



**ADDIS ABABA UNIVERSITY
DEPARTMENT OF EARTH SCIENCE
GIS AND REMOTE SENSING STREAM**

Soil Erosion and Runoff Modeling using GIS, Remote sensing and SWAT model for Keleta Watershed, Ethiopia

**A THESIS
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES,
ADDIS ABABA UNIVERSITY
IN PARTIAL FULFILMENT OF
THE REQUIRMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN REMOTE SENSING AND GIS**

**By: Degefie Tibebe
Advisor: K.S.R. Murty (Ph.D)**

Addis Ababa, Ethiopia

March 2007



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Acknowledgement

First and foremost, thanks to the Almighty God for granting me His limitless care, love and blessings all along the way.

My sincere gratitude goes to my advisor Dr. K.S.R Murty for all his regular advice and guidance from the inception until the completion of the work. I express my deepest appreciation for his encouragement and moral support throughout the study period.

I am highly indebted to all GIS and Remote sensing students especially, Ermias, Brehane and Endaweke who encouraged and supported me during my stay at Addis Ababa University.

I would like to thank staffs of Ethiopian Institute of Agricultural Research: Elisabeth, Demeke, Simachew, Tiruwerk, Ahmed and Aklilu for their kind support in providing me different material throughout my study period.

I would like to thank my best friends: Danile, Girma and Addisu for providing me different technical material and advice that was necessary for the completion of this thesis.

Last but not least, I would like to thank all my friends and family members back home who were with me and gave me the strength to finalize my duties successfully. My family Askale, Amezene, Sisay, Eleni, Mintewab, Samson, Ephreme, Yamrot, Tigist and Selatial – thanks for your encouragement and support.

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List of acronyms

AVSWAT.....	ArcView Soil and Water Assessment Tool
BBF.....	Broad Bed Furrow
CN.....	Curve Number
DEM.....	Digital Elevation Model
GCP.....	Ground Control Point
GIS.....	Geographic Information System
HRU.....	Hydrological Response Unit
HUMUS.....	Hydrologic Unit Model for the United States
ITCZ.....	Inter Tropical Convergence Zone
MoWR.....	Ministry of Water Resource
MUSLE.....	Modified Universal Soil Loss Equation
SCRP.....	Soil Conservation Research Project
SCS.....	Soil Conservation Service
SWAT.....	Soil and Water Assessment Tool
SYI.....	Sediment Yield Index
TIN.....	Triangular Irregular Network
USDA.....	United States Department of Agriculture
USLE.....	Universal Soil Loss Equation
USGS.....	United States Geological Survey
WBISPP.....	Woody Biomass Inventory and Strategic Planning Project

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Abstract

Soil loss by runoff is the most serious problem in the world today because it is threatening agriculture and also natural environment. It can cause in lowering the productivity of a land temporarily or permanently. In order to reverse such kind of problem assessing the level of problem and finding solution at watershed level is necessary. Accordingly this study initiated to evaluate the soil loss and runoff potential spatially and temporarily in Keleta watershed. In order to achieve this purpose SWAT computer model integrated with GIS and Remote Sensing was used. Accordingly the runoff and soil loss simulation were done by dividing the watershed into twenty sub-watersheds. One hydrological response unit was assigned for each sub-watershed. The simulation result showed that runoff and soil loss was increased through out the simulation period. This situation was strongly correlated with the increasing trend of rainfall. Spatially the runoff amount was correlated with the type of soil and land use system. Chromic Vertisol and Eutric Cambisol with cultivated land use were characterized by high runoff potential. The soil loss rate was correlated with type of soil, slope gradient and land use system. Higher soil loss was observed from Eutric Cambisol, slope gradient greater than 25% with cultivated land use system. Prioritization of sub watershed was undertaken based on the degree of soil loss. Remedial measures were recommended based on the level of priority and type of problem.

1. Introduction

1.1 Background

Soil erosion is the gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate its quality. It involves the detachment, transportation and deposition of soil. The most commonly recognized forms of water erosion are splash erosion, sheet erosion, rill erosion, gully erosion and stream bank erosion.

Soil erosion in agricultural areas is the major problem, which is mainly enhanced by water erosion (Matheson, 1996:77). Soil erosion can cause in lowering the capacity of land productivity temporarily or permanently. The decrease in agricultural production and the threatening of natural environment are the main consequences of soil erosion.

Many studies were undertaken to evaluate the level of soil erosion in the world According to Lal & Steward, (1994) nearly 1.1 billion hectares of the world soils are affected by water erosion. Another study indicated that globally 1094.6 million hectare of land is degraded due to water erosion, deforestation; poor agricultural practices, urbanization, road building, and other disturbances expose soil to erosion (Leosmith, 1991: 153).

In Ethiopia soil erosion is a deep concern to agriculturalist and policy makers because the problem is becoming increasingly serious from time to time. Areas which are identified productive today will be turned out to marginal tomorrow. There were many studies were undertaken at different time to quantify the level of soil loss in Ethiopia. Kefeni (1989) in his study reported that Ethiopia is losing about 1 billion tones of productive soil annually, along with ETB, 12 million worth of plant nutrient of various types of erosion. 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 m³ of topsoil per year. Another report by the Soil Conservation Research Project (SCRIP, 1985) of Ethiopia indicated that the rate of soil loss in

extreme cases ranges from 0 to 300 t ha⁻¹yr⁻¹ with an average loss of 70 t ha⁻¹yr⁻¹, which is beyond the concept of any tolerable soil loss. This project also estimated that about 1.5 billion tones of soil are eroded away every year in Ethiopia.

Realizing all these effects, soil erosion has been considered as a national problem and all efforts are being attempted to control it. Proper planning and implementation of development work require prior quantification of soil erosion and runoff spatially and temporally. This is because quantitative assessment of hydrological parameters such as runoff and soil erosion serves as basic information for adopting suitable soil and water conservation measures. Now days, watershed is proved to be an ideal unit for the purpose of planning and implementing conservation measures and optimal use of natural resources. Interest in watershed analysis stems from the evidence that

- (1) Water resource utilization is best optimized through basin-wide management,
- (2) As the water resource component is analogous to the blood systems in animal bodies, it provides the best method to diagnose the state of natural resources utilization in a given watershed, and fluctuation of water debit is most widely interrelated to the other objectives of area-based development.

Watersheds are the fundamental landscape units used to assess and measure direct and off-site impacts of agriculture, soil and water conservation, climatic variation, and watershed management practices in general. Upland watershed responses are collected or integrated by channel and stream networks. These responses are additionally affected by riparian ecosystem processes in the overall watershed response. Watershed responses (e.g., hydrologic, riparian, water quality) to management and climatic inputs result from the complex interactions among numerous watershed factors.

1.2 Justification

In Keleta watershed soil erosion is caused by the intense rainfall and runoff, steep topography, and poor vegetation cover coupled with cultivation of steep lands, and inadequate conservation practices. In reality it is not possible to conserve all areas under the treat of erosion because of the financial constraints. The attention is given to only a few selected locations at a time to suit the constraints in acquiring sufficient funds. Therefore vulnerable areas are prioritized and then undertaken development. Though such prioritization work needs to consider many aspects such as critical areas of soil erosion, threat to lives and property, limitations in accessibility, social constraints and political stability etc., reasonable assessment of soil erosion is the core of any decision making.



Figure 1.1 Cultivation on Steep-Slope without any conservation practice in the Study area

The formulation of soil conservation policies requires an accurate quantification of the impact of water borne soil erosion on agricultural production. This holds especially for developing countries where economic conditions impede the purchase of expensive inputs that could compensate the deteriorative effects of water erosion, leaving farmers extremely dependent on intrinsic productivity

characteristics of the land. The correct assessment of soil degradation becomes therefore a critical issue.

Now a day's quantitative assessment of soil erosion and runoff at large spatial coverage is undertaken by integrating remote sensing data and GIS technology with many different computers models. Among it SWAT (soil and water assessment tool) is the one, which uses bulk spatially and temporally related data that are useful for modeling. Accordingly, in this study an attempt has been made to integrate Remote Sensing, GIS and SWAT model to model runoff and soil erosion in Keleta watershed, Ethiopia.

1.3 Objective of the study

The General objective of the study is:

- To evaluate the spatio-temporal change of soil loss

The Specific objectives of the study are:

- To evaluate the runoff and soil loss in response to rainfall over time
- To apply GIS technique with computer model in analysis of soil erosion and runoff
- To categorize and prioritize the watershed in terms soil erosion rate and runoff potential
- To recommend soil and water conservation measures.

2. Literature Review

2.1 Watershed management

A watershed is an area of land in which all rain and snow runoff and small tributaries drain into a common outlet. Watersheds are usually delineated from surface topography unlike catchments, which include area that provide water to the point through lateral flow over the surface and underground. Watershed is the most acceptable units for the purpose of planning for optimum use and conservation of natural resources (Verma et al 1995). It is also appropriate for most hydrological studies (Mulligan, 2004) and is widely used by many scientists. Scientific management of soil, water and vegetation resources on watershed basis is, very important to arrest erosion and rapid siltation in rivers, lakes and estuaries. It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money-time-effort making scheme.

Sharma et al (2003); Ravishankar et al (1994); Sharma et al (2001) and Suresh et al (2004) have found watersheds as appropriate units for prioritizing their study areas based on the soil erosion indexes.

Rosental et al (1995); Gangodamage and Aggarwal (2001); Tripathi et al (2002) and Jasrotia et al (2002) have used watersheds as the unit for hydrological modeling by using remote sensing and GIS for data acquisition and processing.

2.2 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).

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 inter 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.

2.2.1 Factors affecting soil 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:

2.2.1.1 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.

2.2.1.2 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 would be the amount of soil loss 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 is increased with increase in slope. Some researchers, for instance (Bobe, 2004) indicated that soil erosion increases exponentially with increase in slope gradient.

2.2.1.3 Soil erodibility

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, CaCO₃ (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.

2.2.1.4 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.

2.2.1.5 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.

2.3 Soil erosion modeling

Soil erosion is a complex dynamic process by which productive surface soil are detached, transported and accumulated in a distant place resulting in exposure of sub- surface soil, and siltation in reservoir or natural stream (Verma etal 2000). In face of this, soil erosion due to running water has been one of the most pressing environmental problems through out the world. This scientific approach for modeling of soil erosion and watershed management based on defined objective criteria is really important. Modeling soil erosion is a process of mathematically describing soil particle detachment, transport and deposition of land.

Jasrotia (2002) indicates that there are at list three reasons for modeling erosion as given below:

A).Erosion can be used as productive tool for assessing soil loss for conservation planning, project planning, and soil erosion inventories and for formulating regulations.

B).Physical base mathematical models can predict where and when erosion is occurring thus helping the conservation plan target to reduce erosion.

C). Models can be used as a tool for undertaking process and their interactions for setting reserve priorities.

P.M. Ndomba, F.W. Mtalo and A. Killingtveit(2005) have evaluated the sediment yield/soil loss for Simiyu River subcatchment, Tanzania using SWAT model. The results of Sediment yield modeling using SWAT model in Simiyu basin suggests that the model can be applied in ungauged catchments (i.e. poor data regions). They conclude that sediment yield modeling community from the tropic region to customize the SWAT model in their local area for improved watershed management.

SWAT model, applied to a truly intermittent river as the Mulargia, showed to be able to catch the behavior of the catchments and of most of the processes acting in it (Antonio Lo Porto et al 2005).

2.4 Runoff modeling

Surface runoff estimation is of immense important as it directly affects any planning (Schwab et al 2002). Tripath et al (2002) indicated that watershed parameters such as size of the catchments, slope, soil type, land use, vegetation within channels, and storage capacity of the watershed are of great importance in runoff modeling.

Direct measurement of the runoff from watershed is not only difficult operation but also gives only point data of a particular location. Hence various models have been developed and used for predicting peak runoff rate and runoff volume from each design rainfall based on specially related watershed characteristics.

Lumped and Distributed models are the two basic types of models used for Hydrologic Modeling. They can be deterministic or stochastic in nature, meaning the outputs are given as raw values or as probability of occurrences respectively.

Lumped Models:-Lumped hydrologic models are those models that commonly ignore spatial variations of precipitation, water flow, and other related processes, focusing instead on spatially averaged inputs, outputs, and parameter values. Their usefulness is limited due to their inability to account for the complexities of hydrologic processes and systems. Lumped models therefore are usually limited to those catchments where spatial variability does not dictate the outcome of an event (Muszik, 1996).

Distributed Models:-“A truly distributed model of a process is possible only if the process can be described by an equation having an analytical solution” (Muszik, 1996). These types of models are physically based; meaning they are based on observed parameters rather than estimations. While the majority of distributed models require some degree of lumping, their objective is to account for spatial variations of hydrologic processes and parameters. Previously, limitations of distributed models came from computing the vast amount of data required to run the model. However, due to advancements in computers and modeling software, the current limitation for distributed modeling is the lack of available distributed hydrologic data (Muszik, 1996).

The USDA-ARS Southwest Watershed Research Center and the U.S. EPA Office of Research and Development, has developed GIS tools to facilitate this process: AGWA, KINEROS and SWAT. AGWA uses widely available standardized spatial datasets that can be obtained via the internet. The data are used to develop input parameter files for two watershed runoff and erosion models: KINEROS and SWAT.

KINEROS, the Kinematic Runoff and Erosion Model is an event oriented, physically-based model developed at the USDAARS to describe the processes of interception, infiltration, surface runoff and erosion from small ($= 100 \text{ km}^2$) watersheds. The watershed is represented by a cascade of planes and channels, thereby allowing rainfall, infiltration, runoff, and erosion parameters to vary spatially. KINEROS may be used to determine the effects of various artificial features such as urban developments, small detention reservoirs, or lined channels on flood hydrographs and sediment yield.

Different researcher were used these models to simulate runoff and soil loss in different part of the world. Some of the studies were listed below

Chu and shirmohamadi (2004) have evaluated the hydrology component of soil and water assessment tool (SWAT) made in the piedmont physiographic region of Rary land, china. The surface runoff volume from daily rainfall is predicted in the model using the modified SCS curve number method (USDA-SCS 1972), which is based on daily moisture condition.

Rosenthol et al (1995) and Suresh et al (2004) they demonstrate that GIS can be used to efficiently collect and manage input in to the SWAT model. The result also indicates that the model closely simulated monthly stream flow volume even with no calibration.

2.5 GIS and remote sensing in runoff and soil loss modeling

Rainfall runoff and soil loss modeling using remote sensing and GIS involves extraction of spatially related model input parameters from remote sensing data such as satellite image and aerial photographs. For this purpose, preparation of land use/ land cover and soil maps is required based on which standard values are assigned or calculated as inputs for the model.

Reusing(2003) indicated that the most time and cost effective way to derive an accurate land cover data for larger areas is to interpret satellite remote sensing data. The synoptic view provided by satellite remote sensing offers technologically appropriate method for studying land and water resources, identifying problems, and suggesting conservation measures in watersheds (Mani et al 2003).

A wide variety of satellite remote sensing data from LandSat TM, SPOT and IRS (1B, 1C and 1D) are now available to the earth resource scientist for preparing soil and land resource maps at different scales (Sharma et al 2001).

Sharma et al (2001) have determined the priority categories of sub watersheds of Song river watershed, eastern Doon valley, based on sediment yield index (SYI). They have integrated land use/ land cover, physiographic and soil information obtained from IRS-1C LISS II data and terrain slope information from topographic

maps to generate composite erosion intensity units. The result has shown that 30% of the total areas fall under high priority category.

Pahari et al (1996) have assessed the utility of satellite remote sensing and GIS for monitoring the land use conditions and the rate of soil erosion. They made spatial and temporal analysis of soil erosion using USLE with revised topographic factor. They indicated that the information was then used for developing a suitable land use plan by considering the soil erosion as the limiting factor for sustainability.

Durbude et al (2001) have analyzed a typical watershed using IRS-1B LISS II satellite imagery for estimating the runoff potential under different geographical setup. They estimated the runoff potential using SCS method and recommended eight check dams and five irrigation schemes in the watershed.

