Z (rate of annual soil loss for the given pixel).

The text file is processed in database file to sum up all pixel values. The result is multiplied by the area of a pixel ($50\text{m} \times 50\text{m} = 2500 \text{ m}^2 = 0.25 \text{ Hectare}$). This gives us yearly total amount of the given area from all pixels in ton/year. The following equation summarizes what have been done:

$$\text{Total annual loss from a given area} = \text{total loss rate of all pixels in the area} \times \text{Pixel area in hectare} \dots \text{Eqn 7}$$

Table (10) shows the maximum potential amount of annual soil loss (in ton) from sheet water erosion and transported to depositional areas of the Lake Awassa catchment. Sediment transported from east and southeastern parts of the catchment deposited on the swamp and in Lake Cheleleka. Only little sediment, small in particle size, can be transported from the swamp with water through Tikurwuha River towards Lake Awassa. This is because that the swamp is acting like a filtering area and traps almost all of the sediment. The total sediment caused by sheet erosion and transported by water from the north, west, and southwestern sides towards the lake Awassa and its vicinity is estimated to be 63.6% of the total erodible soil and the rest, 36.4 %, is deposited on the swampy area and in Lake Cheleleka.

Lake Cheleleka shows tremendous lake surface and depth decrease during the last decades. Figure 34, 35 that are a color composition of the swamp area for 1973, 1993 and 2000, indicate that the vegetation growth shows progressive increment to the center of the lake. This is an evidence for the occurrence of sediment deposition in the swampy areas.

Flow Direction	Sediment (ton/year)	Percentage
Lake Awassa and Surrounding floodplain	950122.3	63.6
Lake Cheleleka Swampy	544646.8	36.4
Total	1494769.0	100.00

Table 10: Potential Sediment transported towards Lake Awassa and Cheleleka Swamp in 2004

Further analysis has been done to see the distribution of magnitude of potential Sediment sources in the two regions. Area covered by potential annual soil loss rate greater than 50 and 100 t.h⁻¹.y⁻¹ in the two regions is analyzed independently (Table 11 and Table 12). The result indicate that 30.9 % and 69.1 % of the total region covered by potential annual soil loss rate greater than 50 t.h⁻¹.y⁻¹ is bounded in area where flow directed to Lake Cheleleka and swamp, and Lake Awassa and its surrounding, respectively. Similarly, 27.4 % and 72.6 % of areas having potential annual soil loss greater than 100 t.h⁻¹.y⁻¹ enclosed in the region where flow directed to Lake Cheleleka and swamp, and Lake Awassa and its surrounding, respectively. This indicates that the potential soil loss from north, west and southwestern is higher both in its quantity and in magnitude of potential soil loss rate.

Subwatershed	Area Covered by > 50 t.h⁻¹.y⁻¹ (Hectare)	% coverage From > 50 t.h⁻¹.y⁻¹
Lake Cheleleka and Swampy Area	2409.2	30.9
Lake Awassa	5394.4	69.1
Total	7803.6	100.00

Table 11: Distribution of Potential annual soil loss > 50 t.h⁻¹.y⁻¹

Subwatershed	Area Covered by > 100 t.h⁻¹.y⁻¹ (Hectare)	% coverage From >100 t.h⁻¹.y⁻¹
Lake Cheleleka and Swampy Area	801.1	27.4
Lake Awassa	2118.2	72.6
Total	2919.3	100.00

Table 12: Distribution of Potential annual soil loss > 100 t.h⁻¹.y⁻¹

7.3 Annual Soil loss rate and land cover change Scenario

To see the impact of the land use system on the amount potential of annual soil loss rate, parameters such as erosivity, Soil erodibility, slope and slope length factors have taken as constant and Land cover factor have been modified based on Land cover map 1965 with some adjustment in conservation practice factor (P) of agricultural fields, USLE model applied.

The analyzed result compared with that of 2004 and the result based on the area covered by flow direction towards Lake Awassa and Lake Cheleleka and their vicinity is indicated in Figure 56.

