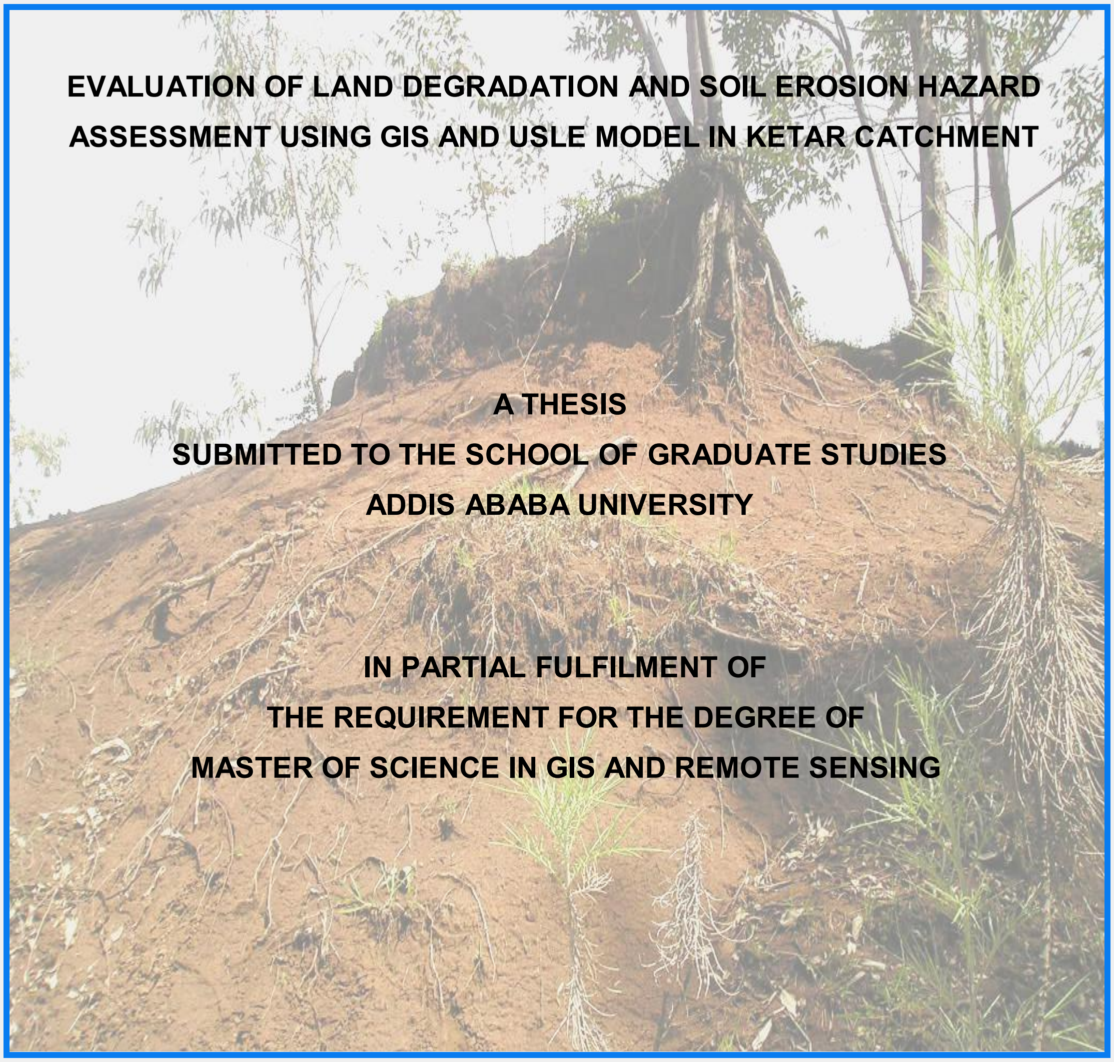

EVALUATION OF LAND DEGRADATION AND SOIL EROSION HAZARD ASSESSMENT USING GIS AND USLE MODEL IN KETAR CATCHMENT

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DECLARATION

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

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CHAPTER THREE

GENERAL DESCRIPTION OF THE STUDY AREA

CHAPTER FOUR

SOIL LOSS ESTIMATION USING USLE MODEL

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATION

Abstract

Land degradation and soil erosion are major problems of Ethiopian highlands. It is estimated that 1.5 billion tones of soil is being eroded every year in Ethiopia. In some parts of the highlands the erosion rate reaches up to 300 t/ha/yr, which is beyond tolerable condition.

This study is intended to assess the spatial distribution of soil erosion risk in Ketar catchment, part of Ziway–Shala basin using GIS and the Universal Soil Loss Equation (USLE). In addition to this, the distribution of gullies and population in each weredas, and livestock data in the zone were compared with the resulting soil erosion map.

A set of the six factors necessary for the USLE model were studied and generated. These include Rainfall Erosivity factor (R), Soil Erodibility factor (K), Slope Gradient factor (S), Slope Length factor (L), Crop and Management factor (C) and Conservation Practice factor (P). Each parameter, which consists of a set of logically related geographic features and attributes, is used as input data for the model analysis.

The analysis of 4 years mean annual rainfall of 9 metrological stations give the R-factor. K-factor was assigned for the soil types in the area obtained from the soil map of ETHIOGIS data sets and other soil map of the area. Digital Elevation Model (DEM), derived from topographic contours, was used to generate the slope map and, from the slope map S-factor and L-factor were generated. Land use/land cover, extracted from Landsat ETM+ with field checking, was used to determine the C-factor and P-factor values.

Each of the above analyzed USLE factors, were rasterized to create six grid layers. Multiplication overlay on these six layers produces the resultant soil erosion (loss) map; each cell of the input grid layers has equal area (100m x 100m).

The USLE model calculation applied on the six input grid maps gave values of the soil erosion (loss) map in t/ha/yr. Values of the out put map were again grouped in to 6 erosion classes of < 4.71, 4.71-9.42, 9.42-28.56, 28.56-51.83,51.83-98.94 and > 98.94 t/ha/yr. High erosion classes concentrate in area where the slope gradient and length factors are high. The resulting map also showed that 96.81% of the area has a soil erosion rate of less than 9.42 t/ha/yr, which is less than the rate of soil formation. This value shows that much of the area is currently in tolerable condition. The field checking of the study area revealed that gully formation is in early stage.

To evaluate the effects of population and livestock growth on the rate of erosion, both data were checked relative to the erosion map, woreda and zone levels respectively. The result confirmed that both data are increasing, which have great impact on the rate of soil erosion. So some measures and strategies should be designed to reduce their effects on the soil erosion rate. Finally, this study showed that, the effectiveness of the application of GIS and remote sensing in modeling soil erosion.

Key words: Ketar, DEM, GIS, Land degradation, Soil loss (erosion), USLE

Land degradation and erosion hazard induced by water erosion, human and physical factors, particularly the denudation of vegetation by human and domestic animals, and the infrequent and irregular distribution of precipitation are becoming a major problem worldwide. The effects are seen more in developing countries than in the developed countries because of the high population growth rate and the associated rapid depletion of natural resources (Feoli et al., 2000).

Severe land degradation affects a significant portion of the earth's arable lands, decreasing the wealth and economic development of nations. The link between a degraded environment and poverty is direct and intimate. Estimation by Brown et al. (1999) showed that the world could be losing 14 million tons of grain outputs because of environmental degradation. Land degradation affects crop, livestock, and forest productions. As the land resource becomes less productive, food security becomes in danger and competition for diminishing resources increases, species diversity will be lessened and often lost as lands are cleared and converted to agriculture. Thus a downward eco-social spiral is created when marginal lands are nutrient depleted by unsustainable land management practices resulting in loss of soil stability leading to permanent damage. These issues are of great public concern and there by demand the attention of governments and researchers. As Kaen (1999) reported that economic impact of land degradation is extremely severe in densely populated and developing countries of South Asia, and sub–Saharan Africa.

Ethiopia being a developing and agricultural country, whose economy is mainly based on renewable resources in most areas, is important to have a good understanding of the relationships between the environmental variables and human agricultural activities. So identifying the spatial extent of these variables and activities is a necessary step in the process of Land Degradation and erosion hazard assessment, and definition of control strategies. That is formulation of effective soil conservation plans for sustainable development. According to Bobe (2004) Ethiopia has a total surface area of 111.8 million hectares: of which 60 million hectares are estimated to be agriculturally productive. Out of these lands, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return with an estimated total loss of 2 billion m^3 of topsoil per year. Another report by the Soil Conservation Research Project (SCRP, 1985) of Ethiopia indicated that the rate of soil loss in extreme cases ranges from 0 to 300 t $ha^{-1}yr^{-1}$ with an average loss of 70 t $ha^{-1}yr^{-1}$, which is beyond the concept of any tolerable soil loss (See table 1.1 for soil loss in some parts of the country). This project also estimated that about 1.5 billion tones of soil are eroded away every year in Ethiopia.

Table 1.1 Soil erosion loss on 6 SCRP sites in various parts of Ethiopia

Site	(Tons/ha/year)
Sidamo	41.2–49.5
Harar	25.5–27.8
North Showa	152.4–214.8
Gojam	40.2–199.2
Illubabur	18.0–135.3
South Wollo	36.5–53.8

The unsustainable agricultural practices along with many other physical, socio-economic and political factors have been the driving forces to a series of land degradation problems in the country. According to some studies, for instance El-Swaify and Hurni (1996) the highlands of Ethiopia are considered to be amongst the most degraded lands in Africa.

Another study by Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2000) indicated that in the Amhara Region 82% of the region has a soil erosion rate of less than 12.5 tons/ha/year while 18% suffers a soil loss of 12.5 - 200 t $ha^{-1}yr^{-1}$. In Oromia 99% of the region has a soil erosion rate of less than 10 t $ha^{-1}yr^{-1}$. The WBISPP estimates are in contrast with the earlier exaggerated estimates of SCRP. The WBISPP used the Universal Soil Loss Equation (USLE) adopted for Ethiopia, which considered erosivity of rainfall, erodibilty of soil; slope gradient, slope length and land cover.

Satellite Remote Sensing (SRS) and Geographic Information Systems (GIS) are widely used for land degradation studies, such as in predicting amount of soil erosion and nutrient depletion. Using these two techniques, sustainable soil management system can be developed to reduce further degradation and restore productivity of the eroded land. Geographic Information System (GIS) is a system for spatial data management and analysis. Spatial data consist of a spatial geometry as well as the characteristics or attributes of the objects being managed or analysed. It is also designed with intrinsic capabilities for georeferencing and making relational associations of data with physical processes (Allard et al., 1994). It could also be used in identifying areas that are at potential risk of extensive soil erosion, and to provide information on the estimated value of soil loss at various locations. There is considerable potential for the use of GIS technology as an aid to soil erosion hazard assessment. Soil erosion hazard is most frequently assessed using Universal Soil Loss Equation (USLE).

Recently, several studies showed the potential utility of GIS technique for quantitatively assessing soil erosion hazard based on USLE. It can also provide answers to spatial queries; for instance whether the erosion is associated with specific factors such as the loss of continuous vegetation cover (Mohammad et al., 2004).

Figure 1.1 Farming on Steep-Slope without Any Conservation Mechanism in the Study Area

Therefore GIS is an important instrument for observing and inferring data links and evaluating the response of environments to human impacts.

In the study area, which is part of Ethiopia highlands, soil degradation is at an alarming rate due to erosion by water and intensive agricultural activities on steep slopes without any conservation mechanisms. Fig.1.1 shows cultivation on steep slope in the study area. This soil erosion is currently a major problem to the local farmers manifesting itself in the form of decreasing productivity of arable lands from time to time. The farmers are also becoming unable to produce the required amount of production to support and feed their families. So, it is very important to assess the rate of erosion (the spatial distribution of soil loss in the catchment) and develop soil erosion (loss) map in the area before formulation of any soil and water conservation strategies, which are crucial for a sustainable food production.

To assess the spatial extent of this soil erosion by water, prominent form of land degradation in the area and generate soil erosion map, GIS techniques and the empirical soil loss model, Universal Soil Loss Equation (USLE) are applied.

1.2. Objectives

1.2.1. General objectives

- To assess spatial soil erosion hazard and land degradation based on GIS Model, Universal soil loss equation (USLE)
- To produce soil erosion hazard map for the study area

1.2. 2. Specific objectives

- To prepare and see the effect of each USLE parameter in the area.
- To study distribution of human and livestock population impact on soil erosion and Land degradation in the study area.
- To suggest prevention or minimizing mechanisms for soil erosion based on the human activities and land use.

many factors, e.g. population pressure, poverty, high cost and limited access to agricultural inputs and credit, low profitability of agricultural production and many conservation practices, high risks facing farmers, fragmented land holdings and insecure land tenure, short time horizons of farmers, and farmers' lack of information about appropriate alternative technologies.

Affecting many of these factors are government policies relating to infrastructure development, market development, input and credit supplies, land tenure, agricultural research and extension, conservation programmes, land use regulation, and local governance and collective action. Land degradation in Ethiopia is usually expressed in terms of soil erosion and soil fertility loss, reflecting the importance and linkage of land degradation to agriculture.

A study by Ethiopian Highlands Reclamation Study (EHRS) showed that about 80% of the soil erosion in the Ethiopian highlands was estimated to occur on croplands and the remainder on overgrazed grasslands, wastelands and newly deforested areas. The annual loss from cultivated land in the Ethiopian highlands was estimated to be 130 tons/ha, and this was expected to result in a loss of 7.6 million ha of cropland to productive use in Ethiopia by the year 2010. Different researches showed that (Bobe, 2003; FAO, 1986; Hurni, 1988; Shibru, 1997) the major cause of land degradation in Ethiopia is soil erosion, which is occurring at an alarming rate warranting for the formulation of appropriate technical packages, land use policy, and legislation that would lead to a more effective farmer participation in conservation and rehabilitation activities.

2.1.1. Soil Erosion

Land degradation due to water erosion is a serious threat to the quality of the soil, land, and water resources upon which man depends for his sustenance. Soil erosion is defined as the detachment and transportation of soil from land surface. It is naturally occurring process on all land. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss worldwide.

A study by Bobe (2003) indicated that water erosion had accounted for about 55% of the 2 billion ha of the degraded soils in the world. There is no region of the globe where water erosion is not a threat to the long-term sustainability of mankind. Accelerated soil erosion is the one influenced by man through overgrazing, cultivation on steep land without conservation measures, road construction, monocultures, etc. It is distinguished from much slower process of geological erosion. Another researcher, Teklehaimanot (2003) suggested the necessity of comparing soil erosion with other processes of landscape denudation in such a way that; soil erosion should be recognized as the dominant problem only when and where it is rapid.

Two major types of erosion can be distinguished that is geological erosion and accelerated erosion. The erosion resulting from the natural causes is called geological or natural erosion without the influence of man and it is in equilibrium between soil formation and erosion. Breaking the annual equilibrium, mostly due to agriculture will create accelerated soil erosion, which is more aggressive than geological erosion (Hudson, 1996).

Soil erosion by water is the principal cause of land degradation, and it is a major constraint to agricultural development in many countries. One important feature of soil erosion by water is the selective removal of the finer and more fertile fraction of the soil. Khon (1999) suggested that soil and water conservation measures have to be adopted not only to reduce on–site soil, water, and nutrient losses, but also to diminish negative downstream effects, such as flooding and the silting up of reservoirs. According to a study by Nyssen et al. (2003) the most important soil degradation processes in the Ethiopian highlands are loss of topsoil due to water erosion and water induced terrain deformation (mass movement).