Tripathi et al (2002) have conducted a runoff modeling of small watershed using satellite data and GIS. They used GIS to extract the hydrological parameters of the watershed from the remote sensing and field data. The land use classification was made from data of Indian remote sensing satellite (IRS-1B) LISS II to compute runoff curve number (CN), which they used to develop empirical models. They have concluded that the model can be applied for estimating runoff and evaluating its effect on structures of the Nogwan watershed.

Jasrotia et al (2002) have done a rainfall-runoff and soil erosion modeling using remote sensing and GIS technique in Tons watershed. The rainfall-runoff relationship for the watershed was obtained by using SCS curve number method in remote sensing and GIS environment. The result has shown that the coefficient of determination (R^2) is 0.99, which indicates a high correlation between rainfall and runoff.

Dutta et al (1995) have studied the potential use of remote sensing and GIS for mapping of soil erosion through USLE. IRS LISS II sensor data and ARC/INFO GIS packages have been used for spatial modeling of soil erosion in the shahbad area of Baran district of western Rajasthan. The result of the study has shown that remote sensing and GIS are too excellent tools to spatially model the

different factors of USEL even with limited ground check and meteorological information.

Sharma et al (2003) and Ravishankar et al (1994) have used the IRS-1C LISS III and IRS-1B LISS I data, respectively, to prioritize watershed using USEL. Chowdary et al (2004) and Sharma et al (2001) used IRS-1C LISS data for watershed prioritization based on sediment yield index (SYI).

2.8 Data sources, Materials and Method

2.8.1 Data sources

The data and their sources were used for this study are described as follows:

- Eight topographic sheets at 1:50,000 scale were purchased from Ethiopian Mapping Agency
- LandSat TM imagery (capture data on December 5, 2000) were acquired from University of Maryland (Global land cover)
- Digital soil map was acquired from WBISPP at 1:250,000 scale.
- Climate data (1981-2000) were collected for four weather stations namely Dhera, Dixis, Kulumsa, Sire from Ethiopian Institute of Agricultural research
- Runoff data from 1981 to 2000 were collected for keleta river from Ministry of Water Resource

2.8.2 Materials

A GIS provides the framework within which spatially distributed data are collected and used to prepare model input files and evaluate results. **ArcView GIS** was used as the main Processing and display as well as a host program to run AVSWAT 2000 model.

The **AVSWAT-2000** (Di Luzio *et al.*, 2002) an ArcView extension and a graphical user interface for the SWAT (Soil and Water Assessment Tool) model was used for the modeling. The AVSWAT-2000 ArcView extension evolved from AVSWAT, an ArcView extension developed for an earlier version of SWAT (Di Luzio *et al.*, 1998).

ERDAS 8.6 was used to classify and interpret the land use/ cover map of the study area. It is one of the raster based GIS software.

Microsoft Excel 2003 was used to prepare and analyze climatic and runoff data.

TIMESPLOT Program was used for base flow separation. It is developed on Microsoft Excel program.

2.8.1 Method

In order to achieve the objectives AVSWAT model integrated with remote sensing data and GIS techniques were used for simulating soil loss and runoff on spatially and temporally. Figure 2.1 shows the complete methodology followed in the present study.

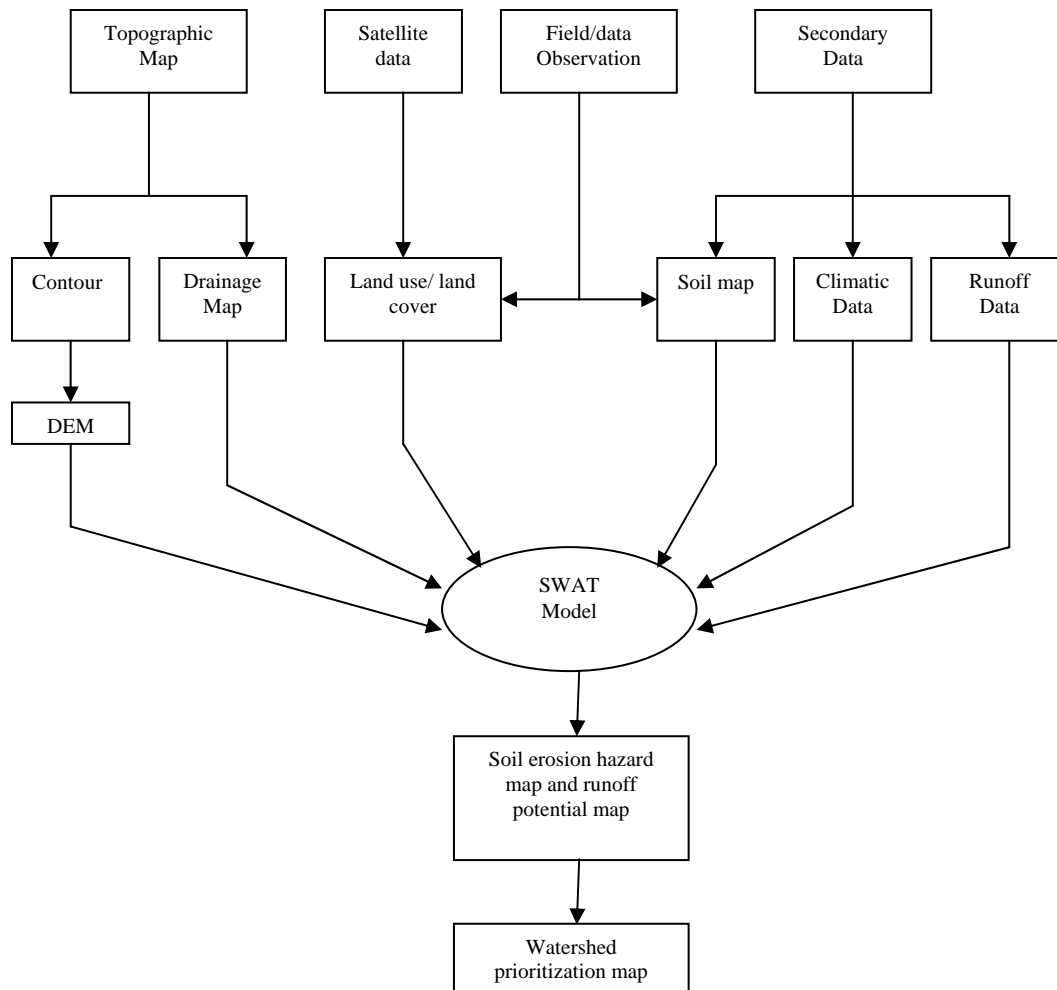


Figure 2.1 Schematic Diagram showing the Methodology

2.8.2 SWAT (Soil and Water Assessment Tool)

SWAT is a physically based, continuous time (Lenhart et al. 2002) and computationally efficient hydrological model, which uses readily available inputs. It was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch (a) et al. 2002). It enables users to study long-term impacts and hence is being used extensively in the US and Europe to assess the impact of global climate on water supply and quality (Rosenberg et al. 1999 cited KU Leuven E-manual). The model can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds (Neitsch (a) et al. 2002). SWAT is used worldwide and has been chosen by the Environmental Protection Agency to be one of their better assessment science integrating point and nonpoint sources (BASINS) models (Whittemore 1998 cited Lenhart et al. 2002). Thus, regulating environmental agencies will likely be using it increasingly (Lenhart et al. 2002).

The main reasons for the selection of SWAT model are that the model is physically based, spatially distributed, and it belongs to the public domain. SWAT simulates hydrological outputs based on a changed climate if the changes in the climate parameters are given as an input to the model. This makes the model suitable for the proposed task. Beyond that, the ArcView 3.2 integrated SWAT interface called the AVSWAT model provides a user friendly GUI that ease the use of the model. The model has also been tested in different tropical watersheds and reported to be able to well explaining watershed hydrological processes: the study by Gosain et al. (2006) in Indian river basin, Benavides and Veenstra (2005) in tropical deforestation, Muthuwatta and Becht (2006) in Kenyan river basin, and Dilnesaw (2006) in Ethiopian Upper Awash River Basin can be sited as examples, which additionally justify the possible use of this model in the study area. A strong interest of testing suitability of different physically based models such as SWAT in different Ethiopian watersheds was also another ground for the selection.

AVSWAT (ArcView SWAT) is a complete preprocessor, interface and post processor of SWAT. It has been developed as an extension of ArcView GIS 3.2 by Blackland Research Center, a Texas Agricultural experiment Station part of Texas A & M University System in Temple, Texas, in collaboration with Grassland Soil and Water Research Lab, a USDAARS laboratory in Temple, Texas. Being in the user friendly ArcView GIS 3.2 environment; the model provides the tools for delineating the watershed, defining the land use and soil, editing the model data bases, defining the weather stations, parameterize and editing the inputs, running the model, reading and mapping the results, and calibrating the simulation results.

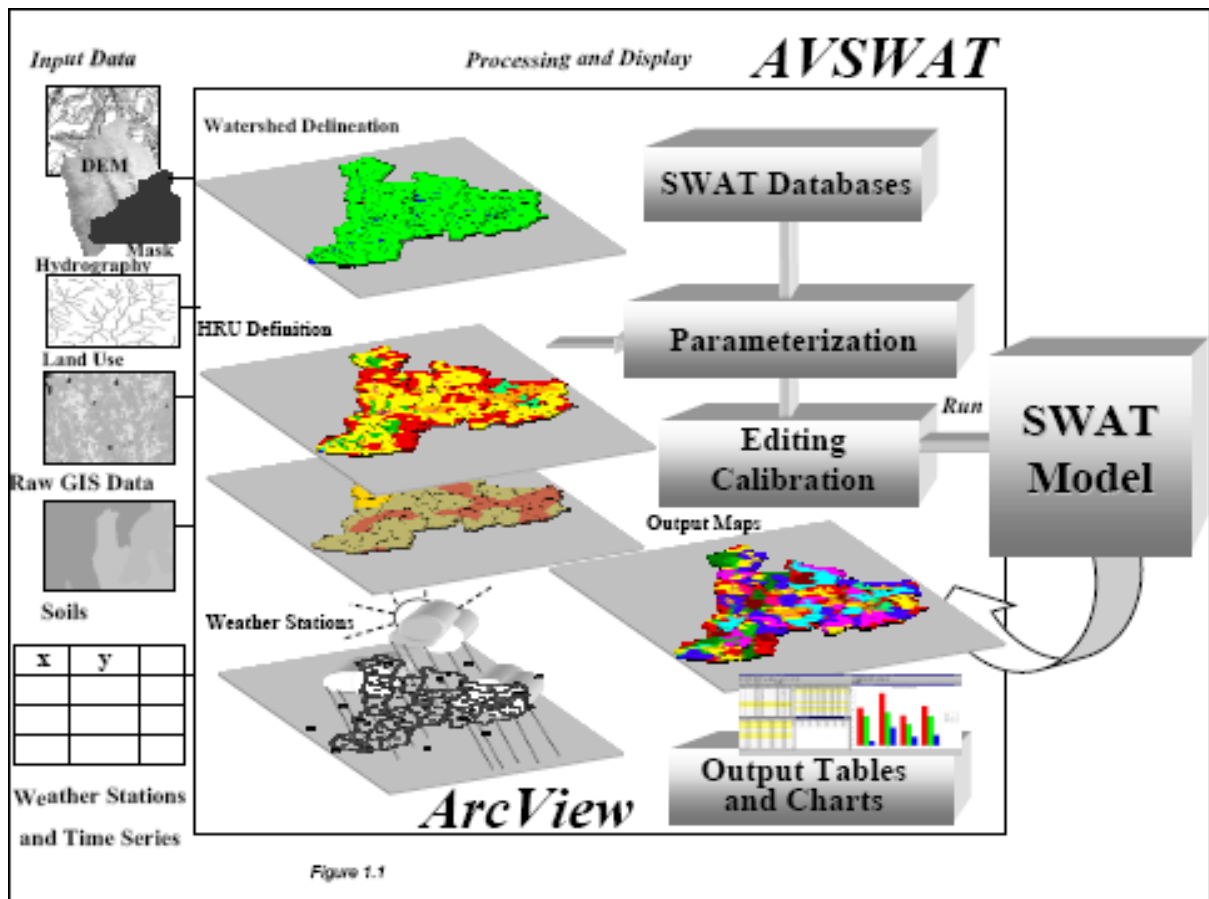


Figure 1.1

Figure 2.2 AVSWAT model

2.8.2 AVSWAT Model Approach

Watersheds can be subdivided into sub watersheds and further into hydrologic response units (HRUs) to account for differences in soils, land use, topography, weather, etc. The model has a weather generator that generates daily values of precipitation, air temperature, solar radiation, wind speed, and relative humidity from statistical parameters derived from average monthly values. The model computes surface runoff volume either by using modified SCS curve number method or the Green & Ampt infiltration method. Flow is routed through the channel using a variable storage coefficient method or the Muskingum routing method. SWAT has three options for estimating potential evapotranspiration: Hargreaves, Priestley-Taylor, and Penman-Monteith. The model also includes controlled reservoir operation and groundwater flow model. The important equations used by the model are discussed as follows. The detailed and complete descriptions are given in the SWAT theoretical documentation (Neitsch (a) et al. 2002).

SWAT splits hydrological simulations of a watershed into two major phases: the land phase and the routing phase. The difference between the two lies on the fact that water storage and its influence on flow rates is considered in channelized flow (Neitsch (a) et al. 2002).

The land phase of the hydrologic processes is simulated based on the following water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where SW_t is the final soil water content (mm H₂O), SW_0 is the initial soil water content on day i (mm H₂O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H₂O), Q_{surf} is the amount of surface runoff on day i (mm H₂O), E_a is the amount of evapotranspiration on day i (mm H₂O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H₂O), and Q_{gw} is the amount of return flow on day i (mm H₂O).

2.8.2.1 Watershed Delineation

The ArcView GIS tool in AVSWAT partitions watersheds into a number of hydrologically connected subbasins based on flow directions and accumulations. The watershed and subbasins delineation was carried out based on an automatic delineation procedure using a Digital Elevation Model (DEM) and digitized stream networks. The model fills all of the non-draining zones (sinks) to create a flow vector, and superimposes the digitized stream networks into the DEM to define the location of the stream network.

The AVSWAT interface proposes the minimum, maximum, and suggested size of the subbasin area (in hectare) to define the minimum drainage area required to form the origin of a stream. Generally, the smaller the threshold area, the more detailed are the drainage networks, and the larger are the number of subbasins and HRUs. However, this needs more processing time and space.

2.8.2.2 Determination of Hydrologic Response Units (HRUs)

The subbasin delineation was followed by the determination of HRUs, which are unique soil and land use combinations within a subbasin modeled regardless of their spatial positioning. This describes better the hydrologic water balance and increases the accuracy of load predictions (Luzio et al. 2002). SWAT predicts the land phases of the hydrologic cycle separately for each HRU and routes to obtain the total loadings of the subwatershed.

The land area in a subbasin may be divided into hydrologic response units (HRUs). Hydrologic response units are portions of a subbasin that possess unique Land use/management/soil attributes. HRUs were incorporated into SWAT as part of the HUMUS (Hydrologic Unit Model for the United States) project. HUMUS used U.S.G.S. 2-digit hydrologic boundaries to divide the contiguous United States into watersheds while 8-digit hydrologic boundaries were used to define subbasins within the watersheds. Only percentages of soil and Land use were known within the 8-digit hydrologic units. The geographic location of the Land use and soils within each subbasin was unknown. To capture the diversity of land use and soils that could be encompassed in an 8-

digit hydrologic unit, a method was needed to account for the complexity of the landscape within the boundaries of the subbasins. The inclusion of HRUs allowed SWAT to account for this diversity. Prior to the HUMUS project, only one Land use/management/soil combination could be defined per subbasin in SWAT. An HRU is not synonymous to a field. Rather it is the total area in the subbasin with a particular Land use, management and soil. While individual fields with a specific Land use, management and soil may be scattered throughout a subbasin, these areas are lumped together to form one HRU. HRUs are used in most SWAT runs since they simplify a run by lumping all similar soil and land use areas into a single response unit. It is often not practical to simulate individual fields. Implicit in the concept of the HRU is the assumption that there is no interaction between HRUs in one subbasin. Loadings (runoff with sediment, nutrients, etc. transported by the runoff) from each HRU are calculated separately and then summed together to determine the total loadings from the subbasin. If the interaction of one Land use area with another is important, rather than defining those Land use areas as HRUs they should be defined as subbasins. It is only at the subbasin level that spatial relationships can be specified. The benefit of HRUs is the increase in accuracy it adds to the prediction of loadings from the subbasin. The growth and development of plants can differ greatly among species. When the diversity in plant cover within a subbasin is accounted for, the net amount of runoff entering the main channel from the subbasin will be much more accurate. As a general rule, a given subbasin should have 1-10 HRUs. For those wishing to incorporate more complexity into a dataset, it would recommend that the user define a greater number of subbasins in the watershed rather than many HRUs within a few subbasins. Of course, there are exceptions to this rule. An example of such an exception would be the requirement that the project uses a particular subbasin delineation that doesn't allow the user to capture Land use diversity without the incorporation of many HRUs.