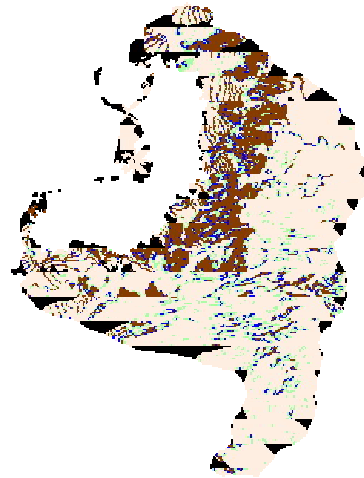


Figure 56: Annual soil loss rate and flow pattern of 1965, flow to Lake Awassa and its surrounding (left) and flow to Lake Cheleleka and its vicinity

Flow Direction	Sediment (ton/year)	Percentage
Lake Awassa and Surrounding floodplain	406453.2	48.1
Lake Cheleleka Swampy	439449.4	51.9
Total	845902.6	100.00

Table 13: Potential Sediment transported towards Lake Awassa and Cheleleka Swamp in 1965

Potential annual soil loss rate of the catchment in the year 1965 and 2004 is compared by taking the flow direction as a base. The total of this two years potential annual soil loss rate has a remarkable change.

Figures 55 and 56 or Table 10 and 13 illustrate that the western area of the catchment has low sediment input in 1965 land use land cover condition ($406453.2 \text{ t.y}^{-1}$, which covers 48.1 % of the total sediment potential) as compared to 2004's condition ($950122.3 \text{ t.y}^{-1}$, which covers 63.6 %). The increment from 1965 to 2004 potential annual soil loss condition is 133.8 %. This is because that the land cover change of this side of the lake is higher. Areas, in 1965, identified as Open Bushy woodland and dense woodland of this side of the lake area currently, in 2004, identified as cultivated land and bare land.

Eastern and southeastern side of the catchment which shows a surface water flow towards lake Cheleleka and its swamp vicinity also shows some change in Landuse cover. The change may not be significant as compared to the western side where almost all of the land is currently delimited as cultivated land. Here, dense bushy woodland, dense bushy woodland and open grassland cover of 1965 is currently changed to open bushy woodland and cultivated land cover type. Potential annual soil loss of 1965 towards the flat land is $439449.4 \text{ t.y}^{-1}$, which covers 52.0 % of the total catchment, and with land cover change explained above, the potential annual soil loss in 2004 increased to $544646.8 \text{ t.y}^{-1}$ (36.5 % of the total catchment). This indicates in 2004, the potential annual soil loss from eastern and southeastern side shows 23.9 % increment from its 1965 condition.

As previously discussed, the eastern side of the catchment has a higher soil loss rate due to slope length factor that is dominated by long steep escarps landscape. Human, at least not in large scale, could not modify the Slope length factor. However, the demand of more agricultural fields and firewood aggravate the land cover change.

To see the impact of the continuation of land cover change to cultivated land forecasting have been done by running the USLE model. The result shows that if the current land covers condition, open woodland and cultivated land, totally changed to cultivated land with out any

change in conservation management practices, the annual soil loss from the upland to the swamp area would be 3000532.0 ton/year. This will produce a tremendous sediment input and the change from the current situation could be 450.9 %, which is 4.5 times that of 2004 condition. As a result of this, there will be an increase of surface runoff from the eastern part to the lake and enhance flooding and sedimentation problem.

7.4 Lake Awassa Water Level and Sedimentation

Related to land degradation problem Awassa lake level rise due to siltation is a crucial impact pointed out by different researcher. As previously explained the sediment from eastern parts of the catchment is deposited on swamp and in lake Cheleleka. Because of this, the sediment regulation is taken by the swamp and amount of sediment traveled to the lake Awassa through Tikurwuha River is almost negligible. Annual sediment loss from the upland of the rest of the catchment is analyzed to estimate the lake level rise due to annual sediment input to the lake.