Water erosion process can be described as detachment of soil particles from the surface due to raindrop impact (splash erosion) and the entrainment by runoff. The soil erosion processes caused by water are frequently lumped into sheet (inter rill erosion), rill, gully, and stream channel erosion. Sheet (inter rill) erosion is the detachment and transport of soil by raindrop impact and shallow overland flow (Ringo, 1999). Here no perceptible channels are formed. It is a uniform thin layer removal of soil (soil surface layer), almost imperceptible layer. Rill erosion (fig. 2.1) is the removal of soil by runoff from the land surface where by numerous small channels are formed across a landscape.

Figure 2.1 Rill Erosion in the study area

The shearing power of the water can detach, pick up and remove soil particles making these channels the preferred routes for sediment transport. As Foster (1988) described rills are small channels cut by concentrated runoff/flow, through which water flows during and immediately after rain. Rill erosion is probably the most important form of soil loss in cultivated fields because in the absence of these channels, which serve the purpose of transporting detached materials, inter rill erosion will be negligible. Hence, assessment of soil loss by surveying rill erosion gives a good understanding of the process of land degradation due to erosion. Soil erosion that occurs in areas between rills by the action of raindrops (causing splash erosion) and surface runoff (causing sheet erosion) is called interrill erosion.

In rill erosion, soil detachment can be by splash or by the overland flow i.e. scouring. When the force of overland flow is high incision (deeper rills) will occur. They are distinguished in size from gullies by the fact that they are largely obliterated by tillage operation. That is rills differ from gullies in that they are temporary features and can be easily destroyed during ploughing, whereas gullies are more permanent features in the landscape. These two types of erosion, account for the major impact of soil erosion on land productivity. Gully erosion is a complex of processes where by the removal of soil is characterized by large channels that cannot be obliterated by normal tillage operations.

There are three basic processes in erosion by water, namely, detachment, transport, and deposition. Detachment occurs when the erosive forces of raindrop impact and surface runoff exceed the soils' resistance to erosion. Transport of detached particles is by raindrop splash and flow. Deposition occurs when the sediment load of a given particle type exceeds its corresponding transport capacity. The relative importance of these fundamental processes depends on whether the processes are leading to inter rill or rill erosion occurrence and on the levels of the controlling variables, such as the slope steepness and length, soil surface cover, amount of and intensity of rainfall, and conservation practice. On inter rill areas, erosion is essentially independent of erosion in the rills; but erosion in the rills depends greatly on runoff and sediment inputs from the inert rill areas. Deposition occurs if sediment inflow from the inter rill areas exceeds the transport capacity of flow in the rills. If the sediment inflow is less than the transport capacity of flow, and if the flows erosive forces exceed the resistance of the soil to detachment, rill occurs.

Down slope movement of sediment is mainly by flow in the rills. Even though, excess transport capacity may exist on the inter rill areas, this transport capacity does not add to the transport capacity of flow in the rills. Conversely, excess transport capacity in the rills is available to transport sediment detached by raindrop impact on the inter rill areas (Haan et al, 1982).

2.1.1.1. Factors affecting water erosion

Several factors influence soil erosion; which include climate, soil, topography, vegetation and management practices. In medium and small-scale farmlands, inter rill (sheet) and rill erosion is the most common problem. Continuous waterways such as drainage channels, irrigation channels will result in gully formation. Erosion is controlled by many factors as described below:

2.1.1.1.1. Rainfall Intensity and Runoff

The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Ability of rain to cause erosion is defined as erosivity and it is a function of rainfall. According to Morgan (1995) soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills for which intensity is generally considered to be the most important rainfall
Characteristics. The amount and peak intensity are two main important characteristics of a rainstorm that influence its potential ability of causing erosion. Volume and peak rate of runoff are measures of runoff erosivity (Foster, 1988). That is soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms.

2.1.1.1.2. Topography

Soil erosion by water is a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. Naturally, the steeper the slope of a field, the greater the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment).

As Stern (1990) put when the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport. Runoff velocity and effective depth of interaction between surface soil and runoff increases with increase in slope. Some researchers, for instance (Bobe, 2004) indicated that soil erosion increases exponentially with increase in slope gradient.

2.1.1.1.3. Soil

The erodibility of the soil refers to the resistance of the soil to both detachment and transport by the eroding agent. Hudson (1996) defines erodibility as the specific property of soil, which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances. Another researcher Imeson (1985) defines soil erodibility as the inherent susceptibility of a given soil to erosion by water, the response of soil to impacting raindrops and slope wash processes. It is the relative ease with which a soil erodes under specific conditions of slope as compared with other soils under the same conditions. The term soil erodibility is limited to inter rill and rill erosion. Generally soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. That is, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils.

Soil texture (particle size composition i.e. sand, silt, and clay), organic matter, structure, and permeability are major factors that effect soil erodibility (Foster, 1988). Wischemeier and Smith (1978) established a regression equation or nomograph for the parameters to estimate soil erodibility (K). Soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content. According to Mainam (1999) soil aggregate stability and infiltration rates can be affected by aggregate size and bulk density, soil texture and soil structure.

Teklehaimanot (2003) indicated that high aggregate densities generally are related with high clay content and increased aggregate strength. Laboratory studies by Morgan (1988) showed that medium and coarse particles are easily detached from the soil mass and that clay particles resist detachment. This may be due to the raindrop energy, which has to overcome the adhesive or chemical bonding forces by which the minerals comprising clay particles are linked. Soils high in silt and low in clay are highly erodible (Ringo, 1999). Wischemeier and Smith (1978) observed that erodibility decrease with a decrease in silt, regardless of whether the corresponding increases is in the sand or clay fraction. The high erodibility of silty soils is explained by their weak structural stability. They rapidly form surface sealing upon raindrop impact. Erosion is less on clayey soils due to their better aggregation. The large pores between sand particles permit rapid water movement hence reducing soil erosion. Fine sand (0.05-0.1mm diameter), however, behaves like silt and is therefore attributed to the silt fraction for soil erosion aspects (Wischmeier & Smith, 1978).

Soil organic matter (SOM) affects or influences soil loss by improving soil structure, root penetration, water holding capacity, and infiltration. Wischmeier & Smith (1978) observed that with increasing SOM, erodibility decreases. The role of SOM as a binding agent is more important on soils deficient of other structuring components, which implies that the importance of SOM decreases with the increase of clay content. Soil structure refers to soil aggregate stability. Soil aggregate stability is improved by: Clay content, organic matter content, $CaCO_3$ (calcium carbonate) or basic minerals (a cementing agent or binding agent), plant roots, water holding capacity, and infiltration capacity. A research by Ringo (1999) shows that erodibility decreases with increasing aggregate stability, as seal formation is delayed and infiltration increases. Large stable aggregate makes soil difficult to detach and transport, hence, it makes it more permeable to water.

2.1.1.1.4. 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). It 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. According to De Ploey (1983) sealing soils often generate more surface runoff, and therefore a greater hazard for rill erosion. Rainfall with a high cumulative energy causes sealing later, and to a smaller degree than lower cumulative rain energies. Soils breaking into smaller stable micro-structural elements give high splash losses and low rates of surface sealing, while soils that disintegrated into primary particles more readily seal and give rise to lower splash erosion rates (Ringo, 1999). Soil conditions, which induce sealing, are low content in organic matter, a clay fraction with reduced activity, high silt content, and dominance of fine and flat particles in the sand fraction.

Soil crust, as Bergsma et al., (1996) defined, is the hardening of the surface seal as the soil dries out and is a common phenomenon occurring in most cultivated soils. It can range in thickness from a few mm to as much as 3cm. Bobe, (2004) wrote that crust can be much more compact, hard and brittle when dry than the material immediately beneath it. He also put the relation between seal and crust as, 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. Crusts are characterized by increased soil surface strength and density that leads to reduced porosity due to change in pore size distribution and infiltration thereby leading to high runoff and erosion rate.

2.1.1.1.5. Vegetation Cover and Management

Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. The canopy intercepts raindrops, and if it is close to the ground, water dripping off the leaves has much less energy than unhindered raindrops (Wischmeier & Smith (1978). Materials in contact with the soil surface reduce erosion more effective than a canopy. No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy. Besides, such materials slow the runoff, which increases the flow depth. This increased flow depth decreases detachability by cushioning the impact of the raindrops. Cover in contact with the soil surface also absorbs much of the flow's eroding and transporting force, which greatly reduces erosion. Strips of dense mulch and grasses can induce deposition and filter sediment from the runoff. For instance Hurni (1985) estimates mean soil loss rates for different types of land use (Table 2.1) in Ethiopia.

Land cover	Area (%)	Soil Loss ($t\ ha^{-1}yr^{-1}$)
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 2.1 Estimated rate of soil loss for various land uses in Ethiopia (after Hurni, 1986) Source Nyssen et al. (2003)

2.2. Methods of Soil Erosion Assessment

Erosion occurs at widely varying rates over the landscapes, over a field, and even along a slope profile within a field. Hence to understand soil erosion over an area, it is necessary to assess soil erosion at different landforms. Soil erosion can be predicted by certain method that is reflected by a magnitude of soil loss or relative erosion rates for a given area. Estimation of soil loss rate has to be done in order to assess whether a defined landform has soil loss rate above or below the tolerance level. There are various ways of assessing soil erosion.

2.2.1. Soil Erodibility

The assessment of erodibility is very complicated because it depends on many variables. Furthermore, the traditional methods of assessing soil erodibility are invariably very expensive (Hudson, 1996). As an alternative to the expensive and time consuming traditional methods, simple field tests have been developed to estimate soil erodibility. As Bergsma et al. (1990) mentioned these simple field tests are the crumb test, pinhole field test, manipulation test, rainfall acceptance test, soil loss test, rilling test, and shear vane test of the surface soil. These tests are considered to provide a good index of the aspects of soil erodibility, and are meant to be used in surveys of the soil erodibility and soil erosion hazards.

2.2.2. Erosion Modeling

A model is a simplified representation of a complex system or models are of necessity simplifications of reality. Modeling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces. Erosion models can be used as predictive tools for assessing soil loss, conservation planning, soil erosion inventories and project planning. Moreover; they can be used as tools for understanding erosion processes and their impacts (Nearing et al., 1994).

Developing erosion prediction or modeling approaches are not new concepts. However, these technologies emerged after mainframe computers became readily available and interest in erosion was stimulated by concern for surface water quality in 1970s (Foster, 1988). Subsequently, like hand tools, many types of erosion assessment methods emerged: each is best at performing a particular task. Hence, no single prediction methods meet all needs (Foster, 1988).

Now a day's available model can be categorized in many ways. Understanding of the principles behind the development of erosion models and types of models may be useful to study the models behavior for different locations with variable parameters. Many types of water erosion models can be found in literature and can be categorized according to principles used in the development of model. Erosion models can be divided broadly into three categories that can be used to assess soil erosion, based on the development principle. These are empirical or statistical, conceptual and physically based or analytical component models (Bergsma et al., 1996; Morgan, 1995). Other researcher for instance (Leavesley, 1994 cited on Dagnachew et al., 2003) classified these three models as black box, gray box, and white box models respectively.

2.2.2.1. Empirical Models

These models describe the erosion primarily based on observations and are statistical in nature signifying relationships between assumed important variables where a reasonable database exists (Morgan, 1995). They are generally based on the assumption of stationeries that is, it is assumed that the underlying conditions remain unchanged for the duration of the study period (Bobe, 2004). These models relate input to out put through some transformation function. Among the commonly used empirical erosion models include: the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) and the Soil Loss Estimation Model for South Africa (SLEMSA).

2.2.2.2. Conceptual Models

These models are based on spatially lumped forms of water and sediment continuity equations. As explained by Merritt et al. (2003) these models are general description of catchment processes, without including the specific details of process interactions, which would require detail catchment information. Conceptual models play an intermediatory role between empirical and physically based models. The main feature that distinguishes the conceptual models from the empirical models is that the conceptual models, whilst they tend to be aggregated, they still reflect the hypothesis about the processes governing the system behaviour. The Agricultural Non-point Source Pollution Model (AGNPS), Agricultural Catchment Research Unit (ACRU), Hydrologic Simulation Program, Fortran (HSPF) are among the conceptual models used in erosion and/or water quality studies.

2.2.2.3. Physically Based or Analytical Component Models

Physically based models are based on solving fundamental physical equations describing stream flow and sediment and associated nutrient generations in a catchment (Merritt et al., 2003). According to Morgan (1995) these models are developed to predict the spatial distribution of runoff and sediment over the land surface during the individual storms in addition to total runoff and soil loss. The common physically based models used in water quality erosion studies include: The Areal Non-Point Source water Shed Environment response simulation (ANSWERS), Water Erosion Prediction Project (WEPP) and European Soil Erosion Model (EUROSEM).

A good model should satisfy the requirements of reliability, universal applicability, ease of use with a minimum data, comprehensiveness in terms of the factors and erosion processes included and the ability to take account of changes in land use and conservation practice (Morgan, 1995). The main criteria that were considered for selection of soil erosion models used in most studies are less input requirement, computational simplicity, wide applicability and relative validity in the study area. In this study the empirical model, particularly USLE model is considered due to its simplicity, easy applicability with minor amendments and less input data requirements.

2.3. Soil Loss Tolerance

Soil loss tolerance is the maximum rate of annual soil erosion that may occur and still permits a high level of crop productivity to be obtained economically and indefinitely (Wischmeier and Smith, 1978). In terms of (FAO, 1996), soil loss tolerance can be defined as soil loss balanced by soil formation through weathering of rocks. This can vary from 1 -12 t $ha^{-1}yr^{-1}$, according to climate, type of rock and soil depth. Soil loss tolerance limits define also the soil loss amounts that are tolerable to maintain, continuously and economically, the sustainability of the soil. Within these limits, soil erosion and soil formation processes are in equilibrium. Soil loss tolerance also depends on the soil type. This is described by Ringo (1999) as, on very deep and homogenous soils, the effects of erosion will be less pronounced than on shallow soils encountered on highlands of semiarid zones or highly weathered soils whose nutrient storage and availability depend largely on the organic matter of the surface layer. The determination of soil tolerance is intended to compare the expected soil loss with the soil loss tolerance. If the soil loss is less than or equal to the soil loss tolerance, the soil loss can be still accepted. However, if the soil loss is more than soil loss tolerance, measurement to reduce soil erosion should be taken into consideration until a level of equal or less than the soil loss tolerance has been reached. (Hudson, 1986) mentioned some important factors to be considered in determining soil loss tolerance. These are: thickness of topsoil, soil physical properties, decreasing organic matter and nutrient loss. The maximum soil loss tolerance for tropical regions is 25 t $ha^{-1}yr^{-1}$ and for temperate regions 13.7 t $ha^{-1}yr^{-1}$ (Ringo, 1999). Commonly used soil loss tolerance rate is 5 -12 t $ha^{-1}yr^{-1}$ for shallow to deep soil. However the current used rates for tolerable soil loss are far too high for fragile tropical soils with low levels of fertility (Lal et al., 1990). It is also indicated that tolerance value for tropical soils has not yet been formulated at international level (Ringo, 1999). Nevertheless, Hurni (1980) and Hudson (1986) established annual soil loss tolerance limits that vary between 0.2 and 11 t $ha^{-1}yr^{-1}$.