The HRUs can be determined either by assigning only one HRU for each subwatershed considering the dominant soil/Land use combinations, or by

assigning multiple HRUs for each subwatershed considering the sensitivity of the hydrologic process based on a certain threshold values of soil/Land use combinations.

2.8.2.3 Soil Erosion Simulation

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) in the SWAT model. MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

The modified universal soil loss equation (MUSLE) (Williams, 1995) is:

$$sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

where *sed* is the sediment yield on a given day (metric tons), *Q_{surf}* is the surface runoff volume (mm H₂O/ha), *q_{peak}* is the peak runoff rate (m³/s), *areahru* is the area of the HRU (ha), *K_{USLE}* is the USLE soil erodibility factor (0.013 metric ton m² hr/(m³-metric ton cm)), *C_{USLE}* is the USLE cover and management factor, *P_{USLE}* is the USLE support practice factor, *LS_{USLE}* is the USLE topographic factor and *CFRG* is the coarse fragment factor. The detailed and complete descriptions are given in the SWAT theoretical documentation (Neitsch (a) et al. 2002).

2.8.2.4 Surface Runoff Simulation

Surface Runoff Volume

SWAT provides two methods for estimating surface runoff: the SCS curve number method (SCS 1972) and the Green & Ampt infiltration method (1911). Even though the latter method is better in estimating runoff volume accurately, its sub-daily time step data requirement makes it difficult to be used for this study. Hence, the SCS curve number method was adopted.

The method is an empirical model, which is based on the following equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Where: Q_{surf} is the accumulated runoff or rainfall excess (mm H₂O), R_{day} is the rainfall depth for the day (mm H₂O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H₂O), and S is the retention parameter (mm H₂O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention Parameter is defined as:

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right)$$

Where: CN is the curve number for the day. The initial abstractions, I_a , is commonly approximated as $0.2S$.

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$

Runoff will only occur when $R_{day} > I_a$. The detailed and complete descriptions about CN are given in the SWAT theoretical documentation (Neitsch (a) et al. 2002).

Peak Runoff Rate

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm

and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method. The rational method is widely used in the design of ditches, channels and storm water control systems. The rational method is based on the assumption that if a rainfall of intensity i begins at time $t = 0$ and continues indefinitely, the rate of runoff will increase until the time of concentration, $t = t_{conc}$, when the entire subbasin area is contributing to flow at the outlet.

The rational formula is:

$$q_{peak} = \frac{C \cdot i \cdot Area}{3.6}$$

Where: q_{peak} is the peak runoff rate ($m^3 s^{-1}$), C is the runoff coefficient, i is the rainfall intensity (mm/hr), $Area$ is the subbasin area (km^2) and 3.6 is a unit conversion factor from (mm/hr) (km^2) to m^3/s . The detailed and complete descriptions for each parameter are given in the SWAT theoretical documentation (Neitsch (a) et al. 2002).

2.8.2.5 Base Flow Separation

For calibration of simulated flows, the total gauged stream flow data should be separated into surface and base flow components. For this study simple base flow separation technique was used. The technique is developed on Microsoft Excel program. The base flow separation implemented in program TIMESPLOT is based on a recursive filter commonly used in signal analysis. This filter has been described by Nathan and McMahon (1990).

2.8.2.6 Flow Calibration and Validation

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, entered with the use of historic meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated. For this study manual calibration was done based on the procedures recommended in SWAT user manual (Neitsch et al. (b) 2002)

The curve number (CN), and the soil evaporation compensation factor (ESCO) are the most sensitive parameters in the surface runoff calibration. Accordingly these two parameters were used to adjust the measured and the simulated discharge. For the calibration work the separated gauged discharge reading from 1990 to 1995 was used. For every calibration work there is a need validation to evaluate how much the simulation performed well.

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation-period stream flows confirm that the model performs satisfactorily. For evaluating the simulation in relation to the measured the regression coefficient (R^2) is the square of the Pearson product-moment correlation was used. It describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to 1, the higher is the agreement between the simulated and the measured flows.

3. Description of the study Area

3.1 Location

Keleta watershed is located between $7^{\circ} 56'$ to $8^{\circ} 23'$ N latitude and $39^{\circ} 12'$ to $39^{\circ} 32'$ E longitudes which is at a distance of 200 km East of Addis Ababa, capital city of Ethiopia. Keleta watershed is sub-catchments of the Awash River basin, which is one of the largest basins in Ethiopia that can be categorized into upper, middle and lower part. Keleta watershed is found particularly in the upper part of the basin. It is one of the major contributors for the Awash River. The drainage area of the watershed is 1060.4 Sq.km. In the watershed two towns exists namely Sire and Huruta.

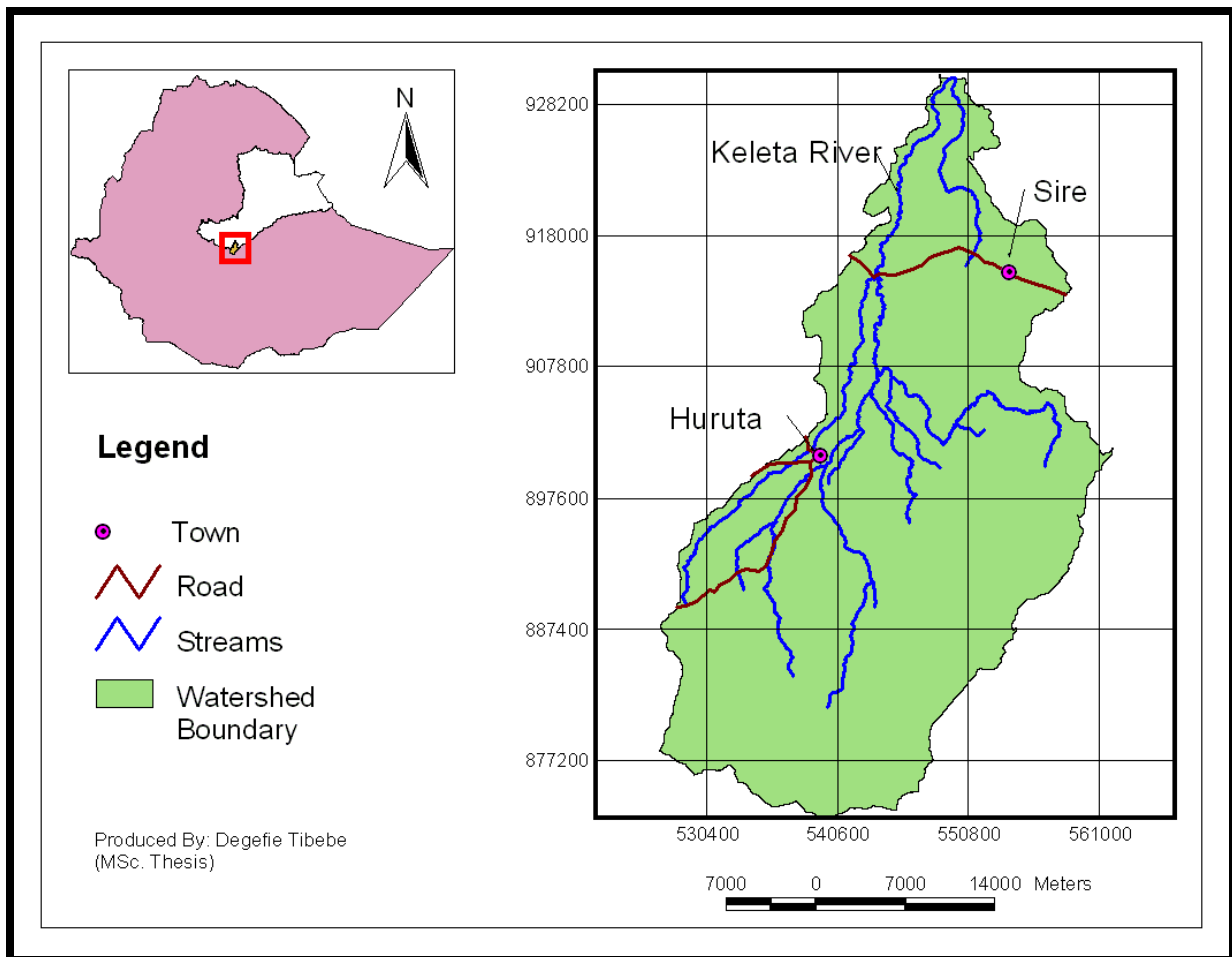


Figure 3.1 Location map of the study area

3.2 Topography

Keleta watershed has a very diverse topography. The altitude range in the watershed is from 1320 to 4180 m.a.s.l. The upper part of the watershed is bounded by the Arsi Highlands specifically by Chelalo Mountain, which is one of the largest mountains in Ethiopia and stretch to lower part that is the main channel of Awash River. The watershed of the area is classified by steep to gentle slope. Most the lower part is gentle slope and the upper and middle part is from steep to moderately steep.

3.3 Climate

The Indian and Atlantic Oceans are the sources of moisture for almost all rains in Ethiopia (Degefu 1987 cited OEPO 2005). Three main seasons characterize the study area: The first one is the long rainy season in summer, which lasts from June to September and locally known as '*kiremt*'. The '*kiremt*' season is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ), which lies to the north of Ethiopia at that time. According to Degefu (1987), the '*kiremt*' rain represents 50-70% of the average yearly total. The second is the dry period, which extends between October and February and locally known as '*bega*'. In '*bega*' the ITCZ lies to the south of Ethiopia when the northeasterly trade winds traverse Arabia dominates the region. Degefu (1987) indicated that occasional rains during this period bring 10-20% of the yearly average. The '*bega*' season is known as the main harvest season in the area. The third season, which is locally known as '*belg*' is of a '*small rain*' season accounting for 20-30% of the annual amount, and stays from March to May.

As per the climate of the watershed, from dry semi arid in the lower part to wet Sub humid in the upper part is identified. The average annual rainfall is ranging from 680.53 mm to 930.60 mm and the mean maximum and minimum temperature ranges from 23.08 °C to 30.85 °C and from 10.28°C to 15.49°C.

3.4 Soils

The watershed has a diversified soil type. The type of soil in the area is influenced by the two major factors, which are Climate and Parent material. According to (WBISPP 2000) the major soil types in the area are, Chromic Luvisol, Chromic Vertisol, Eutric Cambisol, Eutric Gleysol, Eutric Nitosol, Eutric Regosol, Vitric Andosol, and Lithosol. Chromic Vertisol, Lithosol and Eutric Cambisol cover more than 60 % of the watershed. Chromic Vertisol accounts 29.14%, Lithosol accounts 23.03% and Eutric Cambisol accounts 20.23%. The Upper part of the watershed is most covered with Luvisol and Nitosol, this is because of the humid environment which is the result of highly weathering. The middle part of the watershed is dominated by Lithosol and Vertisol with some Regosol. Lithosol and Regosol are characterized by not mature type of soil and can occur on steep slope. The lower part soil in the watershed is mostly covered by Andosol and Cambisol. These soils are developed by the parent material of the area.

3.5 Land use/Land cover

Keleta watershed is characterized by a diverse land use/ land cover types. The major land use /land cover are Grass land, Cultivated land, Mixed Shrub and Cultivated land, Shrub land with exposed rock , Forest land, Mixed forest and cultivated land, Afro alpine with Grass land and Settlement. 73 % of the watershed is covered by cultivated land which is the most dominate land use in the area. The upper part of the watershed is covered with Afro alpine vegetation and Grass land. The middle part is dominated by cultivated land and the lower part is covered by open shrub land and grass land. Exposed rock covered some areas along the Keleta River in the lower part of the valley. Some pockets of land in the middle part of the watershed are covered by dense forest.

3.6 Hydrology and Drainage

Keleta watershed is characterized by the high potential of surface water resources. This is because of high rainfall amount in the area. The relief of the

area makes many streams to be occurred. Some of the major streams are Boru, Bedessa, Wedecha, Chancho, Wabero, Gura, Goro, Robi and Shoya. Boru and Wedecha from the Western, Chancho from Eastern and Bedessa in middle are the biggest streams that are occurred in the area.

Keleta watershed is found in the upper part of the Awash River Basin which is the major river basin in Ethiopia. It is bounded by the Arsi Highlands, specifically, the Chilalo Mountain. There is no inlet source in the watershed. There is one outlet through which the keleta river is joined the main channel of the Awash River. There are many tributaries and streams started from the Chilalo Mountain and form the Keleta River. The sources of these streams are started at elevation of above 4000 m.a.s.l and reached to the out let below 1500 m.a.s.l. The streams are characterized by dendritic drainage network.

3.7 Agricultural Activity

The agricultural activity of the watershed is mainly depending on rainfed agriculture. The watershed is categorized by two growing seasons. These two seasons are strictly coincide with the rainy period of the area. Accordingly the area is classified by bimodal type of rainfall. The first rainy season is called "Belg" which is the short duration rainfall starts from mid February to March and the long rainy season is called "Kiremt" which is long rainy season from early June to mid September. Most of the time the short rainy seasons is used to prepare their land for the coming long rainy season except some areas which used this rainfall for producing short duration cultivars like Maize in the Lower part of the watershed. The long rainy season is used to produce long duration crops like Barely, Wheat and Teff in the upper and middle part and Sorghum, maize and Haricot bean in the lower part of the watershed. Farmers in the area are practicing different type of cropping system. The major cropping system in the lower part is intercropping of cereals crop with legumes for example cropping Maize with Haricot bean. Alley cropping and crop rotations is also some of the cropping system of the lower part of the watershed. Whereas the upper part is dominated by the monocropping of a single cultivar like Barley, Wheat or Teff.

4. Data Analysis and the SWAT Set-up

The predictions of erosion/sediment loss and runoff volume from the keleta watershed were calculated using the MUSLE and SCS-CN methods respectively. SWAT is physically based distributed model, which can predict the hydrology, sediment loss and nutrient load from catchments. SWAT requires information on soils, land use, topography, drainage and climate for a selected catchment and predicts outputs on sub catchments basis. In terms of predicting soil erosion, SWAT uses the MUSEL and Runoff using the SCS-CN as outlined by Wisniewski & Smith (1975).

The keleta watershed study described in this paper was used to simulate the soil loss and runoff for 20 years period and validate the runoff. Although SWAT calculations were made on daily basis, experience has shown it to work best on monthly basis and annual basis. For this study, simulations were undertaken using data from 1981-2000 at monthly and yearly bases

To undertake a SWAT simulation, a Variety of detailed information is required on climate, land use, soil, topography and the drainage network. The process for obtaining this data and other sources are described as follows:

4.1 Remote Sensing Data Analysis

The prime objective of remote sensing is to extract environmental and natural resources data related to the earth. Information about the resource concerned is conveyed to the sensor (loaded on aircraft or spacecraft) which is an information carrier and thus provides the communication link with the earth data acquisition and distribution centers. Therefore, the data or information can be carried out through the basic knowledge of an electromagnetic spectrum which ranges from Ultra Violet to microwave (which includes visible infrared, thermal infrared and radar portions of the wave length).