In 2004, the amount of potential sediment from upland area towards directly to the lake is estimated to be 950122.3 ton/year. The lake surface area from the Landuse land cover map of this year is 92.86 km². The Assumptions to evaluate the impact of sediment input on lake level rise are:

- the depth of the lake is to be constant (average depth),
- the distribution of sediment through the lake surface is uniform, and
- density of sediment entered to the lake is the average of the surrounding soils density (clay loam (1.05 g/cm³), fine sand (1.55 g/cm³), fine sandy loam (1.3 g/cm³), and silty loam(1.15 g/cm³)).

The water level rise due to this sediment input is estimated as follow:

$$\Delta V = V2 - V1 = (A (h + x)) - Ah = Ax \dots\dots\dots\text{Eqn 8}$$

- Where,
- V2-volume after sediment entry
 - V1- Volume before sediment entry
 - ΔV – Change of volume
 - A – Lake surface area
 - h – Average depth
 - X – Water level increase due to sediment entry

$$\Delta V = m/d \dots \dots \dots \text{Eqn 9}$$

where, m - mass of sediment entered to the lake
 d - Density of sediment

Substituting Eqn 9 to Eqn 8 and evaluating for x gives us:

$$\begin{aligned} X &= \Delta V / A = (m/d)/A = ((950122.3 \text{ ton} \times 1000 \text{ kg/ton}) / 1140 \text{ kg/m}^3) / 92.86 \text{ km}^2 \times 10^6 \text{ m}^2/\text{km}^2 \\ &= 0.008975235\text{m} \\ &= 0.9 \text{ cm} \\ &= 9 \text{ mm} \end{aligned}$$

Therefore, the annual sediment input of 2004 from sheet and rill erosion may cause a water level rise of 0.9 cm per year. If we assumed that the processes was retained constantly to the last 10 years, the water level rise due to sediment input would be 9cm. this shows the water level rise from siltation is remarkable. The same procedure have been applied for 1965 condition when the lake surface area was 80 km² before 1972 as interpreted from area photography and the potential annual soil loss was 406453.2 ton/year. The impact of input of sediment from upland sheet and rill erosion on Lake Awassa water level, in the specified year, is estimated to be 0.5 cm/year. This indicates the lake level rise is showing an increase following activated erosion activity.

Reducing the amount of sediment entering to the lake is achieved through detail watershed management through appropriate soil and water conservation. Figure 57 shows some of kebeles in Awassa, Shebedino and Boricha Weredas enclosed in areas where soil loss having more than 50 t¹.h⁻¹.y⁻¹.