2.4. Materials and Methodology

2.4.1. Materials

The following materials are needed to accomplish the research:

- Land use/Land cover map of the study area
- Topographic map of the study area (1:50,000)
- Meteorological data of rainfall
- Existing soil map of the area
- Computer, digitising table, plotter and remote sensing and GIS softwares, Microsoft Excel, Microsoft Word

2.4.2. Methodologies

The methodology involves the application of a soil erosion model (USLE). The Soil Loss is calculated as follows:

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

Where A is annual soil loss (tons/ha/yr)

R is rainfall erosivity factor,

K is soil erodibility factor,

L is the slope-length factor

S is steepness factor,

C is cropping and management factor,

P is conservation supporting practice factor

Wischmeier and Smith (1978)

The various steps of the methodology adopted in this study are:

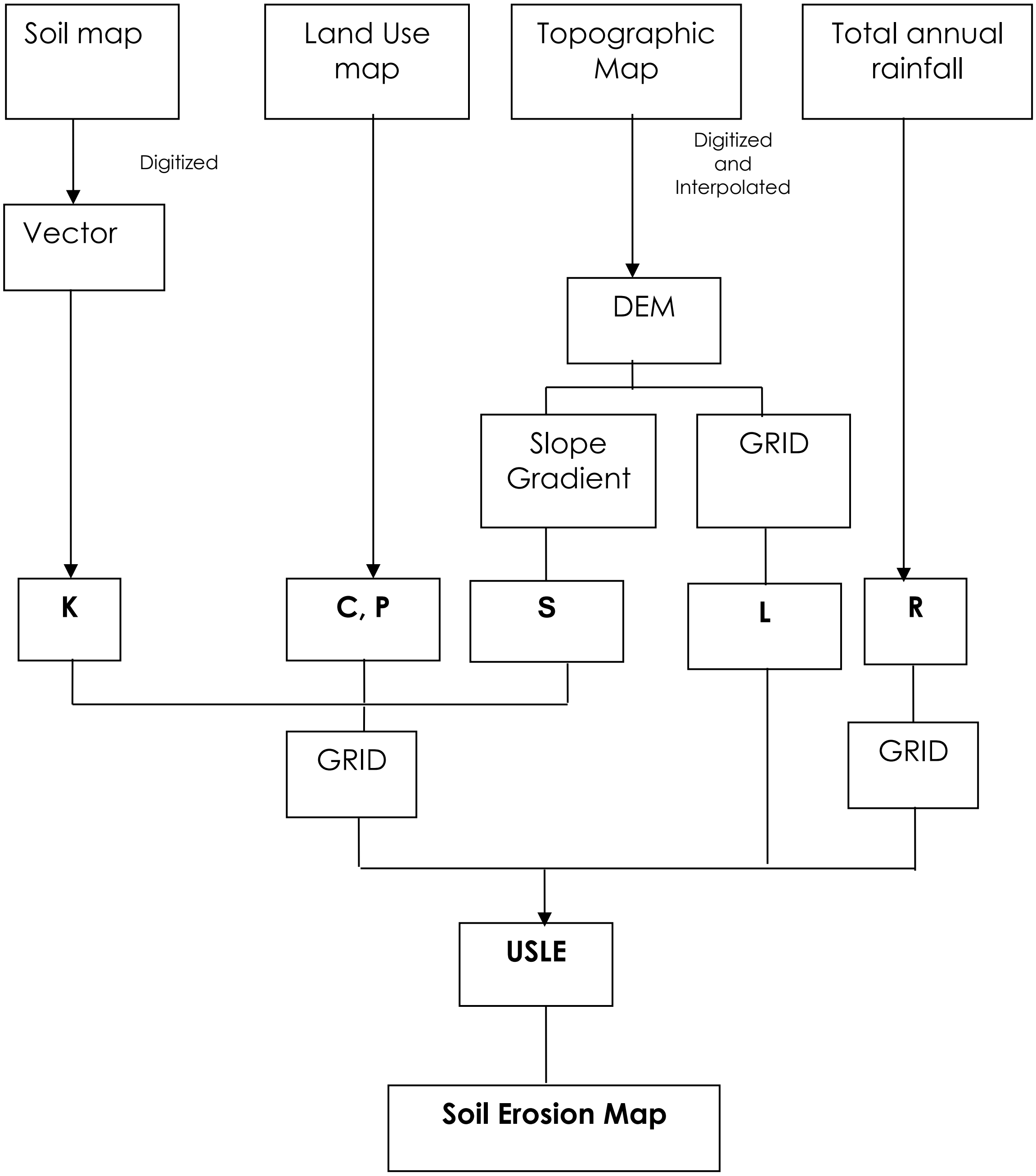
- Perform review of literatures and books on land degradation and soil erosion hazards
- The existing land use land cover with field checking will be used to generate the C and P factors.
- Generation of terrains slope map:

  The terrain slope map will be generated by digitizing the contour lines of topographic map of the area followed by rasterization and interpolation using Archview and used to generate L and S factors
- Digitizing the soil map of the area and assigning K values for each soil series
- The rain fall data of the area will be used for calculating the R factor
- Data on Livestock (Socio-economic data)
- Field measurement for gully erosion
- Overlay Analysis
  - All the vector maps will be converted in to raster format. Then application of spatial overlay on the raster layers to produce the resultant polygonal layer.

Vector → Raster → Reclassification → Multiplication Overlay → Soil erosion Map

  - Application of USLE model on the resultant layer results in the Soil Erosion Map of the area.

- Comparison of the distribution of gullies, the socio economic data with the produced erosion map



2.2 Flow Chart of Soil Erosion Assessment in the Study Area

2.5. Description of the Model (Universal Soil Loss Equation, USLE)

The erosion rate at a given site is determined by the particular way in which the levels on numerous physical and management variables are combined at that site. Physical measurements of soil loss for each of the large number of possible combinations in which the levels of these variable factors can occur under field conditions would not be feasible. Soil loss equations were developed to enable conservation planners to project limited erosion data to the many localities and conditions that have not been directly represented in the research.

The USLE is an empirical erosion model designed to predict the long time average soil losses in runoff from specific field areas in specified cropping and management systems (Wischmeier and Smith, 1978). Widespread field use has substantiated its usefulness and validity for this purpose. It is also applicable for such nonagricultural conditions as construction sites with appropriate selection of its factor values; the equation will compute the average soil loss for a multicrop system, for a particular crop year in a rotation, or for a particular crop stage period within a crop year. It computes the soil loss for a given site as the product of six major factors whose most likely values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but effects of the random fluctuations tend to average out over extended periods. Because of the unpredictable short-time fluctuations in the levels of influential variables, however, present soil loss equations are substantially less accurate for prediction of specific events than for prediction of longtime averages.

The soil loss equation is

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

A, is the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute **A** in tons per acre per year, but other units can be selected.

R, the rainfall and runoff factor is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions.

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

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.

This model was modified and adapted to Ethiopian conditions based on recommendations of the Soil Conservation Research Project (SCRP) by Hurni (1985) and the numerical values for each of the six factors in the study are derived from this modification by Hurni. The soil loss prediction procedure is more valuable as a guide for selection of practices if the user has a general knowledge of the principles and factor interrelations on which the equation is based.

Different researchers had applied this adapted model for Ethiopia to quantify the amount of soil loss in different parts of the country. Belay (2002) applied the model and found that soil erosion by water on cultivated slopes in South Wollo is proceeding an average rate of 35 t $ha^{-1}yr^{-1}$ and Woldeamlak (2003) found that the rate of soil loss in Digil water shed north western highlands of Ethiopia in Gojjam was around 37 t $ha^{-1}yr^{-1}$ exceeding the rate with which soils could be formed (Soil loss tolerance) in the area. Hurni measured a soil loss rate of 282 t $ha^{-1}yr^{-1}$ on a 22 per cent slope on a Nitosol cropped with teff with an annual rainfall of 1556 mm (Hurni 1985). Pilesjo (1992) estimated mean soil loss rates of 88 t $ha^{-1}yr^{-1}$ at an area with comparable rainfall pattern close to Wilbareg/South Shewa whereas Hellde´n (1987) calculated more than 150 t $ha^{-1}yr^{-1}$ in Mertule Mariam around the central Ethiopian highlands.

The Ketar and its tributaries drain the highlands area to south and east of Lake Ziway. This lake is the most northerly of the main Ethiopian Rift Valley lakes, and is fed principally by rivers draining the southeastern and northwestern plateaux and escarpments. Topographically, the study area shows a well-pronounced variation with the altitude ranging from around 1700m near Lake Ziway to about 4000m on the high volcanic ridges along the eastern water shed. There is an intermediate plateau between 2000 and 3000 m followed by a series of steep rocky NNE–SSW running parallel faults leading from the plateau to the rift floor.

3. 2. Climate

The study area (Ketar Catchment) is characterized by a semiarid to subhumid climate with mean annual temperature varying from 700 mm and 20 ^{0}C on the rift floor, to 1200 mm and 15 ^{0}C on the humid plateau and escarpments, respectively. Figure 3.2 shows mean monthly rainfall data at five selected stations in the study area. These stations are Arata, Assela, Ketar Genet, Kulumsa, Sagure.

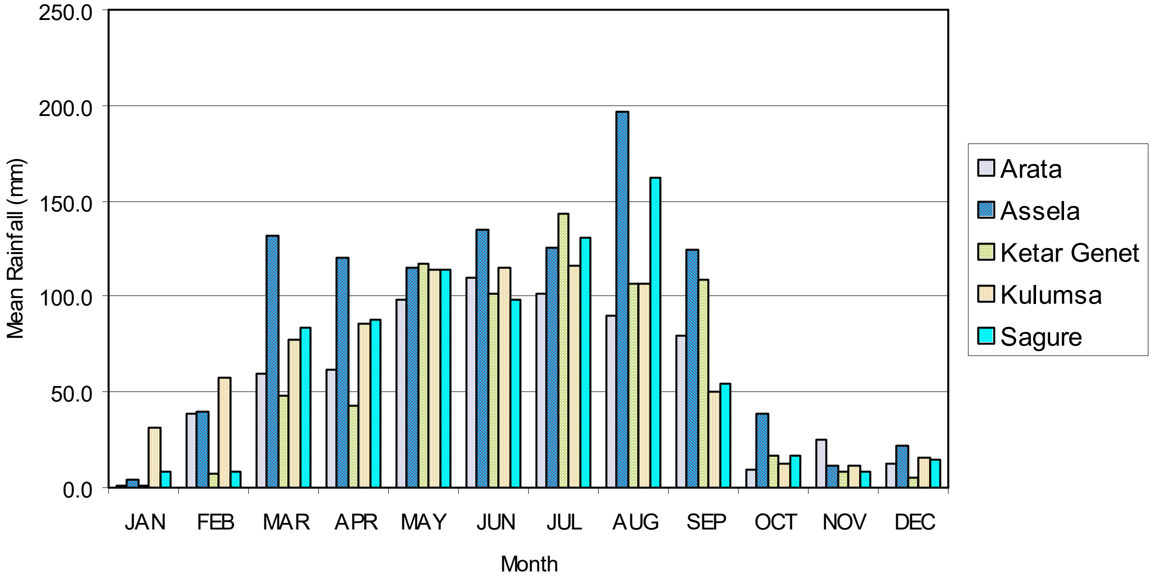


Figure 3.2 Mean Rainfall data at selected stations in the study area (source Ethiopian Meteorological Services)

The region is characterized by three main seasons. The long rainy season in the summer (June – September; summer monsoon rainfall, locally known as ‘kiremt’) is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) which lies to the north of Ethiopia at that time. The ‘Kiremt’ rain represents 50-70% of the mean annual total (Degefu, 1987 cited on Dagnachew, 2003). The dry period extends between October and February (known as ‘baga’) when the ITCZ lies south of Ethiopia. The ‘small rain’ season ‘belg’ representing 20-30% of the annual amount occurs during March to May when the ITCZ moves from south to north over the country.

The pattern of increasing rainfall associated with increasing altitude is modified in the high altitude area by the influence of the high mountains which may cause either rain shadows or areas of heavy orographic rainfall (Makin et al., 1975). Highlands flanking the Rift Valley intercept most of the monsoonal rainfall in the region, resulting in a strong moisture deficit in the rift floor in general and near the lakes in particular. The pattern of the precipitation in the rift floor is more of stormy type with relatively high intensity (up to 100mm/hr) compared to the highlands with only 60 -70 mm/hr (Makin et al., 1975).

3. 3. Vegetation

The low-lying region around Lake Ziway is typically of semi-arid land characterized by dry land acacia. Much of the higher escarpments below 3000 m are either cultivated or under grass. With increasing altitude, the catchment is mainly characterized by traditionally cultivated /pasture land with wheat and barley being the major crops, together with some oil crops, peas and ‘false banana’ *Ensete verticosum (*a staple food in many parts of the catchment and cultivated at altitudes ranging between 1600 and 3000 m). There are only some remnants of the montane forest that still existed some decades ago between 2000 and 3000 m on the eastern Ethiopian plateaux bordering the rift and dominated by *podocarpus gracilior* and *Juniperus pocera* (Friis, 1986 cited on Dagnachew et al., 2003). The Ericaceous belt extends up to 3600 m where it grades into Afroalpine type of vegetation (Chaffey, 1978 cited on Dagnachew et al., 2003).

3. 4. Soil

On the plateau, above 2000 m, the basalt, tuff and ignimbrite with additional volcanic ash give rise to soils wit high silt and clay contents (Makin et al., 1975). These vary from relatively deep (often more than 2 m thick), dark brown silty clay loam and clay loam, to red clays with up to 80% clay content on the well drained undulating terrain around Assela and poorly drained greyish brown to black silty clays on more gentle slopes around Sagure (Makin et al., 1975). On the low land area around lake Ziway, the soils are developed on lacustrin sediments and are predominantly of sandy texture.These are generally thin with less than 1 m thickness(Cherenet, 1982 cited on Dagnachew et al., 2003).The soils on the higher volcanic ridges are generally poorly developed.

3. 5. Geology

The study area is part of Ziway – shala basin (the lake region) in the Main Ethiopian Rift (MER). As shown by Benvenuti et al. (2002), there are six different stratigraphic units, which are highly affected by faults.

3.5.1. Stratigraphic Outlines

The oldest volcanic rocks (unit **Tt**) consist of basaltic lava flows; with inter bedded ignimbritic beds, topped by massive rhyolites and intervening tuffs and basalts. This unt covers much of the central part of the catchment (fig. 3.3).

The second stratigraphic unit (unit **Mt**) covers the eastern part of the area and it consists of trachytes with subordinate basalts and mugerites, and phonolites. (Di Paola, 1972; Merla et al., 1979; Woldegabriel et al., 1990; Bigazzi et al., 1993 cited on Benvenuti et al., 2002). As cited on Benvenuti et al., (2002) the rift floor ignimbrites (unit **Pp**) dominate much of the western part and contain silicic phyroclastic materials mainly per alkaline rhyolitic ignimbrites, inter layered with basalts and tuffs, and associated with layered unwelded pumices.