During the last 20 years, multi-temporal, high-resolution, remotely sensed data and Geographic Information System have been used extensively to monitor environmental change and to map land cover changes on the local, regional, and global scales, Booth (1989), Lillesand and Kiefer, (1999), Berberoglu, (2003).

Such information is essential for Land use planning and sustainable management of resources. Sustainable management of natural resource requires that ecological goods and services to be used to meet both current and future generations need by recognizing and adapting to the inevitable biophysical limitations and interdependences, Evrendilek and Doygun, (2000), Wali et al ., (2002).

4.1.1 Land use Data

Spatial distribution and a list of specific land use parameters were required. The land use/land cover map was prepared from Landsat TM imagery acquired at December 5, 2000. Preprocessing of the image was done and preparing it with 4, 3, 2 band combination for classification. Firstly unsupervised classification was done using the maximum likelihood classification algorithm to cluster the different land use/ land cover classes. Using this classified image, 100 random points were generated for the accuracy assessment purposes.

Accordingly comparison was done with the land use/land cover map that was done by WBISPP in 2000 for these 100 check points for estimating the kappa index statistics. It value was 0.70 and it is moderately acceptable limit for land use/land cover classification. For each land use/land cover, cover factor was assigned based on the standards done by WBISPP in 2000. There are eight land use classes were classified. The classes are Grass land, cultivated land, mixed Cultivated and Shrub land, Exposed rock and shrub land, Forest land, mixed Cultivated and Forest land, Afro alpine vegetation and Grass land, and Settlement.

SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces. Hence, while preparing the lookup-table, the land use types were made compatible with the input needs of the model. Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database.

Table 4.1 Original land use and SWAT code for the watershed

<i>Original Land use</i>	<i>Redefined Land use according to the SWAT Database</i>	<i>SWAT_Code</i>
Grass land	Pasture	PAST
Cultivated land	Agricultural land-Generic	AGRL
Shrub land + Cultivated land	Agricultural land –Row crops	AGRR
Shrub land + Exposed rock	Range Brush	RNGB
Forest Land	Forest Deciduous	FRDS
Cultivated +Forest land	Forest Mixed	FRST
Afro alpine + Grass land	Forest Evergreen	FRSE
Settlement	Urban-Medium Density	URMD

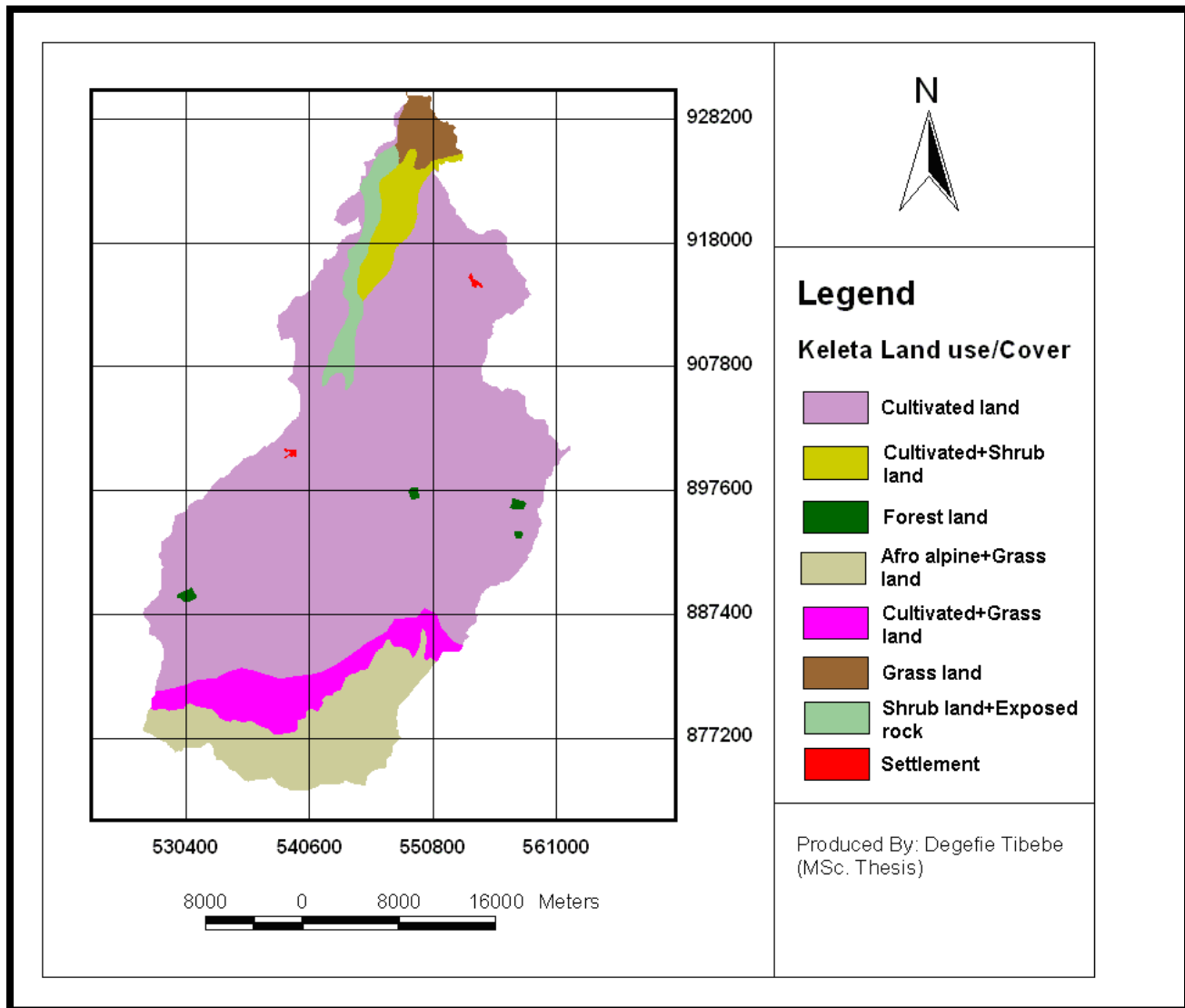


Figure 4.1 Land use map of Keleta watershed

Table 4.2 The area coverage of land use in Keleta watershed

<i>Land use</i>	<i>SWAT Code</i>	<i>Watershed Area Km²</i>	<i>Watershed Area %</i>
Grass land	PAST	20.47	1.93
Cultivated land	AGRL	782.01	73.93
Shrub land + Cultivated land	AGRR	31.78	3.00
Shrub land + Exposed rock	RNGB	28.42	2.68
Forest Land	FRDS	3.18	0.30
Cultivated +Forest land	FRST	69.48	6.56
Afro alpine + Grass land	FRSE	123.02	11.61
Settlement	URMD	1.11	0.10

4.2 GIS Data analysis

Geographic Information System (GIS) has become of greater help in geographic data input, management, manipulation and analysis, and output. It has increasingly become a tool allowing for the identification of spatial relationships in which planners and decision-makers can explore a multitude of possible scenarios and obtain an idea of these relationships. GIS is applied in agriculture and land use planning, forestry and wildlife management, geology, archeology, urban development, watershed management and others. In the natural resource, GIS is being extensively used for investigation of vegetation trends, assessment of hydrological potentials, soil and water conservation planning, soil and relief analysis, and the like.

Accordingly, GIS can be used for this study for preparing the basic inputs soil data, Digital Elevation Model (DEM), and the drainage network of the study area. Besides to this the SWAT model itself running in the GIS environment by integrating the spatial data that is above listed and the none spatial data the climate row data in attribute format.

4.2.1 Soil Data

Soil data were required for the model to provide both the distribution of soil types in the catchments and the various parameters describing the soils hydrological

and textural properties. The distribution of soil types was obtained from WBISPP 2000 at 1:250000 scale. The soil parameters data were obtained from Kulumsa and Melkassa Agricultural Research Centers and some of them were estimated. The SWAT model is required the soil map in grid format. The size of the grid is depending on the base map that was the DEM 30m by 30m.

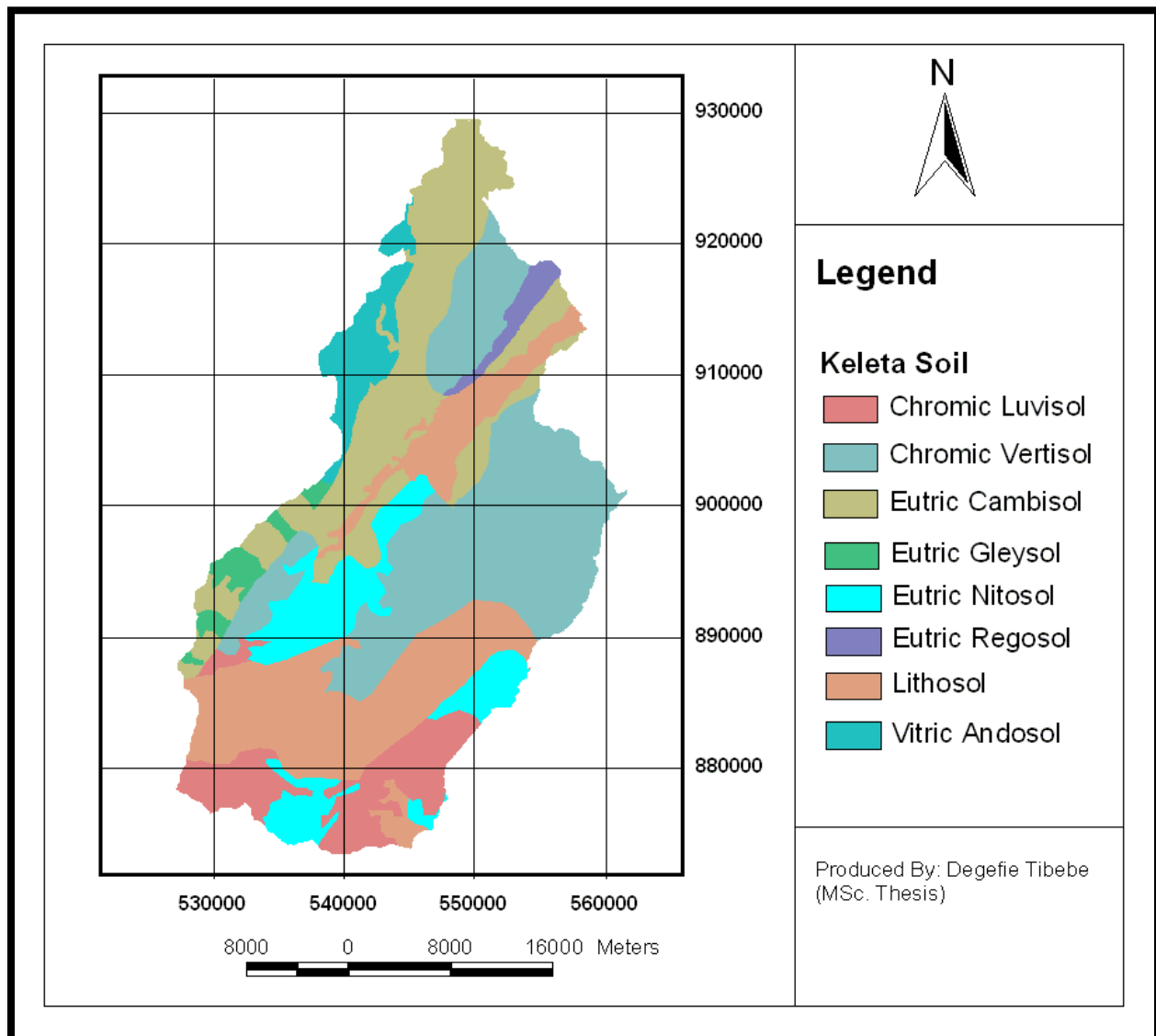


Figure 4.2 Soil map of Keleta watershed

Table 4.3 The area coverage of soils in Keleta watershed

<i>Soil Type</i>	<i>Watershed Area Km²</i>	<i>Watershed Area %</i>
Eutric Cambisol	214.42	20.23
Chromic Vertisol	308.82	29.14
Vitric Andosol	48.94	4.62
Eutric Gleysol	20.51	1.94
Chromic Luvisol	96.22	9.08
Lithosol	244.08	23.03
Eutric Nitosol	110.51	10.43
Eutric Regosol	16.39	1.55

4.2.2 Topographic Data

The topographic data, in the form of a 20m contour map, and a map of the stream network for the area were required initially to delineate the catchments boundary for the keleta, and subsequently for the derivation of cell slope and elevation, the derivation of cell slope and elevation, the derivation of sub-basins. Map of the drainage and topography were obtained by digitizing 1:50000 scale top sheets prepared by the Ethiopian Mapping Agency. After digitizing of the drainage network and contour in shape format, Triangular Irregular network (TIN) was made from the elevation contour and finally converted to grid format at cell size of 30 m by 30m. The digital elevation model (DEM) in grid format and the digitized drainage network were used to delineate the boundary of the keleta watershed and its sub-basins by providing an inlet and outlet sources. SWAT requires sub-basins to model the soil loss and runoff of the keleta watershed.

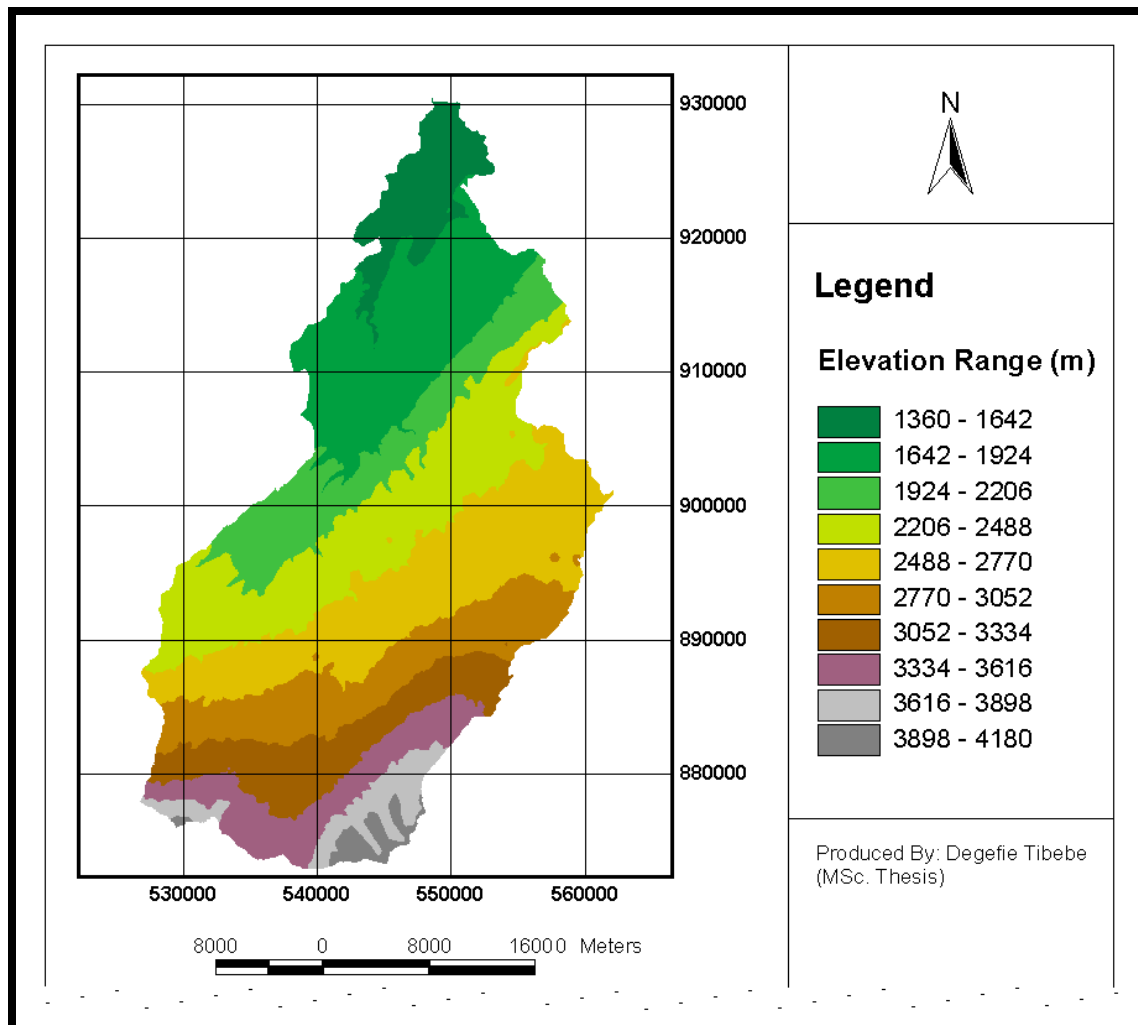


Figure 4.3 Elevation range of Keleta watershed

As figure 4.3 depicted that the elevation ranges from 1360 to 4180 m.a.s.l. Chilao Mountain is the highest peak in the watershed which is the third largest mountain in Ethiopia. This elevation covered small area of the watershed which is in the upper part of the watershed. The lowest elevation range is occurred at the channel of the main Awash River. The rest elevation ranges is in between the two extremes which covered the larger part of the watershed.