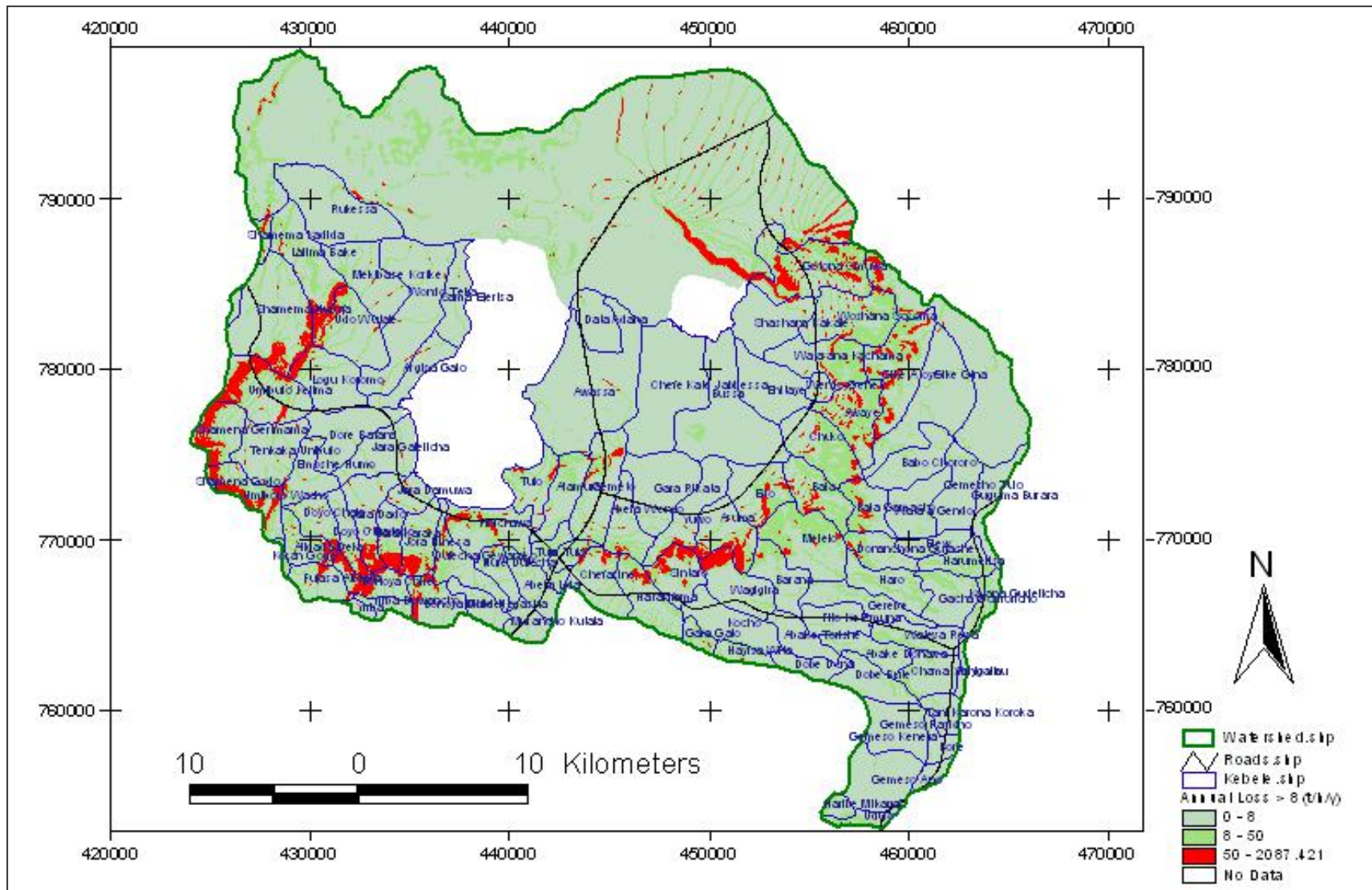


Figure 57: Peasant association encompasses in highly degraded ($> 50 \text{ t.h}^{-1}.\text{y}^{-1}$) area and need immediate remedies to reverse the level of land degradation

8 Conclusions and Recommendations

8.1.1 Conclusions

In the previous topics, data collection, analysis and interpretation have been discussed and based on these works the following conclusion can be formulated.

At present, Lake Awassa catchment is exposed for land degradation problems that are mainly caused by water erosion. The level of land degradation differs depending on spatially distributed major parameters (climate, topography, soil, land cover, and soil conservation practices).

The land cover and soil conservation practices are human induced parameters and play a major role in enhancing or reducing level of land degradation. Population increase and extensive agricultural activities rise demand of agriculture land in the area, as a result natural vegetation covers are modified to intensive agricultural fields and bare lands. This intensifies the level of degradation from its natural stage. As analysis of statistical data about conservation practices indicates there is no major soil conservation practices run in 'weredas' enclosed in the study area.

The surface water flow in the catchment either directly end up to L. Awassa (from northern, western, and southwestern sides) or to L. Cheleleka and its swamp vicinity (from the northeastern, eastern and southeastern sides). In 2004, the potential soil loss from up land of the catchment towards L. Awassa is estimated to cover 63.6% (950122.2 ton/year) and towards L. Cheleleka is 36.4 % (544646.8 ton/year). As we compare these results with 1965's land cover condition when most of the natural cover were preserved, the potential soil loss from up land of the catchment towards L. Awassa is estimated to be 48.1 % (406453.2 ton/year) and towards L. Cheleleka is 52 % (439449.3 ton/year). The land cover change and inapplicability of soil conservation are responsible for intensify of the level of potential annual soil loss. In eastern side of the catchment, is relatively covered by green vegetation, the annual soil loss rate is caused because of high rainfall, presence of long and steep slopes, and

inapplicability of soil conservation practices on agriculture fields. The western side where the rainfall budget is minimum as compare to the eastern region of the catchment, the degradation level is high due to absence of vegetation cover, inapplicability of soil conservation on agricultural fields and the presence of bare lands, gullies and ground cracks related to neo-tectonic activities.