Small part in the north western of the area is covered by most recent volcanic unit (unit **Qb**); it is made up of basaltic lava flows, associated with hayaloclastitites and scoria cones (Kazmin et al., 1980 as cited on Benvenuti et al., 2002). Almost at the same area as unit **Qb** another unit is found. This unit (unit **Qw**) comprises young volcanoes and calderas made up of rhayolitic lava flows, unwelded pumice flows, pumice falls and ashes. The sixth unit found in the area (unit **Qp**) is part of lacustrine deposits, which consists of palustrine clay, organic clay and peat. It covers small part in the study area with in the rift floor ignimbrites.

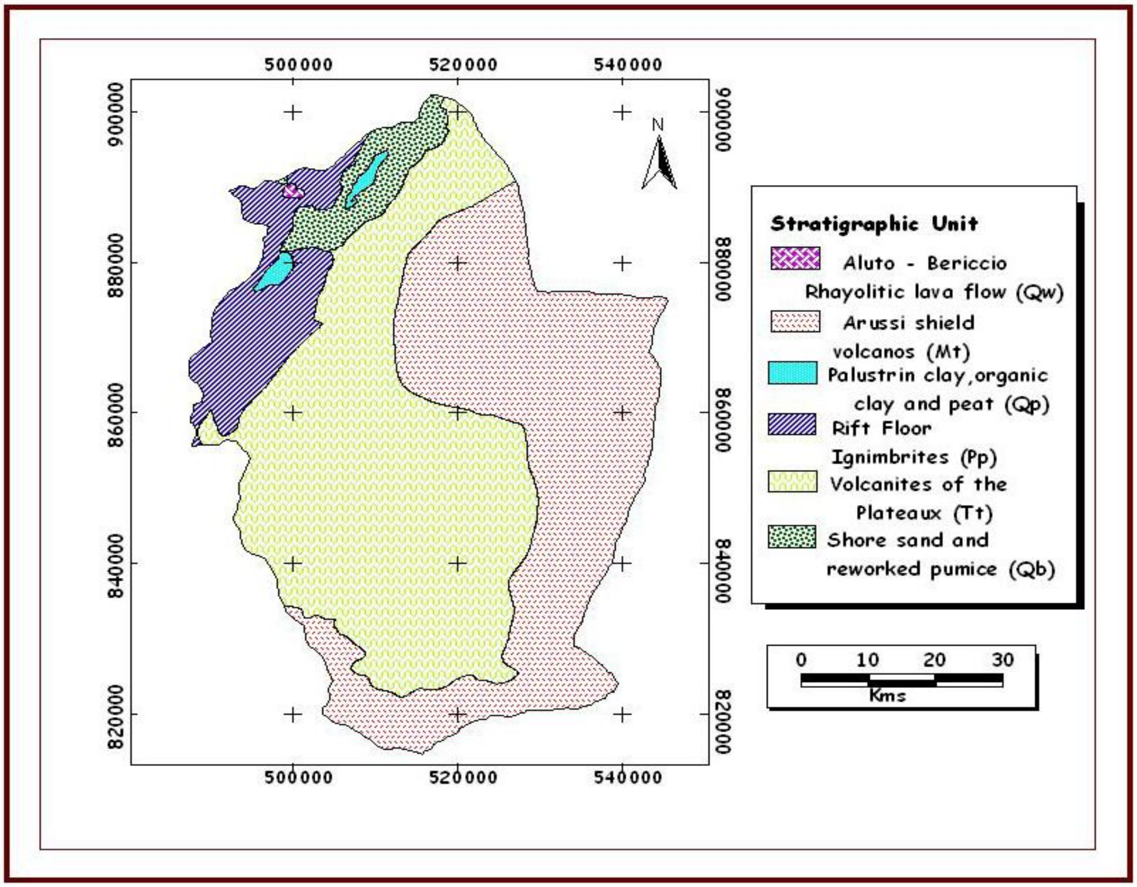


Figure 3.3 Geological Map of Ketar Catchment

The USLE computes sheet and rill erosions using values representing the four major factors affecting soil erosion. These are rainfall erosivity (**R**), soil erodibility (**K**), topographic effect (**LS**, comprising **L** and **S** factors), and land use and management factors (**CP,** comprising **C** and **P** factors). Hurni (1985) modified this model to be adapted for Ethiopian conditions (Appendix 1).

4.2.1. Procedures used to estimate factors in USLE

4.2.1.1. The Rainfall Erosivity Factor, R

The soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1995). According to Wischmeier and Smith (1978) rainfall erosivity is calculated from the kinetic energy of rainfall, which in turn is measured from the mean annual rainfall and 30 minute rainfall intensity value. The most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain. The formula used to calculate erosivity based on (Morgan, 1995) is

$$\mathbf{R = EI_{30}/100}$$

Where;

R = Rainfall erosivity factor in metric unit

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

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

However, rainfall kinetic energy and intensity data are not available in most Ethiopian cases. Therefore the rainfall erosivity factor, R that was adapted by Hurni (1985) for Ethiopian conditions based on easily available mean annual rainfall, P is used in this study. It is given by the equation:

$$\mathbf{R = -8.12 + (0.562 * P)}$$

Where; **P** is the mean annual rainfall in mm

In this study the average annual rainfall data of four years (2000 – 2003 G.C.) of ten meterological stations naming: Arata, Assela, Ego, Huruta, Ketar Genet, Kulumsa, Meki, Sagure and Ziway is used to calculate the R factor based on the above formula. Arata, Assela, Ketar Genet, Kulumsa and Sagure are located inside the study area and the other four meteorological stations outside the area. They are used to increase the accuracy of the interpolation. Annual rainfall and calculated R-values of the stations are presented in table 4.1 below.

Metrological Station	Annual Rainfall (mm)	Rainfall erosivity factor, R
Arata	684.82	376.75
Assela	1065.58	590.73
Ego	818.38	451.81
Huruta	850.80	470.03
Ketar Genet	706.20	388.76
Kulumsa	795.18	438.77
Meki	699.17	384.81
Sagure	787.88	434.67
Ziway	644.47	354.07

Table 4.1 Mean Annual Rainfall and calculated R factor of the stations

After calculating R values of each station, nearest neighbors interpolation with 100m of grid cells of rainfall erosivity factor, R were performed to get the R -values of the study area using GIS software (Arcview Gis 3.2). As a result the R factor of the area ranges between 376 and 591mm, see fig. 4.1. But much of the area's R factor falls between 376 and 425mm.

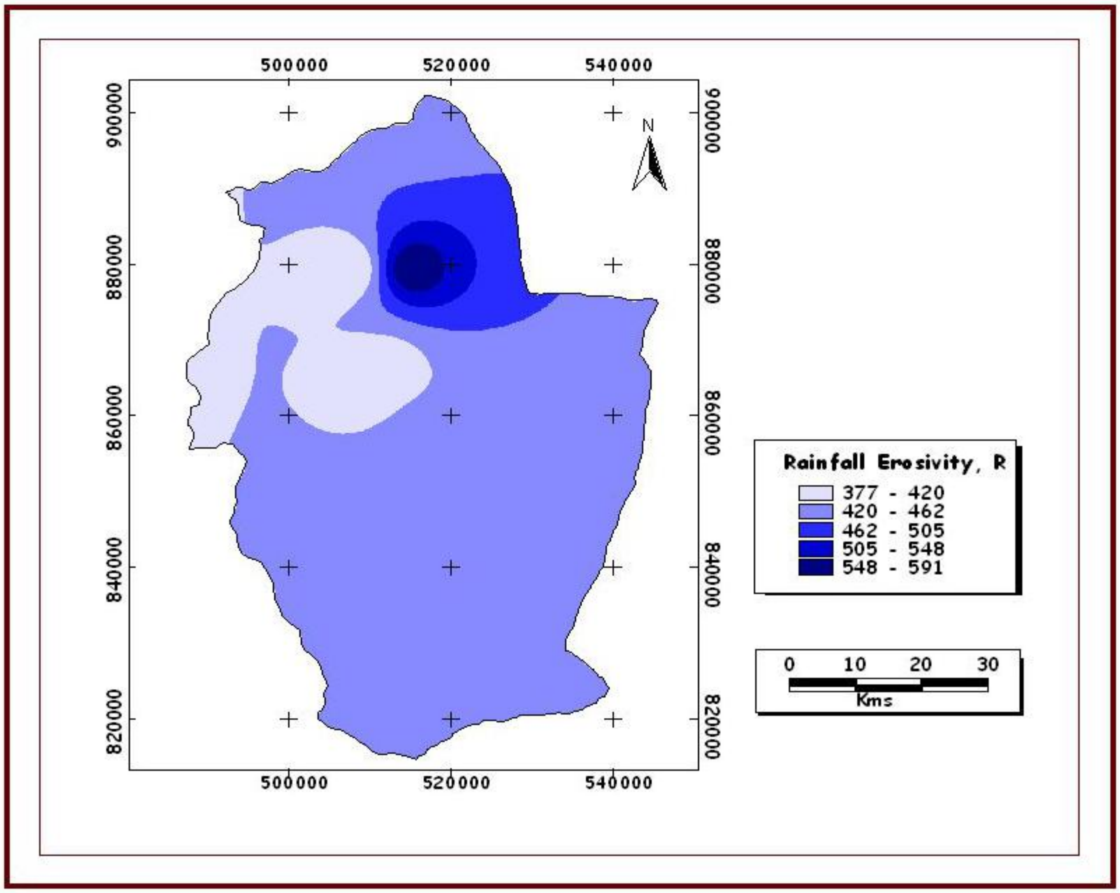


Figure 4.1 Rainfall Erosivity Factor, R

4.2.1.2. The Soil Erodibility Factor, K

The soil erodibility factor K is defined as a quantitative value, which is experimentally, determined taking into consideration the soil texture and structure, the organic matter content and the permeability (Wischmeier and Smith 1978). It is the resistance of a soil to two energy sources: the impact of raindrops on the soil surface, and the shearing action of runoff. Therefore, soil erodibility, K factor represents the average long term soil and soil profile response to the erosive power associated with rainfall and runoff.

According to Morgan (1995) it can also be defined as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 50 and 22 m length, and its values range from 0 to 1.

Hurni (1985) had developed K values for different soil types based on FAO soil classification (see Appendix 1). So in this study the soil types were clipped from ETHIO-GIS data sets and compared with the soil classification of the area by Makin et al., (1975). Based on this, nine different soil types (fig. 4.2) are identified and assigned K- values based on Hurni's adaptation for Ethiopian conditions. The different soil types and their respective K- values are presented in table 4.2 below.

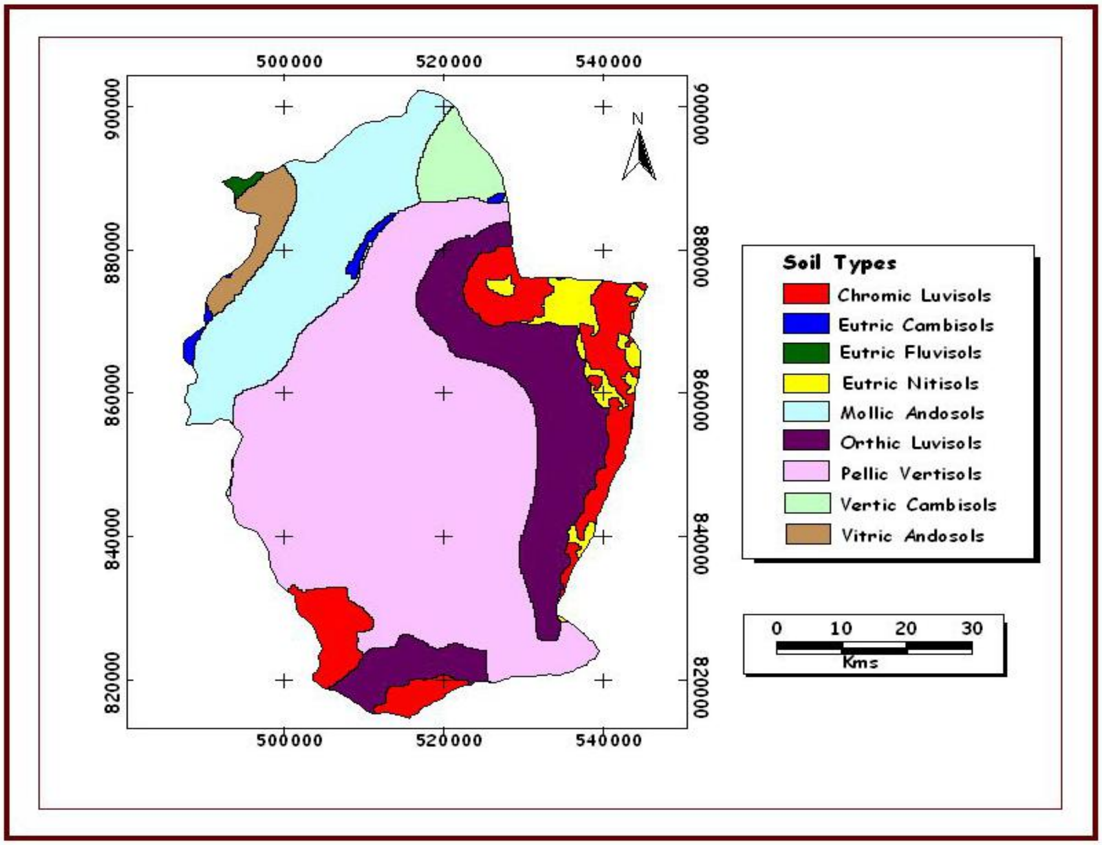


Figure 4.2 Soil Map of the Study Area

The basic soil types, which are in vector format, were changed in to grid with cell size of 100m based on the K-values of each soil type; after that the grid data set was reclassified into five erodibility classes using Arcview Gis 3.2, see fig. 4.3.