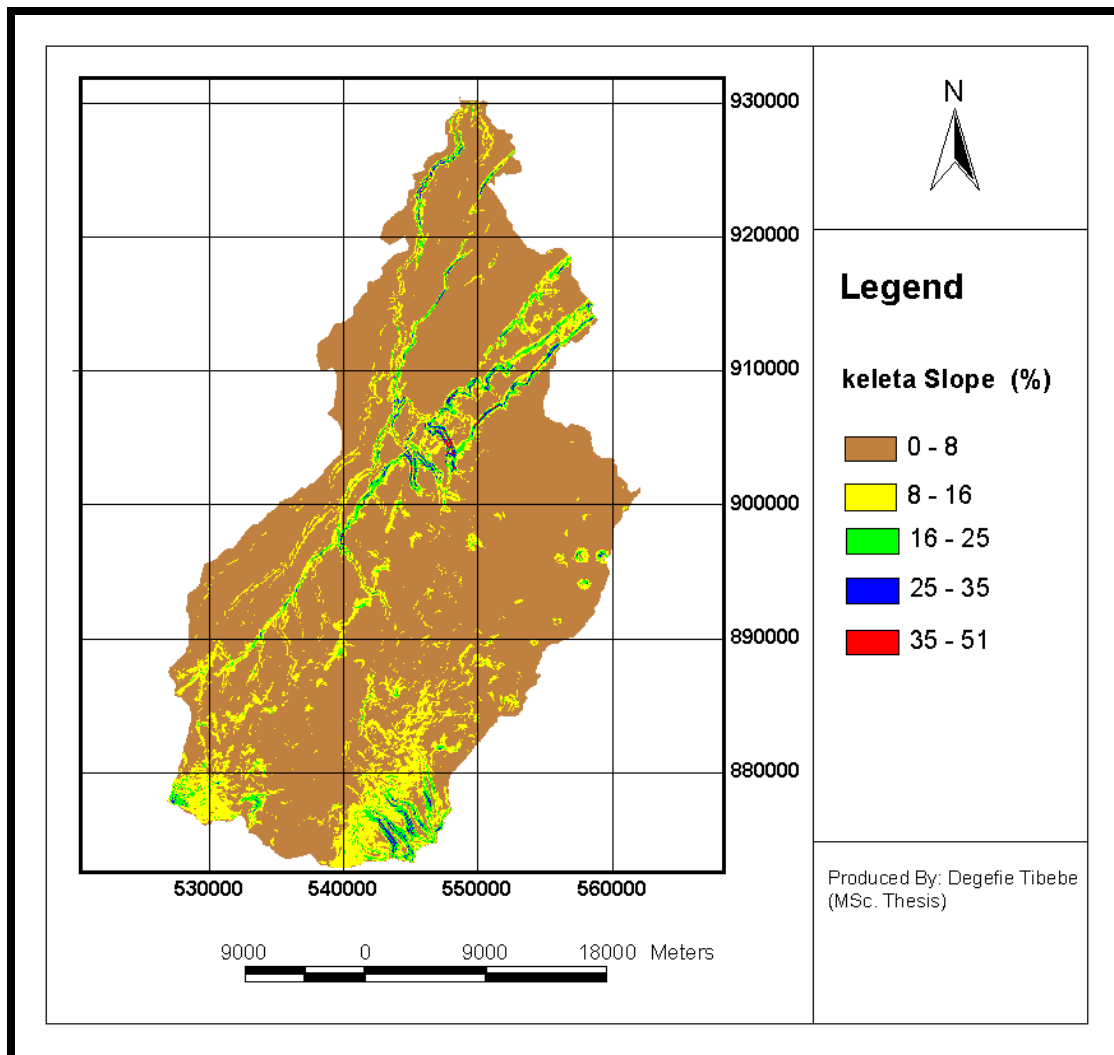


Figure 4.4 Slope gradient of Keleta watershed

As figure 4.4 depicted that the slope range for keleta watershed is from 0- 51%. Most of the area is categorized by gentle slope, that is from 0 – 8%. This slope category is found in all part of the watershed from upper part to lower part of it. The next slope category is from 8 – 16% which is found in left and right upper part of the watershed. It is also found in the middle and lower part of the watershed but its coverage is very small as compared to the upper part. The slope categories from 16-25% and 25-35% are found in some places at the right upper part and on the middle part of the watershed. The steepest slope is found in the middle part of the watershed that covered very few places.

4.2.3 Drainage Network Data

Keleta watershed has a dendritic drainage network. Most of the streams start from the upper part of the watershed which is the Chilalo Mountain. These streams are joined in the middle part of the watershed and form the main river which is the Keleta River. Keleta river joins the the Awash river at its lower parts. Some of the major tributaries that join the Keleta River are Boru, Bedesa, Chancho and Wedecha. This is illustrated in figure 4.5

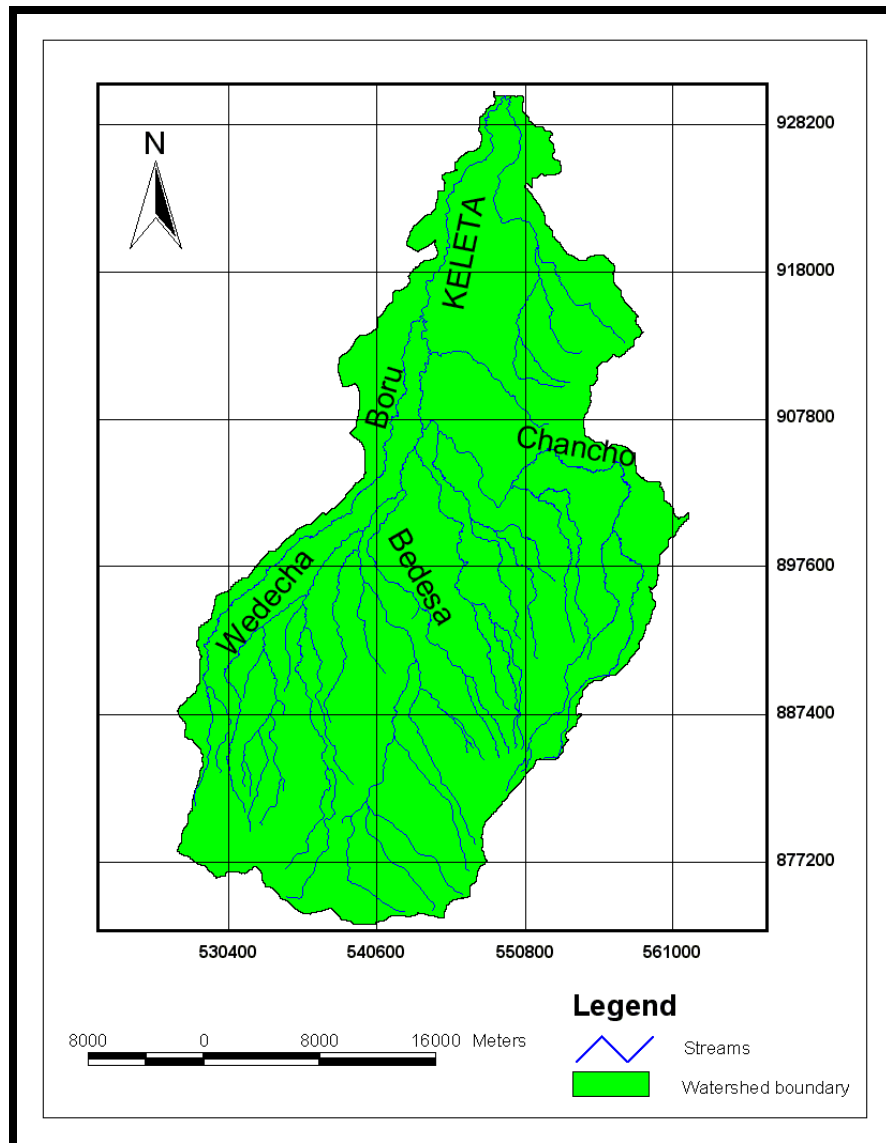


Figure 4.5 Drainage line of Keleta watershed

4.3 Climatic Data

SWAT requires daily rainfall, minimum and maximum temperature, wind speed, solar radiation and dew point temperature. Four weather stations were taken over 25 km radius out from the catchment boundary for the period 1981 to 2000. The weather stations are Dhera, Dixis, Kulumsa and Sire. From these stations 20 years Minimum and Maximum Temperature and Rainfall on daily basis were prepared and organized using the Microsoft Excel program and formatted as dbf4 file type which is the required format by SWAT model. The Relative humidity, solar radiation and Wind speed were taken from Kulumsa and Dhera stations and simulated based on the long year's average monthly data.

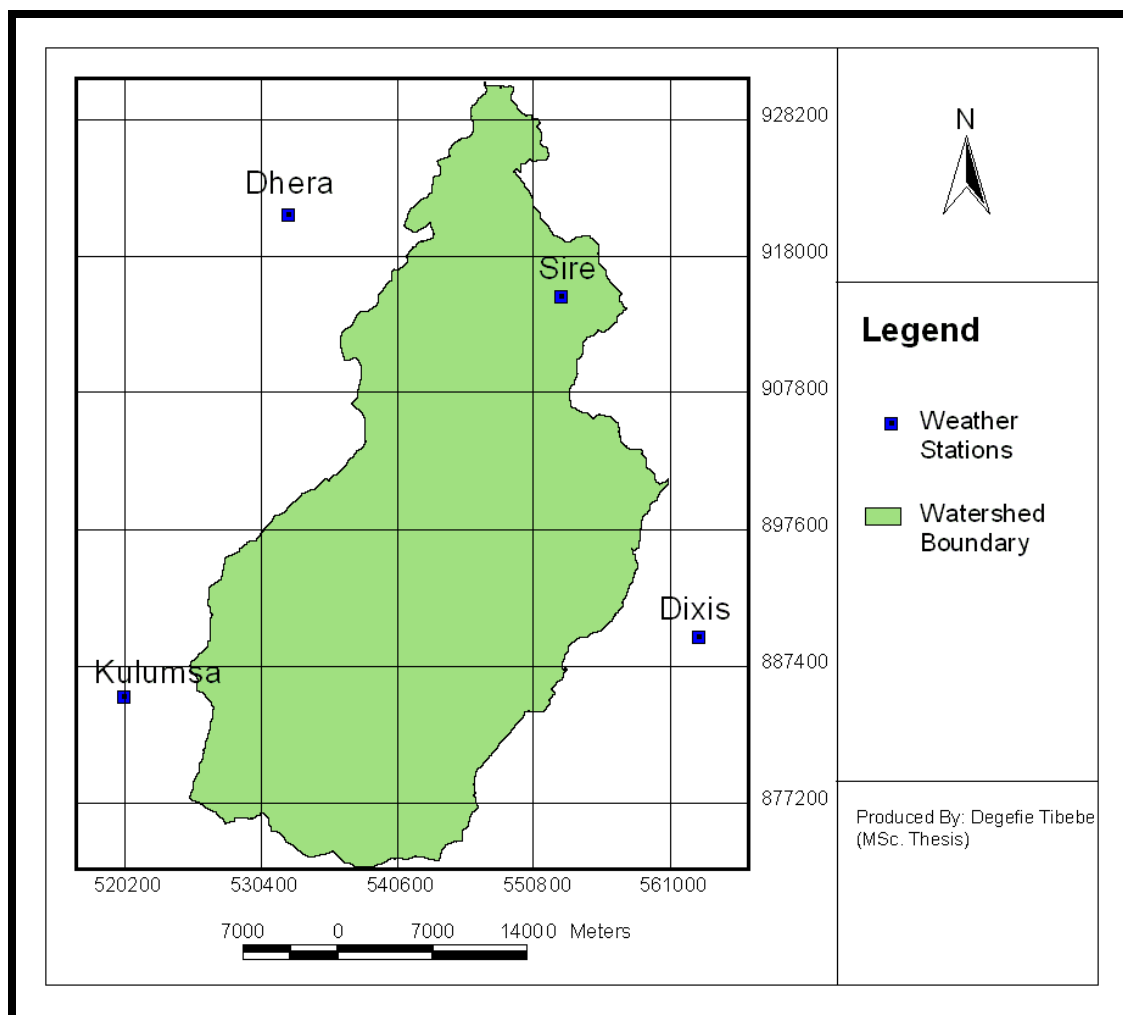


Figure 4.6 Weather stations around Keleta watershed

4.4 River Flow Data

The Keleta watershed has one main river which is called keleta River. Hence flow data of this river was collected, which was used in the calibration and validation process. All this data from 1980 to 2000 was gathered from the Ministry of Water Resources (MoWR). Data was checked for its reliability and its monthly and yearly statistic was calculated for use in the calibration and validation of the simulated flows.

The river flow data is a total of the surface runoff and base flow data. These two components should be separated prior to any calibration and validation work. Accordingly For this study simple base flow separation technique that is working on Microsoft Excel program was used. The base flow separation implemented in program TIMESPLOT is based on a recursive filter commonly used in signal analysis. This filter has been described by Nathan and McMahon (1990).

5. Result and Discussion

5.1 Watershed and Sub watershed Delineation

Keleta Watershed was delineated based on DEM and drainage network and the sub watershed was delineated based on the stream network, inlet and outlet of the streams. Accordingly the watershed was sub divided into 20 sub watershed. The HRU was determined using the dominant soil and land use for each sub watershed delineated. Therefore 20 HRU was identified which were equivalent to the sub basins.