The continuation of land cover change, especially in the eastern side where deforestation of natural vegetation cover is currently going on, further facilitate the level of degradation and it may change the potential amount of annual soil loss towards L. Cheleleka and the swamp area.

As previously mentioned and shown, the capability of GIS and remote sensing technique in data acquisition, data analysis, interpretation, and result presentation play a vital role in studying the level and distribution of land degradation problems.

8.1.2 Recommendations

To control the land degradation rate, some remedial measures should be launched depending on factors that are modifiable in nature. Rainfall erosivity and Soil erodibility may not be modified by man. Slope and slope length can be modified through soil conservation practice at a small scale of agricultural lands and this needs detailed field assessment. This method is vital on agricultural lands where the slope and slope length factor is dominant, i.e. the eastern side of the catchment. Change of landcover, especially revegetation of the western side of catchment is important to minimize the degradation. This may reduce the rate of yearly degradation level to 1/10th of the existing situation. This is because the land cover factor is the dominant factor that enhance the degradation from this side. Neo-tectonic activities seem to play a significant role in triggering gully erosion in the area. This needs further assessment as it was beyond the scope of this thesis.

Reference

- Angela, L. Lamba, Melanie J. Lengb, Henry F. Lambc, Richard J. Telford, Mohammed Umer Mohammede, (2002). Climatic and non-climatic effects on the $\sigma^{18}\text{O}$ and $\sigma^{13}\text{C}$ compositions of Lake Awassa, Ethiopia, during the last 6.5 ka
- Aronoff, S. (1989). Geographic information systems: A management perspective: WDL Publishers, Ottawa, 290 pp.
- B. Temesgen I, M. U. Mohammed and T. Korme, 2000. Natural Hazard Assessment Using GIS and Remote Sensing Methods, with Particular Reference to the Landslides in the Wondogenet Area, Ethiopia: Elsevier Vol. 26, No. 9, pp. 665-615, 2001
- Bojo, J. & D. Cassells. 1995. Land Degradation & Rehabilitation in Ethiopia. A Reassessment. World Bank.
- Erlich, P.R., 1988. The loss of diversity: Causes and consequences In: Wilson. E.O., Peter, F.M (Eds.). Biodiversity. National Academic Press, Washington. DC. pp 21-27
- Eswaran H., R. Lal and P.F. Reich 2001. Land degradation: an overview Published in: New Delhi. Oxford Press.
- FAO, 2000. Manual on integrated soil management and conservation practices. FAO Land and Water Bulletin 8: Rome
- FAO/UNDP, (1984): Geomorphology and Soil maps, Assistance to Land-Use Planning: AGDA ETH/78/003, Field Document 3, Addis Ababa,
- Garberecht J. and L. W. Martz, 2000: Digital Elevation Model Issue in Water Resources Modeling. In. D. Maidment and D. Djokic Hydrologic and Hydraulic, 2000. Hydrologic and hydraulic. Modeling Support. Pp 1-27.
- Gebre Kirstos Teklehaimanot, 2003. Use of simple field tests and revised MMF model for assessing soil erosion :(Case study Lom Kao Area, Thailand). Master Thesis, ITC
- Goodchild, M.F., Steyaert, L.T., Parks, B.O., Crane, M.P., Johnston, C.A., Maidment, D.R., and Glendinning, S., eds. (1996). GIS and Environmental Modeling. Progress and Research Issues. Fort Collins: GIS World, Inc.
- Hellden, U. (1987). An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia—A feasibility study on the use of remote sensing and GIS-analysis for planning purposes in developing countries (Lund: Lund University Press).