Soil type	Area (Km^2)	Area covered in percent (%)	Soil erodibility factor, K
Chromic Luvisols	313.19	9.6	0.15
Eutric Cambisols	20.93	0.6	0.15
Eutric Fluvisols	8.25	0.3	0.15
Eutric Nitisols	87.31	2.7	0.10
Mollic Andosols	512.64	15.7	0.10
Orthic Luvisols	527.07	16.1	0.15
Pellic Vertisols	1628.30	49.9	0.20
Vertic Cambisols	91.40	2.8	0.20
Vitric Andosols	76.67	2.4	0.15
Total	**3265.76**	**100.00**	

Table 4.2 Soil types and their respective K values in the study area

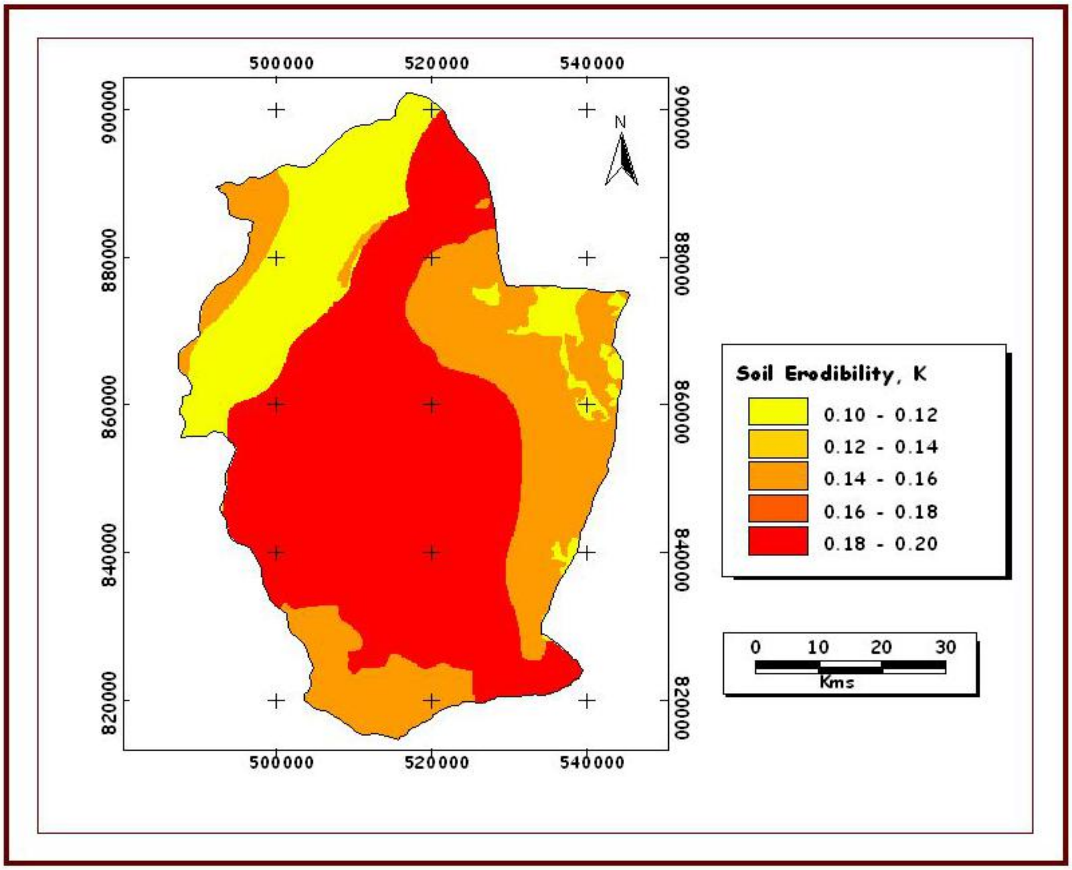


Figure 4.3. Soil Erodibility Factor, K

4.2.1.3. The Slope Gradient Factor, S

The slope-steepness factor, S is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions. As the gradient increases, the kinetic energy of rainfall remains constant, but transport accelerates toward the foot as the kinetic energy of the runoff increases and outweighs the kinetic energy of the rainfall when the slope (S) exceeds 15% (Wischmeier and Smith, 1978). It describes the soil erosion susceptibility of a given slope.

A DEM was developed for the study area using digitized 1:50,000-scale topographic maps of Assela, Bekoji, Chefe Jila, Digelu, Gobesa, Gonde, Kersa, Meki, Meraro and Siltana with contour intervals of 20m obtained from Ethiopian Mapping Authority (EMA). After that, from the DEM a slope map of 100m grid cell size was generated, reclassification (fig. 4.4) was performed and slope gradient factors, S values (fig. 4.5) were assigned to each slope gradient class according to Hurni (1985), see appendix 1.

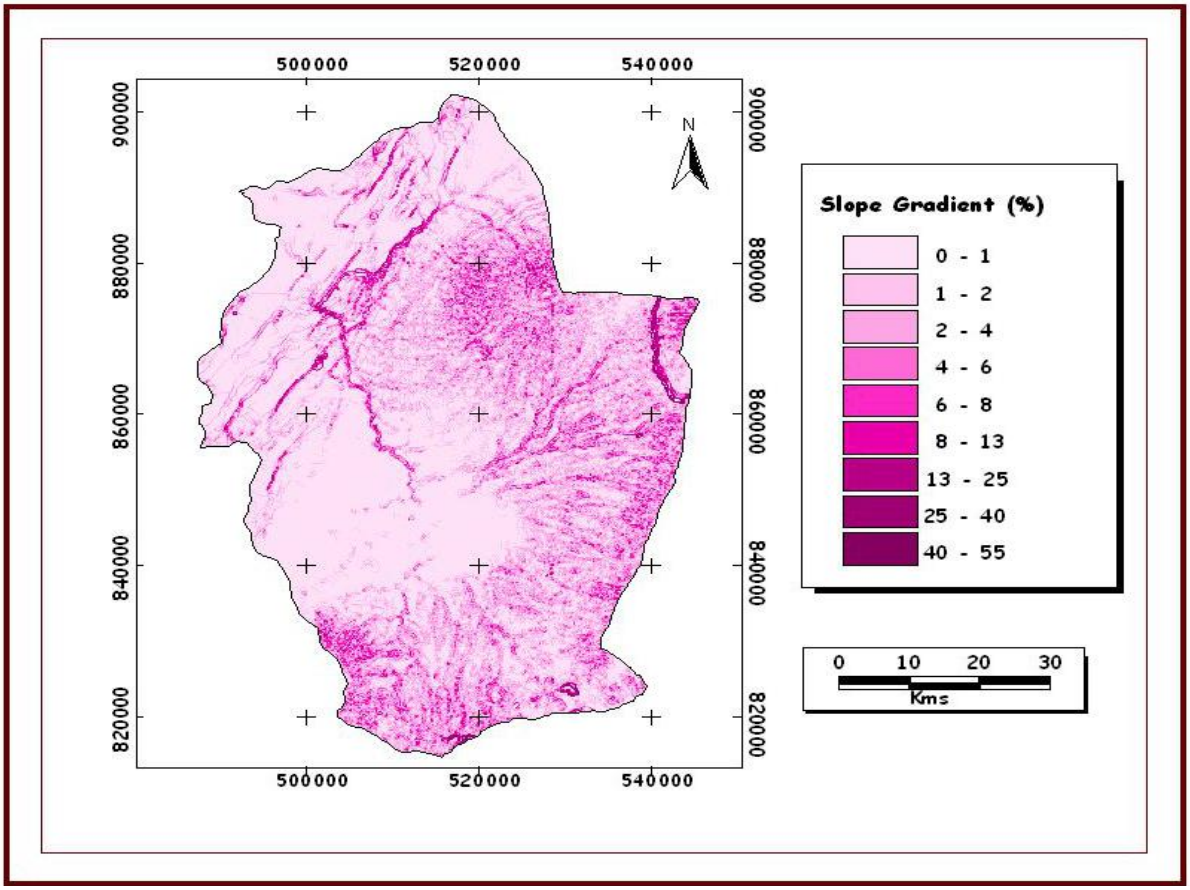


Figure 4.4 Slope Gradients Map of the study area

Much of the study area falls in the first three slope gradient classes that is in 0 -1%, 1 - 2% and 2 - 4% respectively covering 48.3%, 17.9% and 19.4% of the area, the other six classes covering the rest 15% (the different slope gradient classes and the percent area covered by each class is presented in the table below). The NNE–SSW running Wonji faults are the steep parts having the highest gradient in the area.

Class	Slope gradient (%)	Area (Km^2)	Area covered in percent (%)	Slope gradient factor, S
1	0-1	1580.19	48.4	0.10
2	1-2	583.04	17.9	0.10
3	2-4	634.02	19.4	0.20
4	4-6	247.33	7.6	0.35
5	6-8	105.80	3.2	0.60
6	8-13	82.89	2.5	1.00
7	13-25	23.96	0.7	2.00
8	25-40	7.49	0.2	3.20
9	40-55	1.04	0.1	4.20
Total		**3265.76**	**100.00**	

Table 4. 3 Slope gradient classes, their area coverage in percent (%) and the slope gradient factor, S

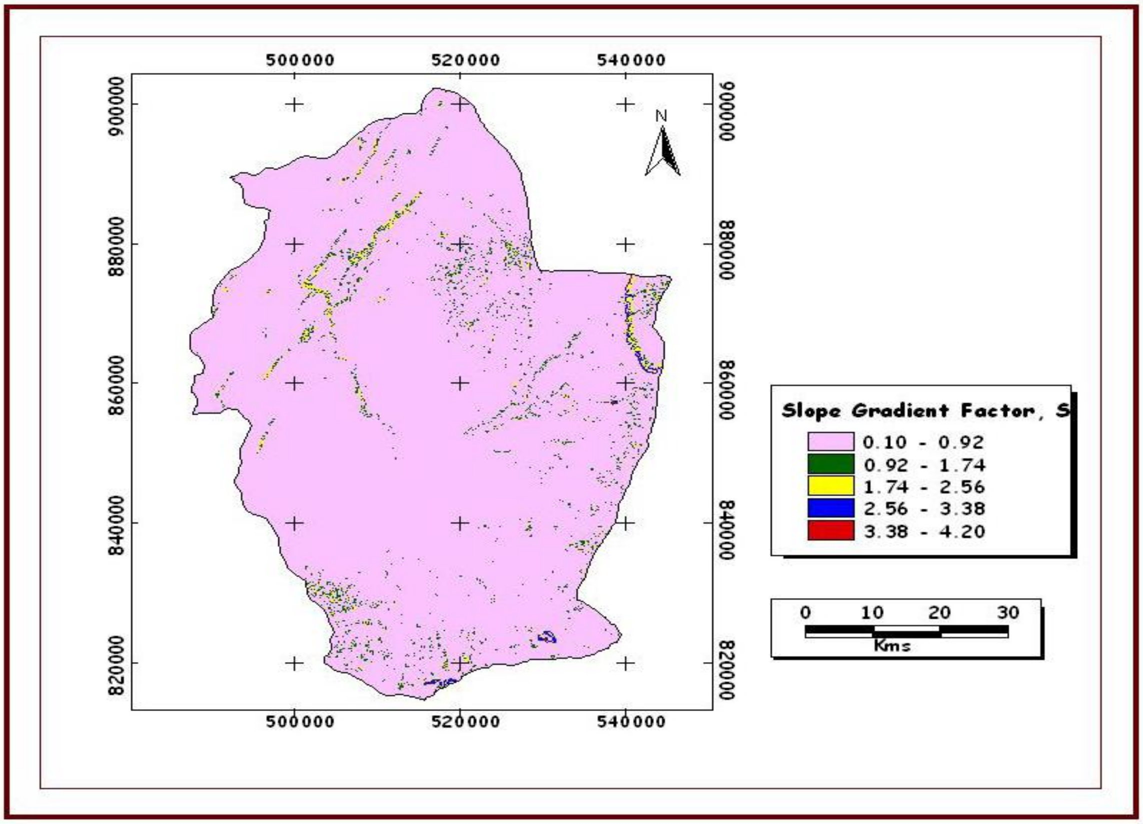


Figure 4.5 Slope Gradient factor, S

4.2.1.4. The Slope Length Factor, L

According to Wischmeier and Smith (1978) slope length factor, L is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions. It can be defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel.

In theory, the longer the slope, the more runoff will accumulate, gathering speed and gaining its own energy, causing rill erosion and then more serious gullying. However, Morgan (1995) found that the soil loss per unit area generally increases substantially as slope length increases. This means the greater accumulation of runoff on the longer slopes increases its detachment and transport capacities.

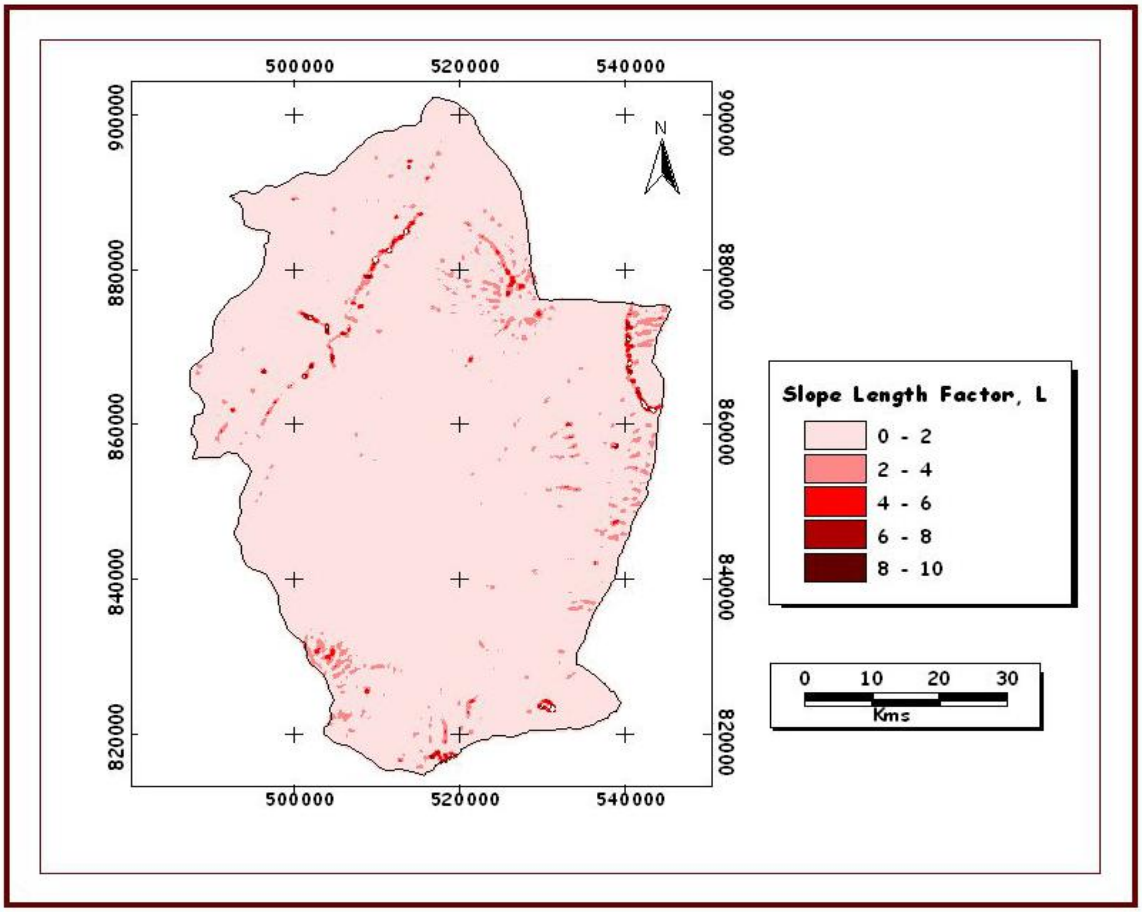


Figure 4.6 Slope Length Factor, L

As confirmed by most researchers the slope factor is the most complex factor to estimate without direct measurement and observation in the field, which is so difficult to do. So in this study the factor is derived from the DEM of the area. To calculate this factor first the DEM would be converted to grid with cell size of 100m. Then from the grid using the extension terrain analysis, the slope length factor, L of the catchment could be calculated. From the result (fig. 4.6), it is possible to observe that there are five classes out of which more than 90% of the area having slope length factor in the first two classes (0 - 2 and 2 - 4) and the rest in the other three classes.

4.2.1.5. Crop and Management Factor, C

Crop and management factor, C in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). This factor measures the combined effect of all the interrelated cover and management variables. According to Morgan (1995) C factor represents the ratio of soil loss under a given crop to that of the bare soil.

The land use map of Ketar catchment, the study area, which is used in this study, is based on the land use produced by Dagnachew (2002), used as a base land use map and with field checking of the classifications in the area. This map is derived from Landsat ETM+ (December 3, 1999).