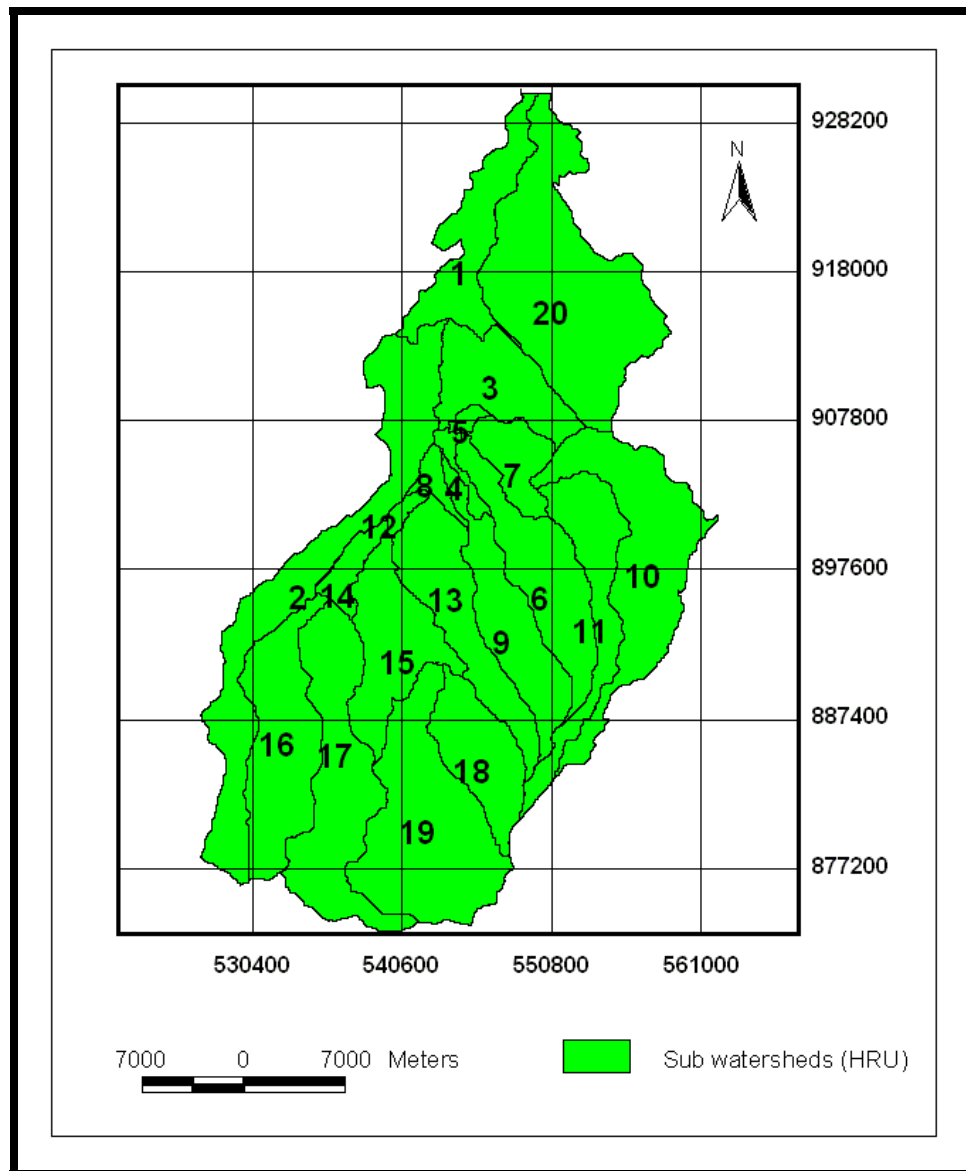


Figure 5.1 HRU and sub watersheds of keleta watershed

Table 5.1 Dominant soil type and land use for sub watersheds

<i>Sub Watershed</i>	<i>HRU</i>	<i>Dominant Soil</i>	<i>Dominant Land use (SWAT code)</i>	<i>Area (ha)</i>	<i>Area %</i>
1	1	Eutric Cambisol	AGRL	4832.4812	4.5572
2	2	Eutric Cambisol	AGRL	10843.1312	10.2253
3	3	Eutric Cambisol	AGRL	4629.6624	4.3659
4	4	Eutric Cambisol	AGRL	569.0624	0.5366
5	5	Eutric Cambisol	AGRL	297.6896	0.2807
6	6	Chromic Vertisol	AGRL	5819.1216	5.4876
7	7	Lithosol	AGRL	2302.7288	2.1715
8	8	Eutric Cambisol	AGRL	694.3113	0.6548
9	9	Chromic Vertisol	AGRL	5105.1536	4.8143
10	10	Chromic Vertisol	AGRL	9171.7648	8.6492
11	11	Chromic Vertisol	AGRL	4854.9808	4.5784
12	12	Eutric Cambisol	AGRL	383.7881	0.3619
13	13	Chromic Vertisol	AGRL	5644.4876	5.3229
14	14	Eutric Cambisol	AGRL	1160.7865	1.0947
15	15	Eutric Nitosol	AGRL	5406.5796	5.0985
16	16	Lithosol	AGRL	7133.2608	6.7268
17	17	Eutric Nitosol	AGRL	8558.8408	8.0712
18	18	Lithosol	AGRL	4201.5256	3.9621
19	19	Chromic Luvisol	FRSE	10440.9048	9.8460
20	20	Eutric Cambisol	AGRL	13991.4128	13.1943

Out of the 20 sub watershed 9 of them categorized by Eutric Cambisol soil type and Agricultural land use system. It accounts 35.3% of the total area of the watershed.

5.2 Runoff Simulation

5.2.1 Calibration and Validation of Surface runoff volume

Flow calibration was performed for a period of five years from January 1st, 1990 to December 31st, 1995. Parameters were used for calibration are curve number (CN) and soil evaporation compensation factor (ESCO). First of all the total river flow was separated into surface and base flow. Then the simulated flow was calibrated manually using the separated observed surface flow gauged at the outlet of the sub watershed. It was calibrated temporally by making delicate adjustments to ensure best fitting of the simulated flow curves with the gauged flow curves. Manipulation of the parameter values were carried out within the

allowable ranges recommended by SWAT developers. The initial/default and finally adjusted parameter values are shown in table 5.3

Table 5.3 Initial and finally adjusted parameter values of the flow Calibration

No.	Parameters	Description	Effect on simulation when parameter values increase	Range	Initial Value	Adjusted Value
1	CN2	Initial SCS CN II value	Increase surface runoff	-25%-25%	Default.	-25%
2	ESCO	Soil evaporation compensation factor	Decrease evaporation	0-1	0.95	0.1

After Calibration the surface runoff volume was validated. The purpose of the validation was to observe visually how much the simulated pattern seems to be the measured one based on monthly basis. Besides the visual observation, statistical investigation was done to see the correlation between the two. According to the statistical result the r is 0.9. This indicated that the simulation is positively and highly correlated with the measured one. As the figure 5.7 depicts that the simulated runoff line similarly follows the pattern of the measured runoff line except deviation in some points.

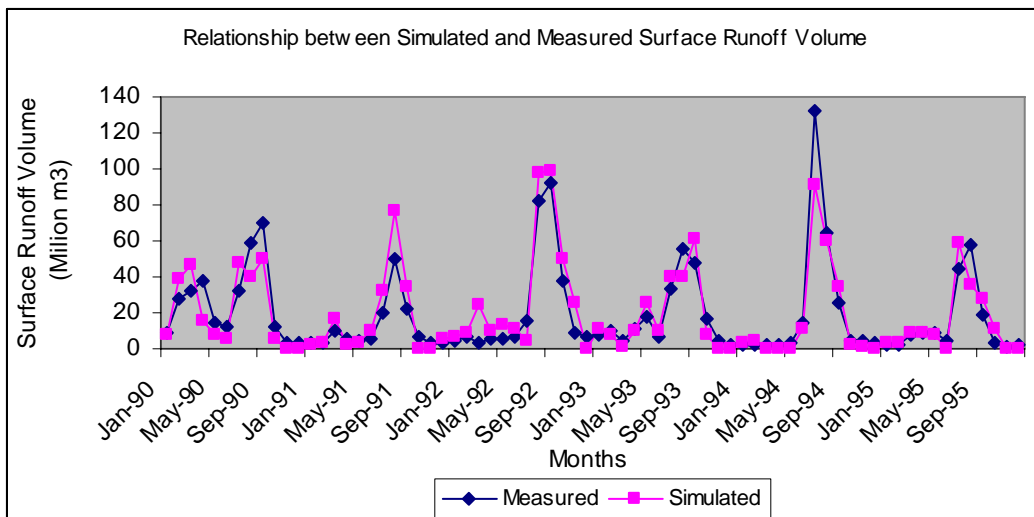


Figure 5.7 Measured and simulated surface runoff volume

5.2.2 Validation of discharge

Discharge was simulated in monthly basis using SWAT. As it was discussed in the SWAT approach, surface runoff volume and discharge are the basic parameters for MUSLE for simulating soil loss of the watershed. Hence it is necessary to validate the runoff discharges to have a better estimation of the soil loss. The validation was done based on monthly basis from 1990 to 1995. Validation was done to observe how much the simulation similar to the measured one. Statistical analysis was also made to see the degree of correlation between the simulated and the measured one. Accordingly the correlation coefficient (r) is 0.85. This value showed that the simulated is strongly correlated to the measured one. As the figure 5.8 depicted that the simulated and the measured chart lines follows similar pattern within the specified period.

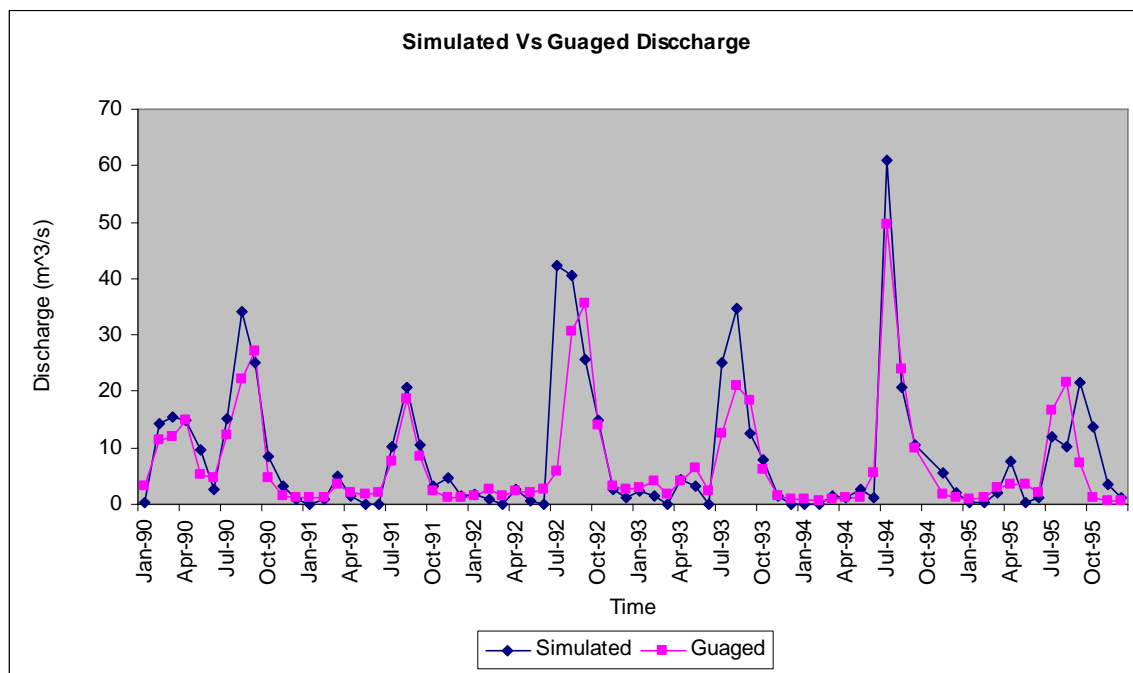


Figure 5.8 Measured and simulated discharge

5.2.3 Surface runoff

The amount of daily surface runoff from 1981 to 2000 in terms of depth for each HRU/ sub watershed was simulated by SWAT. Based the daily data, monthly and average annual surface runoff was summarized for each HRU. The annual surface runoff ranges from 13.23 mm to 135.81 mm. Higher value of the surface

runoff correlated with chromic vertisol soil type and agricultural land use system. As it is well known vertisol soil type is characterized by poor drainage and low infiltration capacity. Hence surface runoff is a common characteristic for such kind of soil type. Moreover agricultural practicing without conservation measure will aggravating the runoff processes. This situation was well observed in those sub watersheds which are characterized by this type of soil type and land use system.

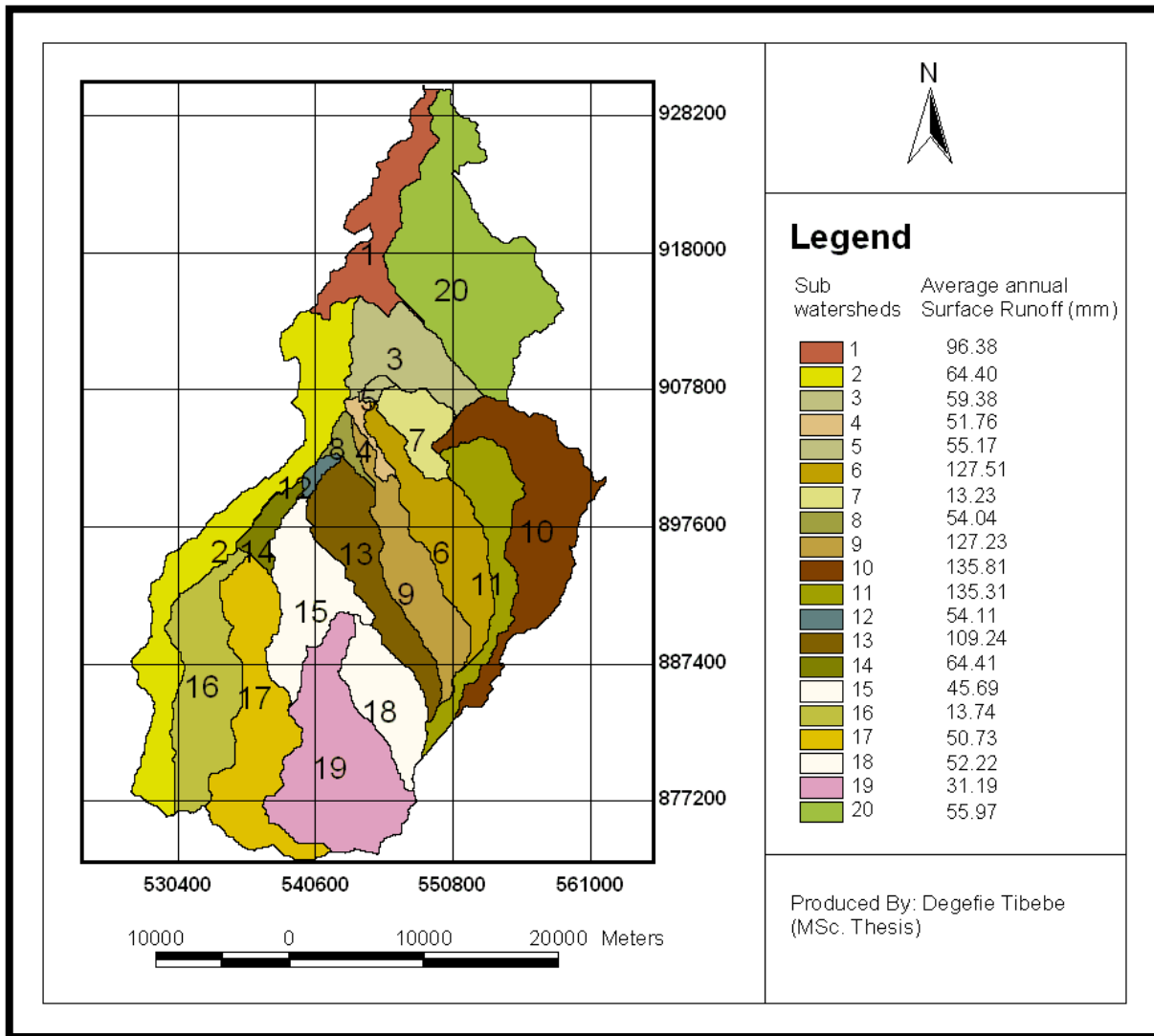


Figure 5.2 Average annual surface runoff for each sub watershed

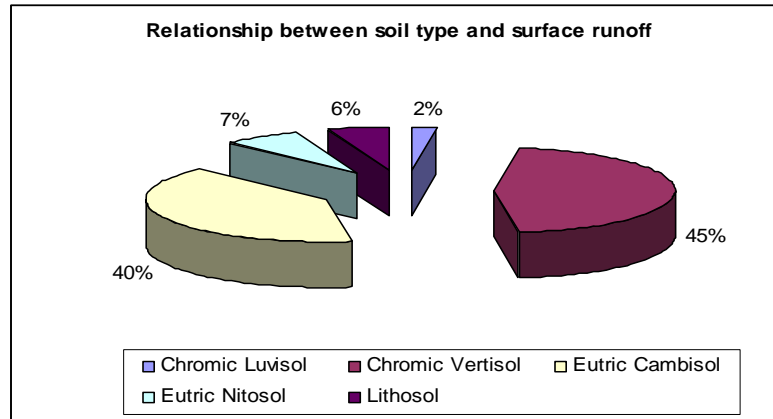


Figure 5.3 Surface runoff volume in relation with soil type

As the figure 5.3 depicted that 45 % of the runoff was generated from Chromic Vertisol and 40 % which is the next high surface runoff was generated from Eutric Cambisol.