- Helena Mitasova, Lubos Mitas, William M. Brown, Douglas M. Johnston, 1993 – 1998: Multidimensional soil erosion/deposition modeling and visualization using GIS, Final Report, U.S. Army Construction Engineering Research Laboratories
- Hurni, H. (1985). Soil conservation manual for Ethiopia, First draft. Ministry of Agriculture, Natural Resources Conservation and Development Department Community Forests and Soil Conservation Development Department. Addis Abeba.
- Jurg, krauer, (1988). Soil conservation Research project Rainfall, Erosivity & Isoerodent Map of Ethiopia. MOA, 132pp
- Kang-tsung, Chang (2001). Introduction to Geographic Information System: Tata McGraw-Hill Edition
- Keyzer, M.A. & B. G. J. S. Sonneveld. 2001: The Effect of Soil Degradation on Agricultural Productivity in Ethiopia: a Non-Paramatic Regional Analysis in Economic Policy Reforms & Sustainable Land Use in LDC's. (Heerink, H. Van Keuken & M. Kurpios - Eds.) Physica Verlag pp 269-292.
- Leonard, Berry 2003. Land Degradation in Ethiopia: Its Extent and Impact GM and WB
- Lillesand, T.M. and R.W. Kiefer. (2000). Remote Sensing and image interpretation: John Wiley & Sons, New York.
- M. Raunet, 1974. Morpho-Pedological Reconnaissance survey in the Awassa area. Soil survey of Awassa Farm, IRAT
- Meijerink A.M.J., Brouwer H.A.,M Mannaerts C.M, and Valenzuela C. 1994: Introduction to The Use of Geography Information Systems for Practical Hydrology. ITC
- Morgan, R. P. C. (1995). Soil Erosion & Conservation. 2nd Edition, Silsoe College, Cranfield University, Longman Group, Essex, England.
- R.P. Tripathi and H.P.Singh (1998) Soil Erosion and Conservation 303pp
- Renard, K.G. and V.A. Ferreira. 1993. RUSLE model description and database sensitivity. J. Environ. Qual. 22(3):458-466.
- Peter A. Burrough and Rachael A. McDonnell, 2000. Principle of Geographical Informtion Systems. Oxford University Press Inc, Newyork
- Sonneveld, B. G. J. S. & M. A. Keyzer. 2002. Land Under Pressure; Soil Conservation Concerns and Opportunities for Ethiopia in Land Degradation & Development. Wiley InterScience.

www.interscience.wiley.com.

- Stan Arnoff, 1989. *Geographic Information Systems: A Management Perspective* . WDL Publication. Ottawa, Canada
- Steegeen, A., Govers, G., Takken, I., Nachtergaele, J., Poesen, J., Merckx, R., 2001. Factors controlling sediment and phosphorus export from two Belgian agricultural catchments. *Journal of Environmental Quality*, 30(4): 1249-1258.
- Sutcliffe, J.P. 1993: *Economic Assessment of Land Degradation in the Ethiopia Highlands*. Addis Ababa, Natural Conservation Strategy Secretariat Ministry of Planning and Economic Development
- Tadesse and Zenaw. 2003. *Hydrogeology and Engineering Geology of Awassa Lake Catchment*. Geological survey of Ethiopia, Addis Ababa.
- Telford, R.J., 1998. *The palaeoenvironmental record of Holocene environmental change in the Ethiopian Rift Valley*. Unpublished Ph.D. Thesis, University of Wales.
- Tor Bernhardsen, 1999. *Geographic Information Systems: An Introduction*. 2nd edition. JohnWiley & Sons, Inc
- W.W.D.S.E. 2001. *The study of Lake Awassa level, lake Awassa study and design project*. Water. Works Design and Supervision Enterprise, Addis Ababa.
- Wilbur W. Frye (1987). In: *The Effect of Soil Erosion on crop productivity* , John M. Harlin and Gigi M. Berardi 1st edn, Westview Press, Colorado, pp. 151-172
- Wischmeier, W.H. and D.D. Smith. 1978. *Predicting rainfall erosion losses: A guide to conservation planning*. Agriculture Handbook No. 537, US Dept. of Agric., Washington, DC.
- Zemenu Geremew, 2000. *Engineering Geological Study of Awassa town and its surroundings*. Master Thesis, Addis Ababa University. 147pp