According to the field checking and the base land cover map classification there are seven different landuses (fig. 4.7). These are cultivated land, Afro–alpine, fallow land, planted eucalyptus trees, wetland, woodland and town. From the land uses Afro-alpine and eucalyptus are considered as forest land and assigned equal amount of C factor. Those land uses grouped as acacia/cultivated, cultivated/woodland and cultivated are considered as cultivated land and assigned C factor of 0.15. Most of the cultivated land near and around Assela town is covered by wheat and near and around Bekoji town is covered by Barley. But according to Hurni (1985), appendix 1; both wheat and barley have C factor of 0.15 (See table 4.4).

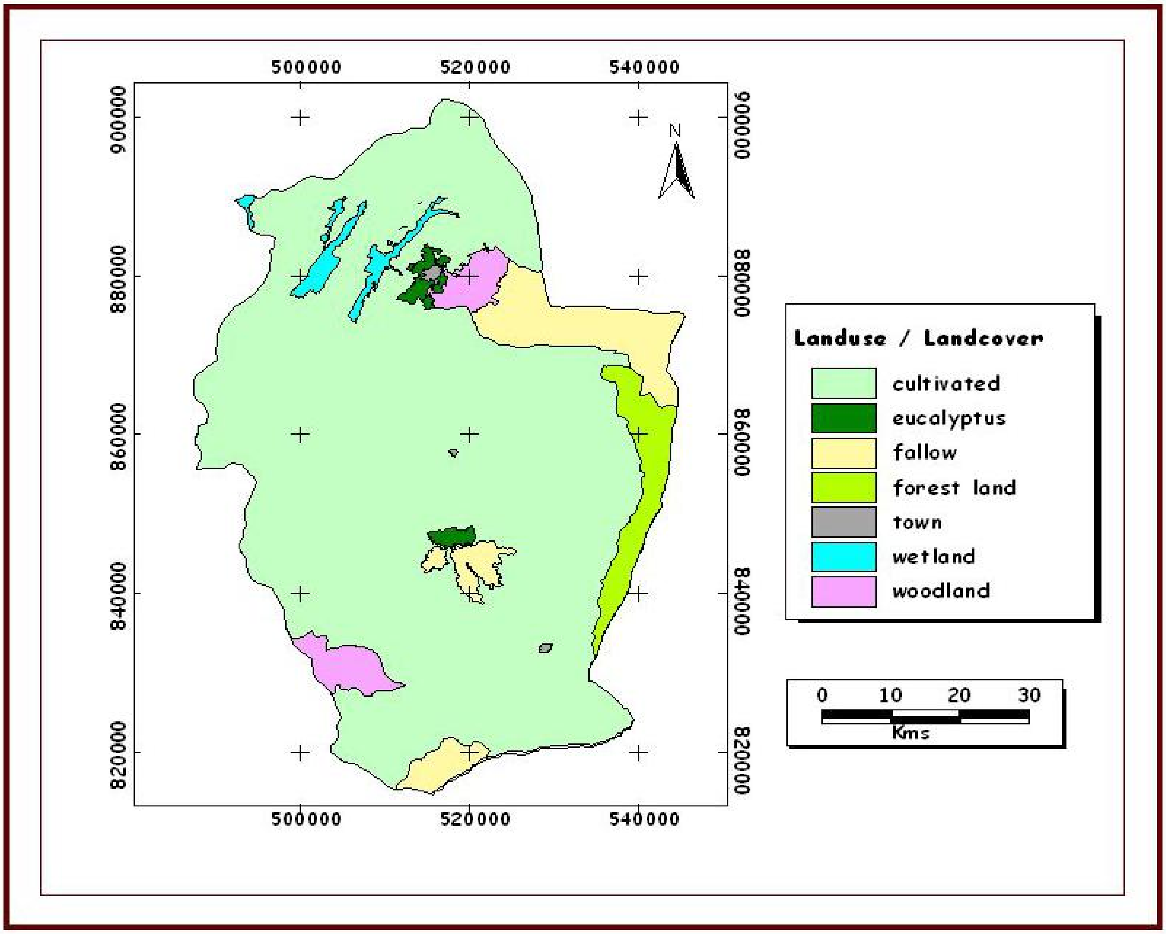


Figure 4.7 Landuse / landcover Map of the study area

Land use	C-Factor	P-Factor
Woodland	0.100	0.800
Afro-alpine	0.001	0.800
Fallow	0.050	0.800
Eucalyptus	0.001	0.800
Town	0.003	0.800
Wetland	0.003	0.800
Cultivated	0.150	0.900

Table 4.4 Land use classes with their respective C-factor and P-factor

The C factor for the land use classes was assigned based on Hurni (1985) and Reusing et al. (1997). After assigning C factors for the land uses in the area, the resulting map was converted to a grid map of 100m cell size (fig. 4.8) taking C factors as values for the cells.

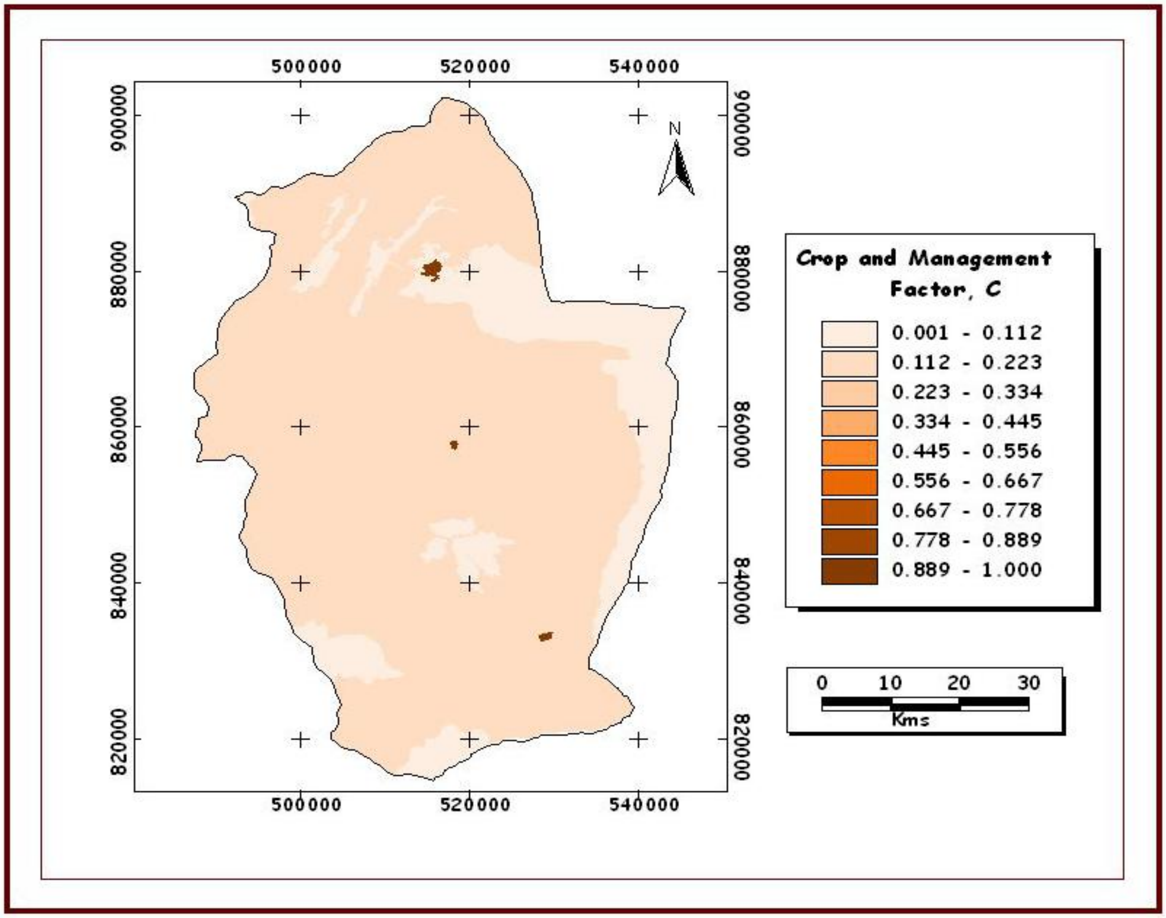


Figure 4.8 Crop and Management Factor, C

4.2.1.6. Support (Conservation) Practice Factor, P

P factor in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture (tillage). It reflects the impact of support practices on the average annual erosion rate. As discussed by Mohammad et al., (2004) P factor indicates the fractional amount of erosion that occurs when any special practices are used compared with what would occur without them. The support practice affects erosion primarily by modifying the flow pattern, grade and direction of surface runoff and by reducing runoff amount and rate (Lorenz and Schulze, 1995). The P-factor value ranges from 0-1 depending on the soil management activities employed in the specific plot of land.

In the study area the only conservation mechanism observed during the field trip is contour ploughing on cultivated areas. So for the cultivated areas P factor of 0.9 and for all other land uses a value of 0.8 (table 4.4) were assigned. After assigning P factor values for the land uses, the map was rasterized to a grid map with 100m cell size. The resulting grid map is shown in fig. 4.9.

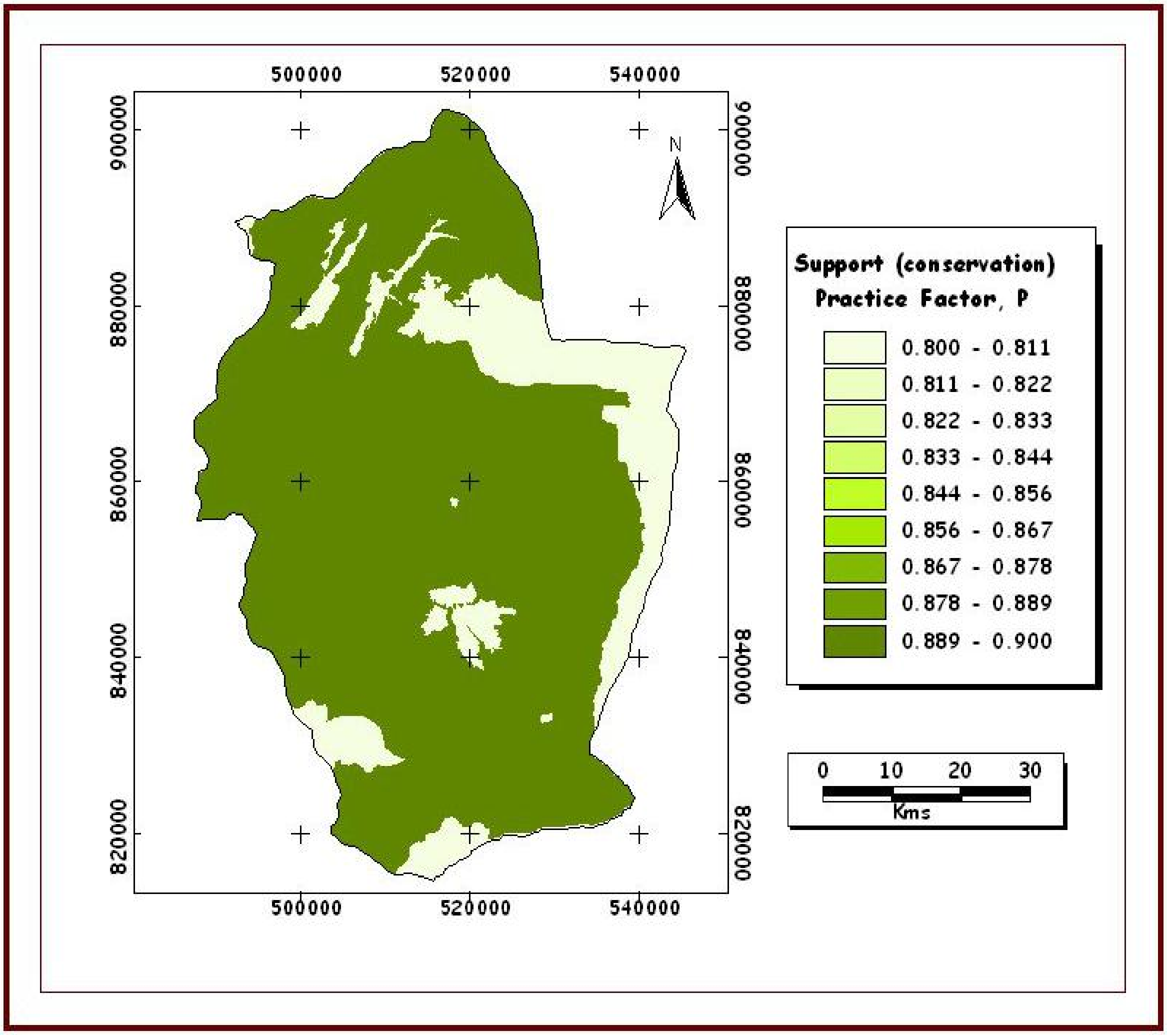


Figure 4.9 Support (Conservation) Practice Factor, P

4.3. Results and Discussions

The soil erosion (loss) map (fig. 4.10) of the area was generated by multiplication overlay, cell-to-cell operation; of the grid (raster) maps of the six USLE input parameters. In the study area the soil erosion rate was classified in to six erosion potential classes (table 4.5) ranging from low erosion hazard (0 – 4.71 t/ha/yr) to exceptional erosion hazard (> 98.94 t/h/yr).

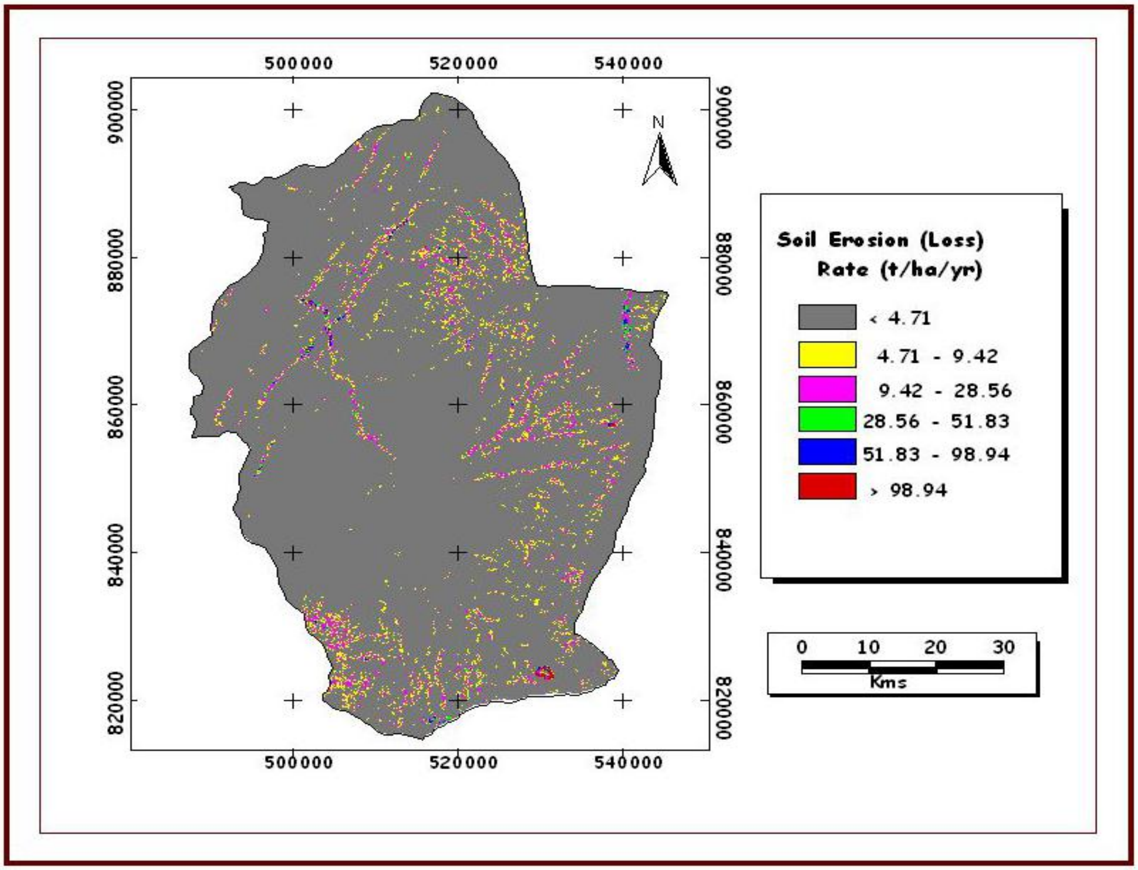


Figure 4.10 Soil Erosion (Loss) Map of the Study Area

Generally, 96.8% of the study area is under low to moderate erosion rates, which is good in the current situation and 3.2% of the area is under high to exceptional erosion rates. According to Morgan (1995) erosion increases with the increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff. Most of the erosion risk of classes 3 to 6, high to exceptional; are concentrated around areas having both higher slope length and slope gradient factors. That is, in the study area 38.18 Km^2 area has slope length factor length above 4 and out of this area 22.8 Km^2 (57.8%) is under high to exceptional erosion risk.