Table 5.2 Average annual surface runoff volume for each sub watershed

Sub Watershed	HRU	Average Annual Surface Runoff (mm)	Area (ha)	Area %
1	1	96.38	4832.4812	4.5572
2	2	64.40	10843.1312	10.2253
3	3	55.98	4629.6624	4.3659
4	4	51.67	569.0624	0.5366
5	5	55.17	297.6896	0.2807
6	6	127.51	5819.1216	5.4876
7	7	13.23	2302.7288	2.1715
8	8	54.04	694.3113	0.6548
9	9	127.23	5105.1536	4.8143
10	10	135.81	9171.7648	8.6492
11	11	135.31	4854.9808	4.5784
12	12	54.11	383.7881	0.3619
13	13	109.24	5644.4876	5.3229
14	14	64.41	1160.7865	1.0947
15	15	45.69	5406.5796	5.0985
16	16	13.74	7133.2608	6.7268
17	17	50.73	8558.8408	8.0712
18	18	52.22	4201.5256	3.9621
19	19	31.19	10440.9048	9.8460
20	20	55.97	13991.4128	13.1943

5.2.4 Temporal variation of Surface runoff

After simulation of surface runoff trend analysis was made using 8 years moving average. Accordingly monotonic upward trend was observed in the analysis. This can be illustrated in figure 5.4. Though many factors are responsible for runoff, rainfall is the main driven factor for the cause of runoff. Based on this fact trend analysis was made for rainfall amount.

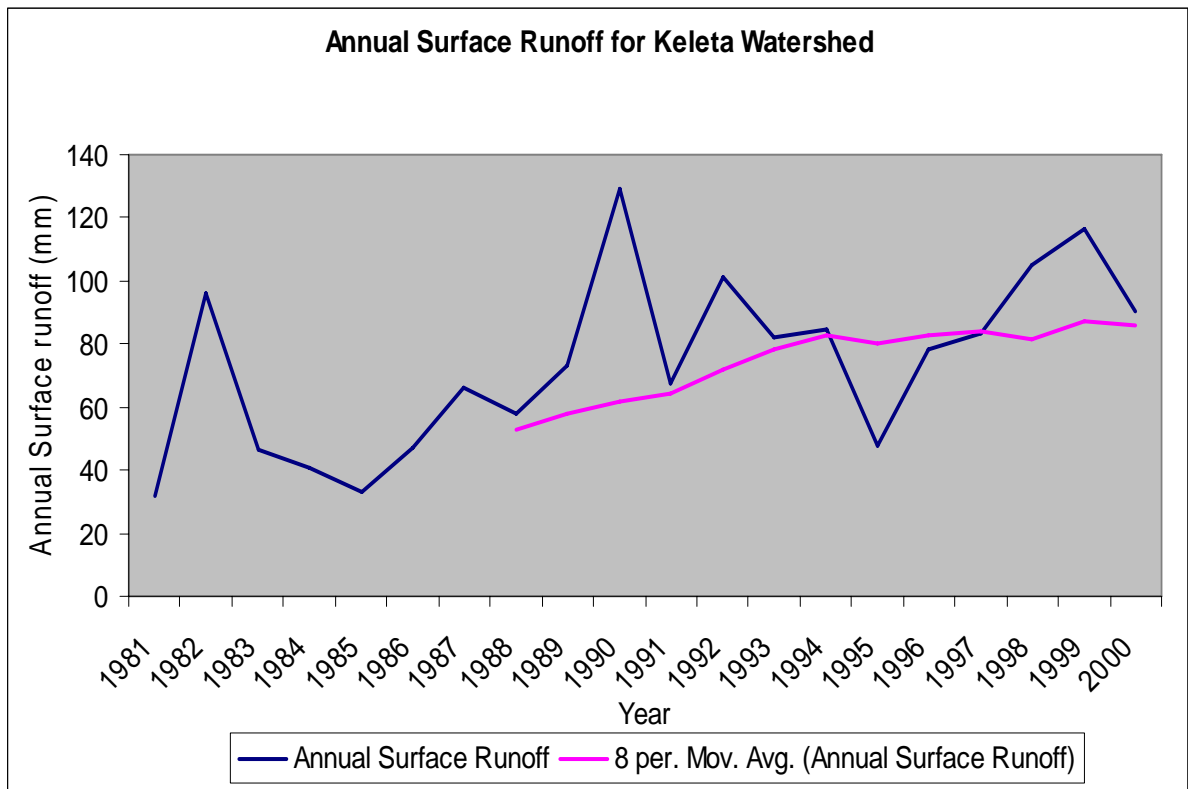


Figure 5.4 Temporal variation annual surface runoff volume in keleta watershed

The 8 years moving average trend analysis showed that an upward trend was observed in the rainfall amount. This can be depicted in figure 5.5 shown.

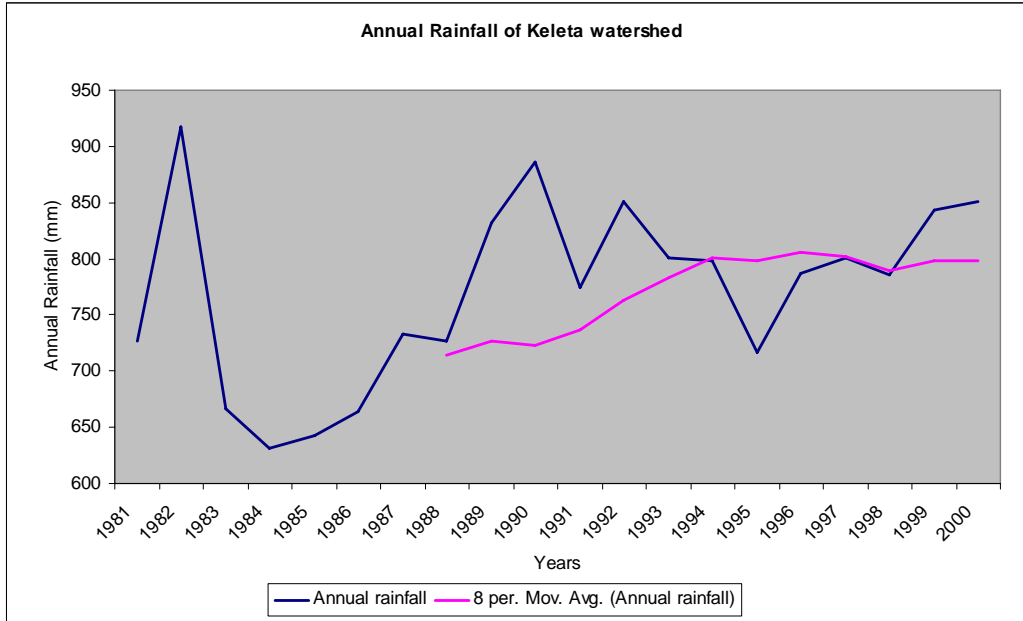


Figure 5.5 Temporal variation annual rainfall in keleta watershed

Based on the above two analysis the amount of runoff volume was increased because of the increment of rainfall amount. This can be strengthening by the statistical result of the correlation coefficient between the rainfall amount and the runoff volume. The correlation coefficient was $r = 0.87$. It showed that the rainfall amount and the runoff volume were positively and strongly correlated. It is illustrated in figure 5.6.

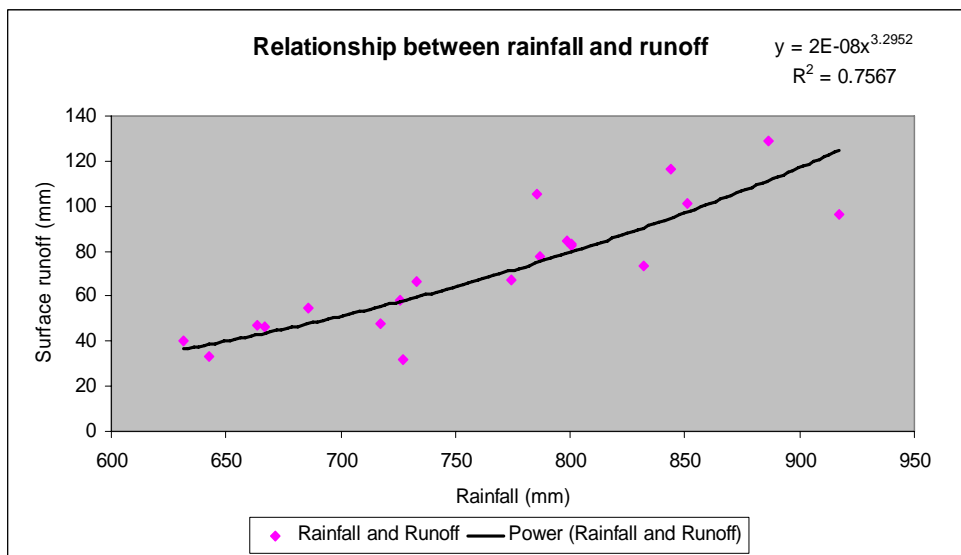


Figure 5.6 Relationship between runoff and rainfall in keleta watershed

The rainfall and runoff relation was modeled by the power function which was the best curve fit. This equation will be used to compute the runoff amount from rainfall on yearly basis.

5.3 Soil loss simulation

Soil loss for sub watersheds were simulated on yearly basis from 1981 to 2000. Accordingly the highest average soil loss was 17.72 t/ha/yr. This soil loss rate was observed from sub watershed number 4. The lowest average soil loss was 0.25 t/ha and it was observed from sub watershed number 19. The rest sub watersheds were categorized between the highest and lowest soil loss rate. As it was observed in the simulation soil loss was strongly related with soil type, land use and slope gradient. Highest soil loss was correlated with Eutric Cambisol and Chromic Vertisol soil types with cultivated land use system and slope gradient greater than 35%. The combination of these three factors was responsible for determining the soil erosion hazard level in the watershed. Lowest rate was observed from Chromic Luvisol soil type with forest covers Land use system. As it is well known Eutric Cambisol and Chromic Vertisol are characterized by high clay content and low infiltration rate. As a result high surface runoff was generated from these soils. The slope gradient created opportunity for the runoff to get high velocity. Besides to this the cultivated land use system facilitated the runoff to wear out the top soil in a higher rate.

In most cases sub watersheds which were characterized by high soil loss rate are found on slopes their gradient greater than 35 % with cultivation land use system. But this situation may not always be true. Because sub watersheds which were characterized by low soil loss rate are found on slopes gradient ranges from 25 to 35%. The reason to this situation was due to the Land use system of the sub watersheds dominated by Afro alpine vegetation.

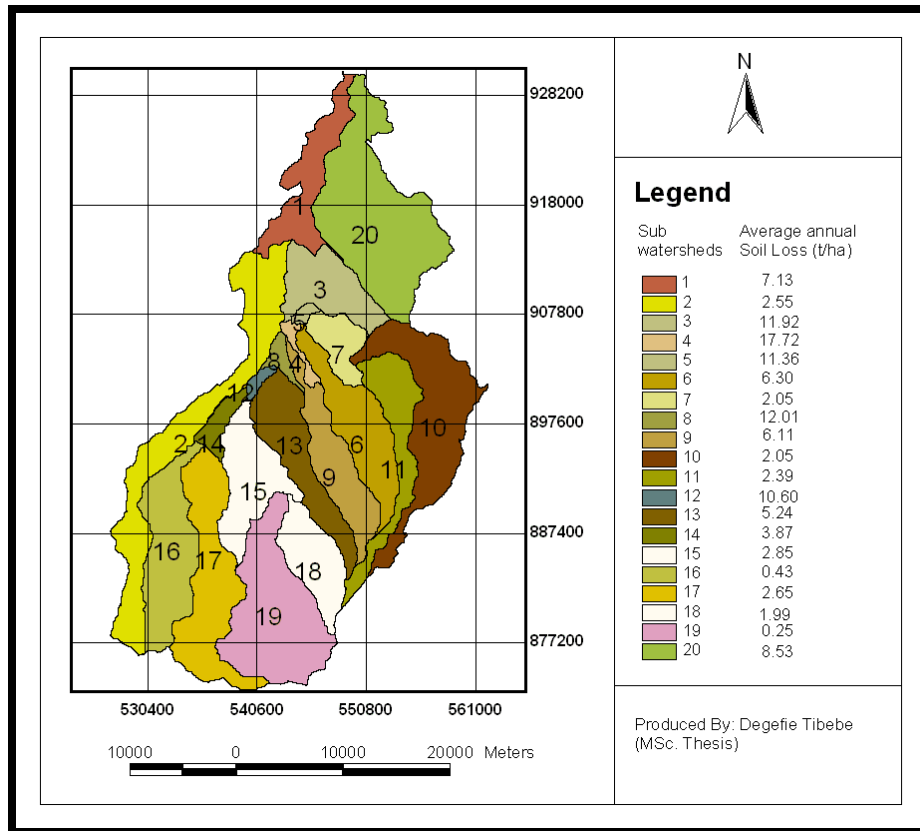


Figure 5.9 Average annual soil loss rates of sub watersheds

Table 5.4 Average annual surface soil loss rates for each sub watershed

Sub Watershed	HRU	Average Annual Soil loss (t/ha)	Area (ha)	Area %
1	1	7.13	4832.4812	4.5572
2	2	2.55	10843.1312	10.2253
3	3	11.92	4629.6624	4.3659
4	4	17.72	569.0624	0.5366
5	5	11.66	297.6896	0.2807
6	6	6.30	5819.1216	5.4876
7	7	2.05	2302.7288	2.1715
8	8	12.01	694.3113	0.6548
9	9	6.11	5105.1536	4.8143
10	10	2.05	9171.7648	8.6492
11	11	2.39	4854.9808	4.5784
12	12	10.60	383.7881	0.3619
13	13	5.24	5644.4876	5.3229
14	14	3.87	1160.7865	1.0947
15	15	2.85	5406.5796	5.0985
16	16	0.42	7133.2608	6.7268
17	17	2.65	8558.8408	8.0712
18	18	1.99	4201.5256	3.9621
19	19	0.25	10440.9048	9.8460
20	20	8.53	13991.4128	13.1943

5.3.1 Soil Loss Rate Classification

Soil loss rate classification was done for the watershed. Accordingly four classes were identified. The first class was recognized by very low soil loss rate which is less 1 t/ha. The second class was recognized by low soil loss rate which is from 1 to 5 t/ha. The third class was categorized by moderate soil loss rate which is from 5 to 10 t/ha and the last class which was categorized by high soil erosion rate which is greater than 10 t/ha. This can be illustrated in table 5.4.

Most of the sub watersheds were fallen under low and very low soil loss rate. Some of the sub watersheds were categorized by high soil loss rate.