Class	Soil loss (t/ha/yr)	Erosion Potential	Area (Km^2)	Area (%)
1	< 4.71	Low	3031.3	92.8
2	4.71 - 9.42	Moderate	130.16	4.0
3	9.42 - 28.56	High	83.18	2.5
4	28.56 - 51.83	Severe	12.92	0.4
5	51.83 - 98.94	Extreme	5.27	0.2
6	> 98.94	Exceptional	2.97	0.1

Table 4.5 Soil Erosion (Loss) Potential Classes of the Study Area (according to Mohammad, F.R., et al. (2004))

Regarding to the slope gradient factor around 32.49 Km^2 of the study area have a value of greater than or equal to 2 (>=13% of slope gradient) and 25.14 Km^2 (77.4%) of this area is under high to exceptional erosion risk. It is also observed that areas with slope length factor above 4 and gradient factor of greater than or equal to 2 cover an area of 10.60 Km^2.

From these results we can see that there is high to exceptional rate of erosion related to either the steeper, longer or both steeper and longer slopes in the area so topographic factors are responsible (governing factors) for these high to exceptional rates of erosion in the catchment.

Previous studies using this model in Ethiopia showed different outputs for instance a study by Belay (2002) showed that soil erosion by water on cultivated slopes in South Wollo was 35 t/ha/yr and Woldeamlak (2003) found that the rate of soil loss in Digil watershed northwestern highlands of Ethiopia in Gojjam was around 37 t/ha/yr. Another researcher, Hurni (1985); measured a soil loss rate of 282 t/ha/yr on a 22 % slope on a Nitosol cropped with teff with an annual rainfall of 1556 mm and Pilesjo (1992) estimated mean soil loss rates of 88 t/ha/yr at an area close to Wilbareg/South Shewa whereas Hellde´n (1987) calculated more than 150 t/ha/yr in Mertule Mariam around the central Ethiopian highlands, and Reusing et al. (2000) found that predominant part of a study area near Lake Tana has a soil loss rates in excess of 256 t/ha/yr. Another study of erosion by Eweg, et al. (1997) applying this model in part of central Tigray near Adwa estimated that 18% of the area studied was eroding at rates exceeding 10 tons/ha/year.

Results in the study area, which is in Oromia region; compared with other erosion rates in the country showed that much of the area (96.8%) is under low to moderate (<9.42) rate of erosion. This confirms a report by Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2000), which reported that 99% of Oromia region has a soil erosion rate of less than 10 ton/ha/year. The WBISPP used the Universal Soil Loss Equation (USLE) adopted for Ethiopia in estimating the rate of erosion in the region.

As defined in the second chapter soil tolerance is the maximum acceptable rate of soil loss that is the rate of soil formation equals the rate of soil loss. Average rates of soil formation in Ethiopia, Hurni (1983) cited on Nyssen et al. (2003) had categorized using agro climatic zones that are delimited based on altitude (m) and annual rainfall (mm). Accordingly the soil formation rates range from 1 t/ha/yr for Bereha “desert” (altitude <1500 m) to 16 t/ha/yr for Wet Weina Dega (altitude 1500 – 2300 m with annual rainfall > 1400 mm) agro climatic zones (see Appendix 2). From this and the soil loss rate of the catchment obtained by using the USLE model it is possible to say that much of the study area is under tolerable condition.

4.3.1. Woredas in the Study Area and Erosion rate

The Ketar cachment consists of 6 woredas of the Arsi zone (fig. 4.11); these are Bekoji, Digelu Tijo, Hitosa, Munesa, Tiyo, Ziway Dugda. Much of the study area is in Digelu Woreda followed by Bekoji; the area covered by the woredas in the study area is presented on table 4.6.

Much of the area, in all of the woredas has a soil loss rate of less than 4.71 t/ha/yr (table 4.7 and fig. 4.12), which is a good thing to observe because this rate is less than the rate of soil formation. But it is also possible to see that 3.2% area of Digelu Tijo and 5.5% area of Tiyo show a soil loss rate of greater than 9.42 t/ha/yr; these areas need special attention and good conservation practices before causing any further damage (e.g. changed to gully, reduced soil depth).

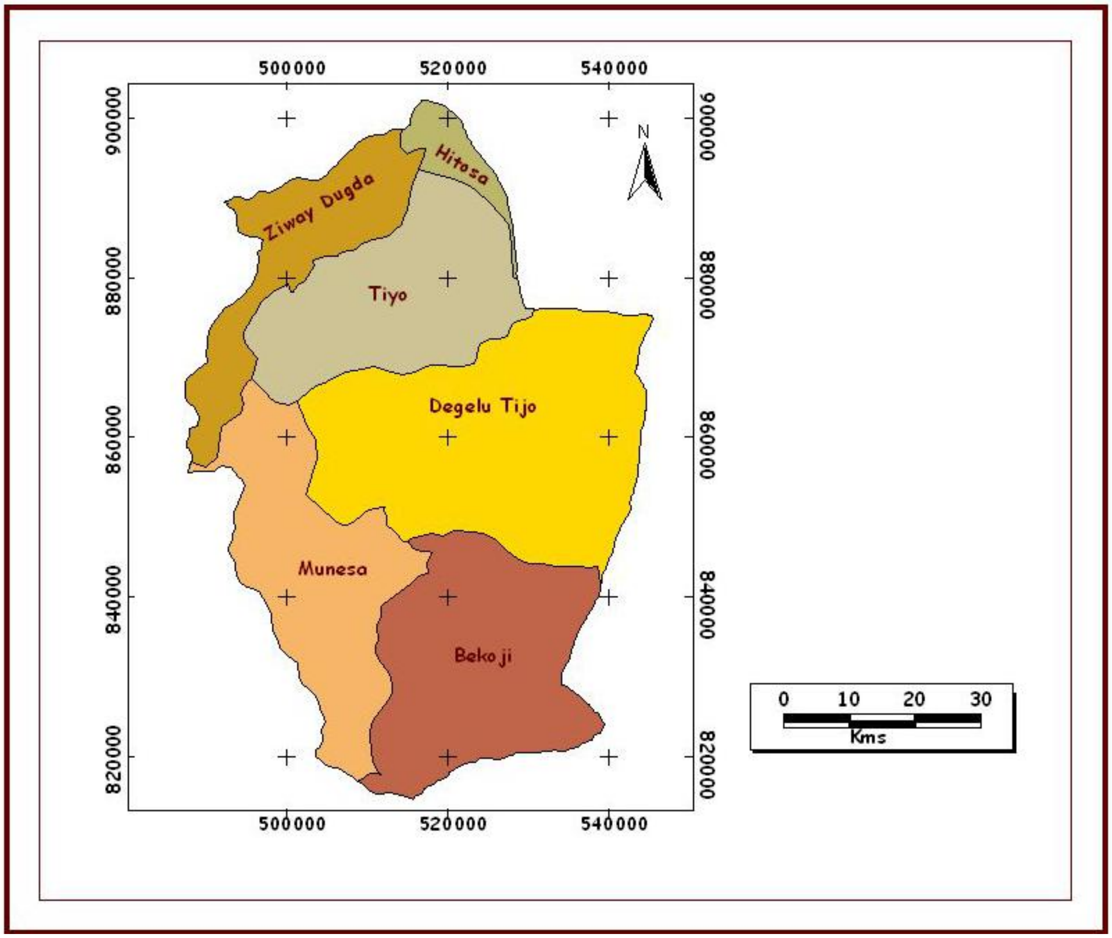


Figure 4.11 Woredas in the Study Area

Woreda Name	Area (Km2)	Area (%)
Bekoji	675.68	20.69
Digelu Tijo	995.49	30.48
Hitosa	82.89	2.54
Munesa	584.94	17.91
Tiyo	572.27	17.52
Ziway Dugda	354.49	10.85
Total	**3265.76**	**100.00**

Table 4.6 Woredas and Area Coverage in the Study Area

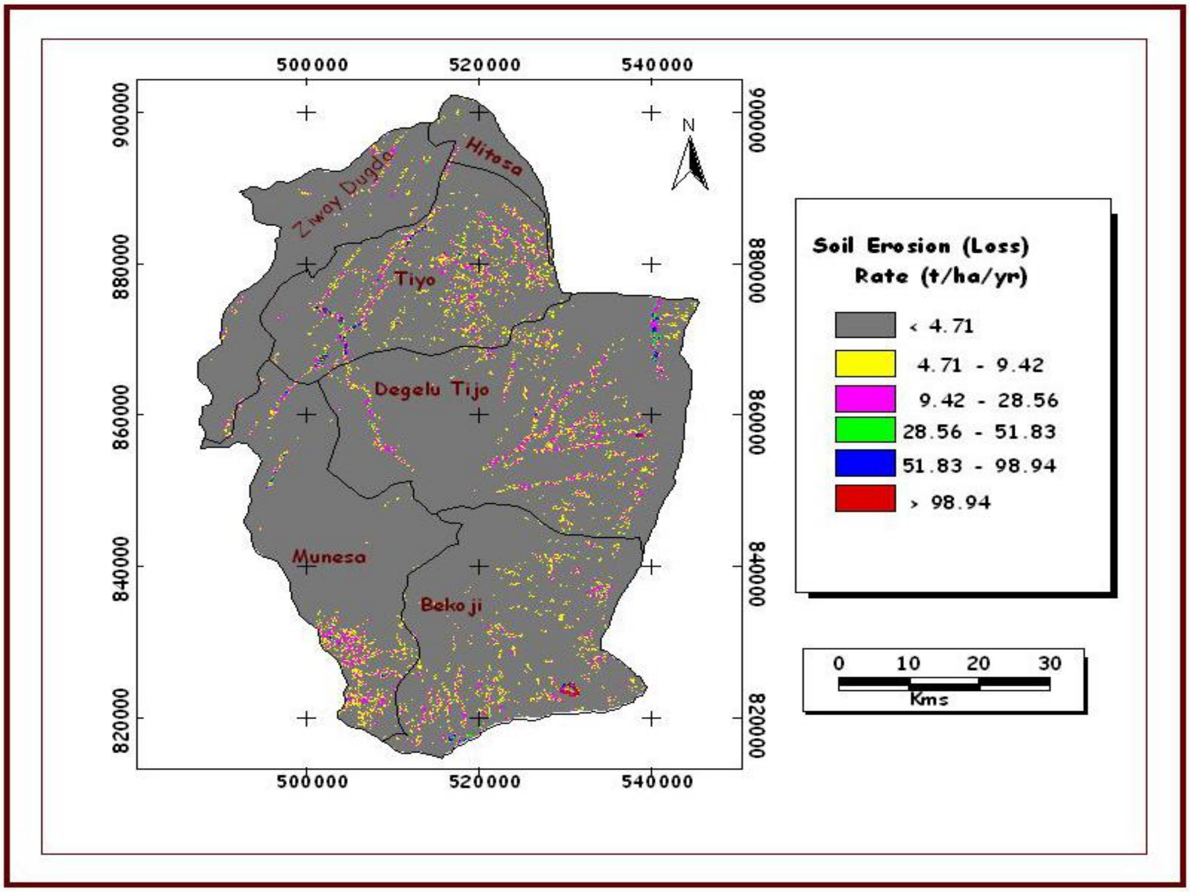


Figure 4.12 Soil Erosion in the woredas

Soil Erosion Rate (t/ha/yr)	Bekoji (km^2)	Digelu Tijo (km^2)	Hitosa (km^2)	Munesa (km^2)	Tiyo (km^2)	Ziway Dugda (km^2)	Total (km^2)
< 4.71	624.33	926.13	81.5	549.16	504.91	345.1	3031.1
4.71-9.42	28.62	37.77	1.09	20.54	37.36	4.84	130.22
> 9.42	19.39	31.91	0.69	16.93	31.79	3.7	104.41
Total Area (Km^2)	**672.34**	**995.81**	**83.28**	**586.63**	**574.06**	**353.64**	**3265.8**

Table 4.7 Woredas in the Study Area and rate of erosion in t/ha/yr

4.4. Gully formation and distribution in the Study Area

A gully is a deep depression, channel or ravine in a landscape, looking like a recent and very active extension to natural drainage channels. Gullies may be continuous or discontinuous; the latter occurs where the bed of the gully is at a lower angle slope than the overall land slope. According to Nyssen et al. (2003) gully system in Ethiopia is discontinuous and there are no studies, which indicate the regional distribution of gullies in Ethiopia.

Gully erosion is an advanced stage of rill erosion where surface channels have been eroded to the point where they cannot be smoothed over by normal tillage operations. Gullies are generally caused by the action of water. They tend to form where land slopes are long and land use has resulted in loss of vegetation and exposure of the soil surface over a large area so that the land now produces more runoff.

Gullies can be prevented if good land conservation measures are practiced on the farm. Good tillage and cropping practices increase the absorptive capacity of the soil resulting in less run-off and also protect the land surface from erosion.

Figure 4.13 Early stage of Gully formation in the Study Area, Digelu Tijo woreda

Currently, in the study area gully formation is at an early stage that is the soil erosion is manifested in the form of sheet and rill erosions but from the field observation (survey), it is possible to identify some areas with small sized gullies (Fig. 4.13). These gullies (early stage of gully erosion) are observed at areas where there is high agricultural activity on relatively steep slopes without application of any conservation techniques near the town Digelu and Gonde. As can be seen in figure 4.13, due to gully erosion the topsoil of the area where the photo has been taken is removed exposing the underlying rock. This small gully on the figure has a length of about 50 m with a width of 1m and a depth of 30 - 40 cms, it has lost 15 -20 m^3 of soil. In the near future unless proper conservation measures are not taken much the arable land in the study area will be highly affected by gullies, losing its productivity.

4.5. Population and Livestock impacts in the Study Area

Population growth increases the demand for land and contributes to farming on steep and fragile soils, also leading to erosion problems. It increases demand for biomass as a source of fuel, leading to deforestation and increased burning of dung and crop residues, thus increasing the problems of erosion and nutrient depletion (ILRI, 1999). Population growth increases demand for livestock products and therefore leads to increased livestock numbers, causing overgrazing and consumption of crop residues by animals. In Ethiopian highlands, which only cover 44% of the total area of the country; the population is increasing at an alarming rate. Different studies, for instance (Shibru, 1997; Tamirie, 1997) show that around 88% of the human population and 75% of the livestock population are located in these highlands. The next sections discuss about the human and livestock population, and their impact on the soil erosion in the study area.

4.5.1. Population impacts in the Study Area

Pressure on land resources due to population growth leads to cultivation of marginal land and steep slopes causing land degradation. According to studies by ILRI (1999), Alemneh (2003) and Tamirie (1997), population on the highlands of Ethiopia has grown very fast on the limited land area and every possible piece of land is put into cultivation to produce food without any conservation causing high soil degradation.

The study area being part of Ethiopian highlands, it is necessary to study the impact of population growth in each of the six woredas• found in it.

As mentioned previously, there are six woredas in the study area of which Bekoji, Digelu Tijo, Munesa and Tiyo (see table 8) cover relatively larger area compared to the other two woredas. If you see the population growth in each of the woredas, it shows 15.93%, 15.57%, 16.17%, 15.47%, 19.80%, 14.98% rate of increament in Bekoji, Digelu Tijo, Hitosa, Munesa, Tiyo and Ziway Dugda respectively (see table 4.8) from the year 1999 to 2005 G.C; that is within only six years. The same rate of increment is observed in the number of persons per Km^2 in each of the woredas within the specified years as a result, the total area of land each farmer cultivates is decreasing steadily.

Zone	Area (km^2)	1999G.C	2000G.C	2001G.C	2002G.C	2003G.C	2004G.C	2005G.C
Bekoji	1501.72	191,903	197,722	203,621	209,626	215,721	221,917	228,255
Digelu Tijo	889.22	120,138	123,696	127,293	130,958	134,671	138,439	142,288
Hitosa	1215.47	202,295	208,531	214,858	221,300	227,840	234,502	241,319
Munesa	1454.85	170,646	175,669	180,745	185,916	191,151	196,463	201,886
Tiyo	638.44	140,933	146,348	151,934	157,616	163,451	169,488	175,720
Ziway Dugda	1269.07	99,498	102,330	105,187	108,094	111,033	114,004	117,035

Table 4. 8 Total Area (km^2) and Population of Woredas in the Study Area, CSA (2005)

Based on report of Khon (1999), Gedion (2003) high population density is not necessarily related to land degradation but what the population does to itself and to the land that it depends on determine the extent of land degradation. People can be a major asset in reversing the degradation trend. In all woredas of the study area, as can be seen on table 10; the population is increasing at an alarming rate to use the limited land resource available. Even though what Khon and Gedion reported is true the problem in the area due to intensive agricultural activities (over cultivation of the

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• **The population data used is for the whole woreda i.e. it is not for part of each woreda in the catchment** land without any relaxation period) performed on the arable land to feed the growing population without application of any conservation and agricultural intensification techniques would lead areas currently having low erosion rate to sever erosion rate in the near future. According to some farmers in Bekoji and Digelu Tijo woredas, they used to produce 35 - 40 quintals per hectare but now on the same plot of land they are producing only 20 - 25 quintals per hectare due to loss of the fertile topsoil and lack of agricultural inputs such as fertilizers, improved seeds etc. (fig. 4.14). This decrease in production is one implication of land degradation. The other problems observed in the field survey related to increasing population in the area are lack of non-farm income and employment so continuous expansion of cultivation on new and more fragile (marginal) areas to fulfill the demand for land which in turn leads to soil erosion.

Figure 4.14 Cultivation on land, which lost much of the topsoil, Bekoji woreda

From all of the above observations there should be necessary conservation strategies and policies to be taken in association with the regional government and the local farmers to keep the current soil erosion rate as it is. If proper strategies are not taken there would be high erosion rate and farmers could completely abandon seasonal fallowing and practice continuous cultivation of land as one of their strategy to get the required amount of production to feed their family.

4.5.2. Livestock impacts in the Study Area

The increasing livestock density and the associated overgrazing on both arable and grazing lands have serious impact on the land and vegetation cover. Over 80 % of the livestock are in the highly degraded and vulnerable Ethiopian highlands (Alemneh, 2003). As described earlier population growth increases the need for livestock products, which in its turn increases number of livestock leading to overgrazing and consumption of crop residues (which is used as organic fertilizer) by animals. Most Ethiopian farmers do not like their livestock size to be reduced even if they have shortage of land.

In this study it was not possible to get data on the livestock of each woreda so data of the whole zone is used. As can be seen on table 4.9, in the zone except some decrement on the number of cattles from 2000/2001 to 2002/2003 the livestock data is increasing.

Livestock	2000/2001 G.C	2003/2004 G.C	2004/2005 G.C
Asses	224,251	253,606	266,893
Cattle	2,569,660	2,205,631	2,340,245
Goats	392,160	418,098	456,978
Horses	240,970	251,516	260,825
Mules	17,270	26,520	28,731
Sheep	1,095,440	1,239,594	1,507,642

Table 4.9 Livestock data of Arsi zone, CSA (2005)

Farmers in the study area have strong tendency in holding livestock as indication of wealth, which increases overgrazing. This overgrazing has different consequences on the environment such as soil degradation, compaction of fine textured soils, decreased soil organic content, decreased surface roughness, and reduction of vegetation and biomass cover. All these factors have their own role in decreasing infiltration and increasing runoff volume. So there should be proper policy designed to this increasing livestock population. The other thing to be considered in the zone regarding this increasing livestock population is introducing alternative source of livestock food (e.g. planting fodder trees and grasses) and delineation of grazing lands since it is important from the point of both food security and prevention of natural resource degradation.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

Land degradation is becoming a major issue in the world particularly in the developing countries. Ethiopia being a developing and agricultural country it is very important to study the causes of land degradation and design controlling mechanisms to this risk. In most parts of Ethiopia, land degradation is manifested in the form of soil erosion. The study area, Ketar catchment, is one of highly arable lands in the country susceptible for high soil erosion. In this study, erosion risk was assessed spatially using GIS.

The study area is topographically located with the altitude ranges of around 1700 m to 4000 m. It has a mean annual temperature and rainfall of 700 mm and 20 ^{0}C on the rift floor, to 1200 mm and 15 ^{0}C on the humid plateau and escarpments respectively. The area is characterized by intensive cultivation of wheat around Assela and barley is the other dominant crop cultivated further to the south near and around Bekoji. This area comprises six different stratigraphic units of which inter bedded ignimbrites overlain by massive rhyolites and trachytes with subordinate basalts are the dominant ones.

In this study to model the soil erosion and develop the erosion risk map of the area in t/yr/ha USLE model of Wischmeier and Smith (1978) was used. This empirical model was selected due to its universality and easily adaptability with little modifications (black box nature). Hurni (1985) has adapted this model for Ethiopian highlands so in the study this adaptation was used in modeling soil erosion that exists in the area.

The first factor, that is R factor, was calculated by using the formula developed for Ethiopia. For the calculation four years rainfall data of nine metrological stations was used, as a result minimum value of 376 and maximum value of 591 mm was obtained. The soil map of the area was obtained by clipping from ETHIOGIS (soil map of

Ethiopia prepared by FAO) and for each soil type k value of 0.10, 0.15 and 0.20 was assigned based on Hurni's adaptation.

The DEM of the area created from the digitized contour maps was used to generate L and S factors. Slope map obtained from the DEM was converted in percent and reclassified to assign the S factor values of the adaptation. Values of the L factor that was also generated from the slope map ranges from 0 – 10.

In this study the C factor and P factor values were assigned based on the land use map and field observations. From the field observation, the only conservation technique practiced by the farmers on the farm is contour ploughing. The C factor values range from 0.001 for forestlands and 0.15 for cultivated lands. In the case of the P factor only cultivated areas show a value of 0.9 and other land covers a value of 0.8.

The resulting soil erosion map produced by multiplication overlay of grid maps of the six factors showed that more than 90% of the area has a soil loss rate of less than 4.71 t/ha/yr. This rate is less than the soil formation rate, so much of the area is under tolerable condition. Those areas, which showed high erosion rate, are related to the steeper and longer slopes. Of the six weredas in the study area Digelu Tijo and Tiyo have larger area showing erosion rate > 9.42 t/ha/yr. The field observation showed the absence of gullies in most parts of the study except some early stages, which should be controlled before getting out of hand. The human population in all weredas is increasing at an alarming rate. For instance, in all weredas, it is possible to observe an average increament of 15% between the years 1999 and 2005. Eventhough, there was no livestock data for each wereda like the human population; its number is increasing in the zone.

This study also shows the effectiveness of GIS in modeling soil erosion and to develop erosion risk map, which can be used for decision support system.

5.2. Recommendations

The following points are recommended for other researchers and the regional government

- The output from this study shows the area is currently in tolerable condition but I further recommend other researchers to include the population and livestock data of each kebele and study their impacts in the soil degradation processes in the catchment because there was a problem to get these data in kebele level in this study.
- Expansion of non farm employment and alternative income generating strategies for the farmers to decrease the need for additional farm land which also decreases farming on marginal lands
- Creating awareness among farmers about short-term and long-term impacts of land degradation and designing appropriate strategies that participate farmers in soil and water conservations
- Providing the farmers with agricultural intensifying inputs so that they can get sufficient amount of production from their farm land, which would avoid their need for additional land
- Development of infrastructures like road, which could help the farmers in accessing markets easily for their increasing livestock on the other hand this would keep the number of livestock constant, schools for the farmers' children that would enable the new generation get opportunity in non-farm employments, which can possibly reduce the pressure on a plot of land.

Gleyaols: calcaric (Gc) or humic (Gh) or mollic (Gm)
Phaeozems (H), Lithosols (I)
Fluvisols: calcaric (Jc)
Luvisols: ferric (Lf)
Nitosols (N), Arenosols (Q)
Regosols: calcaric (Re)
Andosols: humic (Th) or mollic (Tm) Histosols (O)
Rankers (U), Solonchaks: mollic (Zm)

K = 0.15, if the soil type is:

Acrisols: gleyic (Ag) or plinthic (Ap)
Cambisols: chromic (Be) or dystric (Bd) or eutric (Be)
or gleyic (Bg) or calcic (Bk)
Gleysols: dystric (Gd) or eutric (Ge) or plinthic (Gp)
Fluvisols: dystric (Jd) or eutric (Je)
Kastanozezas (K)
Luvisols: chromic (Lc) or gleyic (Lg) or calcic (Lk) or orthic (Lo)
Greyzems (M)
Podzols: humic (ph) or leptic (Pi)
Regosols: dystric (Rd) or eutric (Re)
Solonetz: mollic (Sm)
Andosols: orthie (To) or vitric (Tv)
Planosolc: humic (Wh) or mollic (Wn)
Solonchaks : gleyic (Zg) or orthic (Zo)

K =0.20, if the soil type is:

Cambisois: vertic (Bv) or gelic (fix)
Podzoluvisols (D)
Gleysols: gelic (Gx)
Fluvisols; thionic (Jt)
Luvisols: albic (La) or plinthic (Lp) or vertic (Lv)

Podzols: ferric (Pf) or gleyic (Pg) or orthic (Po) or placic (Pp)
Regosols: gellic (Rx)
Solonetz: gleyic (Sg) or orthic (So)
Vertisols (V)
Planosols: dystric (Wd) or eutric (We) or solodic (Ws) or gelic (Wx)
Xerosols (X), Yermosols (Y)
Solonchaks: takyric (Zt)

High surface stoniness decreasees ths factor by 0.05

3. Slope Length Factor, L

Slope Length	L Factor
< 50m	1.2
50 - 200m	2.5
> 200m	3.8

4. Slope Gradient Factor, S

Slope Gradient (%)	S Factor
< 1	0.10
1 - 2	0.10
2 - 4	0.20
4 - 6	0.35
6 - 8	0.60
8 - 13	1.00
13 - 25	2.00
25 - 40	3.20
40 - 55	4.20
55 - 100	5.50
> 100	10.00

5. Land cover factor, C

Coffee, tea, banana, citrus, ensete	0.01
Paddy rice, sugarcane pineapple, sisal, grape	0.05
Sorghum, maize, millet sweet potato	0.10
Wheat, barley, oats, beans, peas, lentils, vetch, soybeans, niger seed, pepper, tomato, white potato, groundnut, sesame, sunflower, flax, cotton, tobacco	0.15
Upland rice, cabbage	0.20
Teff, shallot	0.25
Dense grass cover	0.01
Nondense forest	0.01
Degraded grass cover, grazing,hard badland, fllow	0.05
Soft badland	0.40
Continuous fallow	1.00

6. Management Factor, P

Mulch Application	0.60
Dense Inter cropping	0.70
Strip Cropping	0.80
Contour Ploughing	0.90
Up and down Ploughing	1.00

For the non-land use and non-management specific estimates of sheet erosion hazard, the values 0.15 (for the land cover) and 0.80 (for the management) were taken.

Appendix 2

Average soil formation rates in Ethiopia (after Hurni, 1983 a, b)

Agroclimatological Zone	Altitudinal limits (m a.s.l.)	Annual Rain (mm $year^{-1}$)	Soil Formation Rate (t ha^{-1} $year^{-1}$)
High Wurch	>3700		2
Wet Wurch	3200-3700	>1400	4
Moist Wurch	3200-3700	900-1400	3
Wet Dega	2300-3200	>1400	10
Moist Dega	2300-3200	900-1400	8
Wet Woina Dega	1500-2300	>1400	16
Moist Woina Dega	1500-2300	900-1400	12
Dry Woina Dega	1500-2300	<900	6
Moist Kolla	500-1500	900-1400	6
Dry Kolla	500-1500	<900	3
Berha "desert"	<500		1

Kulumsa

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	11	62.9	97.1	135	146	200	185.4	56.4	33.4	0
2001	0	19.5	76	54.3	210	143	128	73.3	80.2	10.5	0	0
2002	3.7	4.1	94	15.6	69	47	97	89.9	48.3	0	0	15.4
2003	1.1	5.6	10	36.9	94	80	204	61.7	122	0	0	5.2

Meki

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	0	77.4	63.3	56.6	113	181.4	138.3	18.1	63	19.2
2001	0	44.1	147.7	15.3	113.6	50.3	181	154.8	47.6	0	0	0
2002	0	8.6	42.1	72.3	12.7	65.1	122	145.6	29.3	0	0	24.2
2003	31.3	X	86.5	166.5	9.7	44.5	269	94.5	15.7	0	0	55.5

Sagure

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	X	X	X	X	X	X	71.6	228.7	70	42.5	26.2	16
2001	0.4	4.8	100.8	66.4	213.4	118.5	173.9	213.2	48	12.5	6.1	1.6
2002	21.4	8.6	120.7	35.8	109.3	116.1	106.9	86.4	43.7	6	0	23.1
2003	4.3	10.7	28.9	161	19.8	60.4	172.4	121.7	57.7	4.8	0.2	17

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