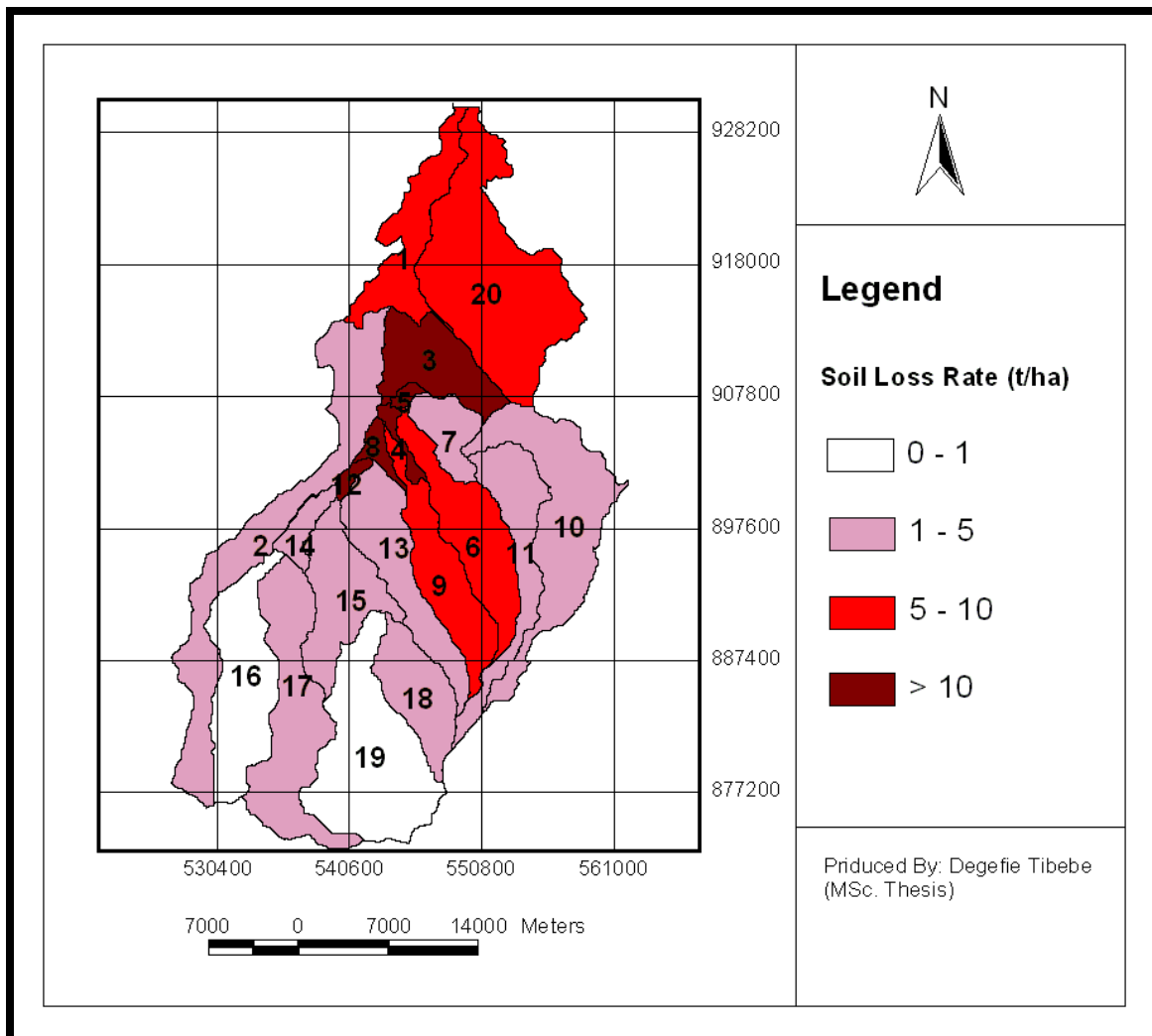


Figure 5.10 Soil erosion rate (t/ha/yr) of the watershed

Table 5.5 Soil erosion rate's in the study area

Soil Loss Rate (t/ha/yr)	Erosion potential	Sub watersheds No.	Area (ha)
0 - 1	Very low	16, 19	17574.17
1 - 5	Low	2, 7, 10, 11, 13, 14, 15, 17, 18	50139.79
5 - 10	Moderate	1, 6, 9, 20	29748.17
> 10	High	3, 4, 5, 8, 12	6574.514

5.3.2 Temporal Variation of Soil Loss

The soil loss simulation result was done from 1981 to 2000 and summarized on yearly basis. Trend analysis was made using 8 years moving average method. It is illustrated in figure 5.11 and up ward trend was observed. This situation was strictly correlated with the increasing trend of the annual surface runoff volume which was discussed in the runoff simulation part. As the statistical result was shown in figure 5.12, the correlation coefficient between the runoff volume and soil loss was 0.72. This value indicated that it was strong and positive correlation between the two variables. This relationship was modeled by power function which was depicted in figure 5.12.

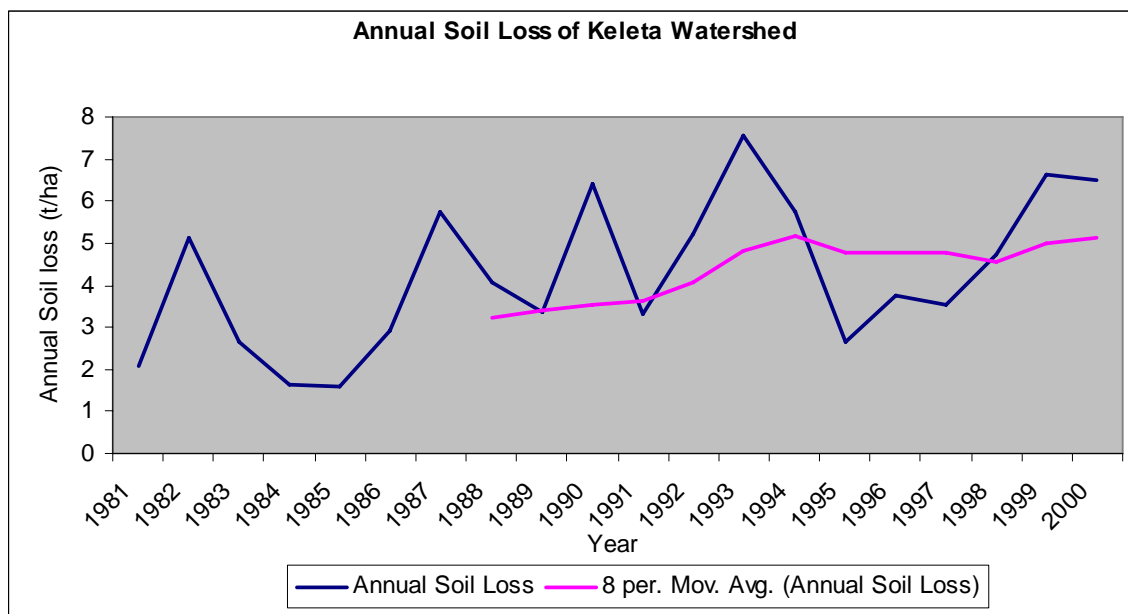


Figure 5.11 Temporal variation of annual soil loss of keleta watershed

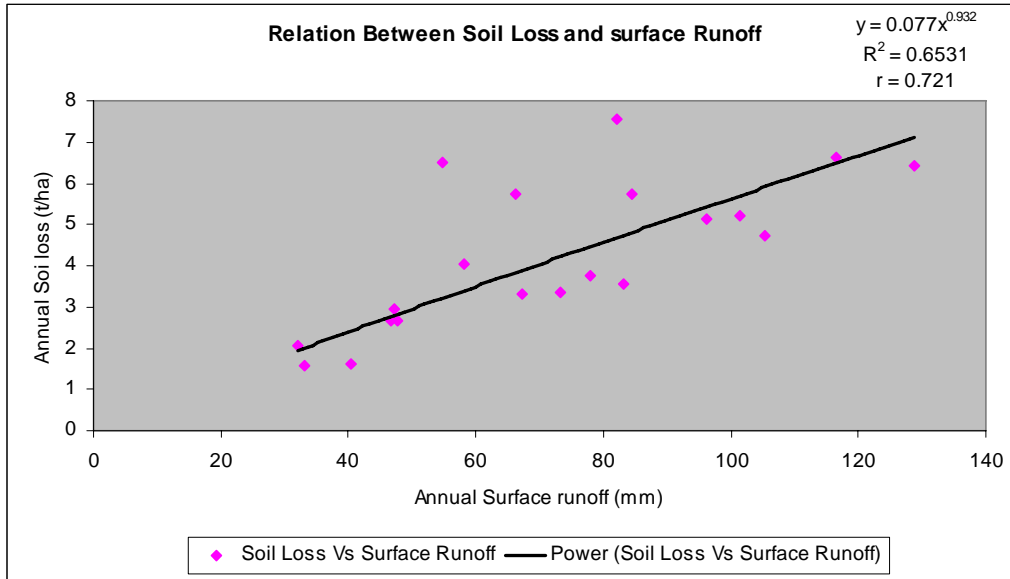


Figure 5.12 Relationship between soil loss and surface runoff

The amount of rainfall and soil loss was related by the correlation coefficient of $r = 0.59$. Though this value indicated that rainfall was positively correlated with soil loss, the degree of correlation was not strong to that of the correlation coefficient between runoff and soil loss. Hence runoff was significantly influence the soil loss than the rainfall. The relationship between the rainfall and soil loss was modeled by power function and illustrated in figure 5.13.

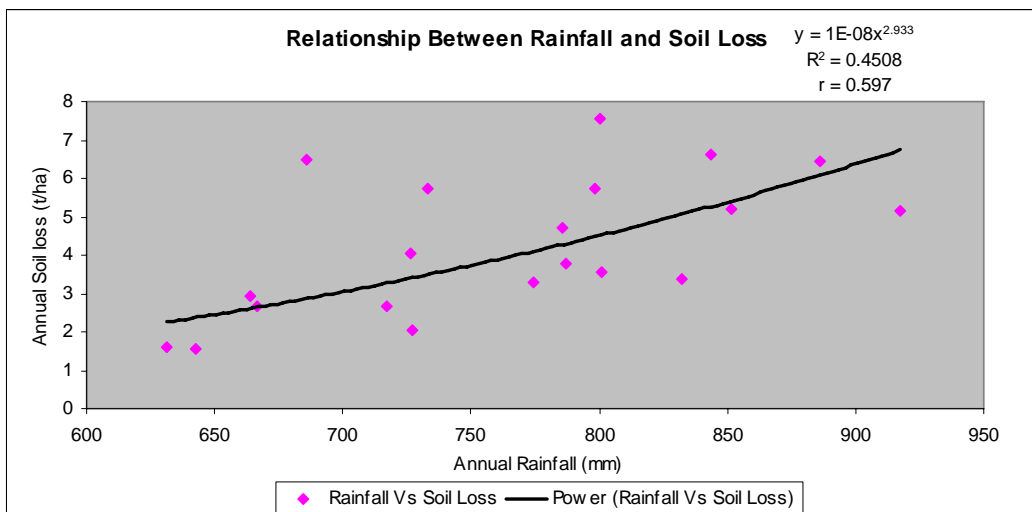


Figure 5.13 Relationship between soil loss and rainfall

5.3.3 Comparison between MUSLE and USLE in simulating soil loss

MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy. Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor represents energy used in detachment only. Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment.

Accordingly comparison was made between the two models in simulating the soil loss from 1990 to 2000 for 10 years period. Figure 5.14 indicated that the two models simulated soil loss similarly through out the simulation period except deviation on some points. The statistical result which is the correlation coefficient $r = 0.87$. This result indicated that there was strong and positive correlation between the two models.

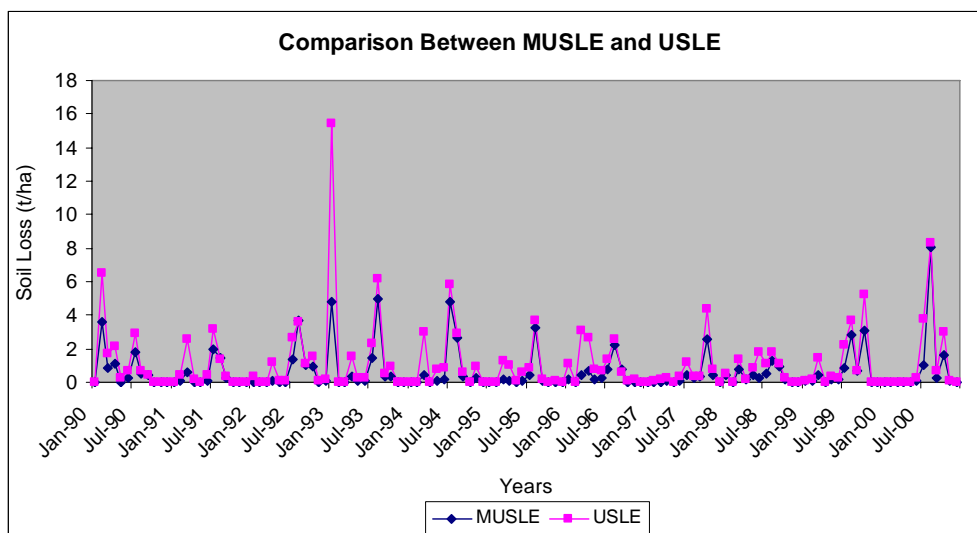


Figure 5.14 Soil loss simulated by MUSLE and USLE

5.4 Prioritization of sub watersheds and remedial measures

A comprehensive watershed management usually has multiple objectives such as controlling damaging runoff and managing and utilizing the same for useful purpose on one hand, and controlling erosion and reducing the effect of sedimentation on the other hand. Hence, any attempt of assessment of erosion hazard and prioritization of sub watersheds for treatment would aid better development planning.

The prioritization of sub watershed in this study was done based on estimated mean annual soil loss. Rank was assigned based on the amount of mean soil loss in which the first rank was given to the sub watershed with maximum soil loss. Other ranks were assigned in decreasing order of soil loss intensity where the last rank goes to the sub watershed with the least soil loss. Prioritization map was then prepared based on erosion hazard.

Table 5.6 Ranked sub watersheds in terms of soil loss rate

<i>Sub Watershed</i>	<i>HRU</i>	<i>Average Annual Soil loss (t/ha)</i>	<i>Rank</i>	<i>Area (ha)</i>	<i>Area %</i>
1	1	7.13	7	4832.4812	4.5572
2	2	2.55	14	10843.1312	10.2253
3	3	11.92	3	4629.6624	4.3659
4	4	17.72	1	569.0624	0.5366
5	5	11.66	4	297.6896	0.2807
6	6	6.30	8	5819.1216	5.4876
7	7	2.05	15	2302.7288	2.1715
8	8	12.01	2	694.3113	0.6548
9	9	6.11	9	5105.1536	4.8143
10	10	2.05	16	9171.7648	8.6492
11	11	2.39	17	4854.9808	4.5784
12	12	10.60	5	383.7881	0.3619
13	13	5.24	10	5644.4876	5.3229
14	14	3.87	11	1160.7865	1.0947
15	15	2.85	12	5406.5796	5.0985
16	16	0.42	19	7133.2608	6.7268
17	17	2.65	13	8558.8408	8.0712
18	18	1.99	18	4201.5256	3.9621
19	19	0.25	20	10440.9048	9.8460
20	20	8.53	6	13991.4128	13.1943

Accordingly the rank was classified into three category based on the soil loss rate. The categories were high priority which was the soil loss rate > 11 t/ha/yr,

moderate priority which was the soil loss rate in between 5 and 11 t/ha/yr and the last was low priority which was the soil loss rate < 5 t/ha/yr. This categorization was done based on the assumption of the tolerable soil loss limit is 11 t/ha/yr as it is recommended for tropical areas.

5.4.1 High priority

This category was characterized by high soil loss rate. It was greater than the soil loss tolerance limit. Four sub watersheds 3, 4, 5, and 8 which were given high priority based on the soil loss rate >11 t/ha/yr.

These sub watersheds are found in steep slope, heavy clay soil which is poor infiltration capacity soil and agricultural land use with poor conservation. These factors were responsible for aggravating the soil loss rate of the sub watersheds. Hence ameliorative measures should be proposed based on the problem itself. Therefore areas that have a slope gradient greater than 25 % should not be used for cultivation rather be reserved for natural forest purpose. The agricultural practices should incorporate conservation measures that will facilitate infiltration like Broad Bed Furrow (BBF) and Tied-ridges.

5.4.2 Moderate priority

This category is characterized by moderate soil loss rate. Five sub watersheds 1, 6, 9, 13, and 20 which were given moderate priority class based on the soil loss rate in between 5 and 11 t/ha/yr.

These sub watersheds are found in moderately gentle slope, heavy clay soil which is poor infiltration capacity soil and agricultural land use with poor conservation. Hence soil type and agricultural activity is the principal factor for the soil loss. Accordingly measures should be recommended based on these two factors. Therefore the agricultural activity should incorporate the conservation measures like BBF and Tied-ridges that will decrease the runoff and the soil loss as well.

5.4.3 Low priority

This category was characterized by low soil loss rate. Eleven sub watersheds were fallen under this category class based on the soil loss rate <5 t/ha/yr.

These sub watersheds are found on gentle to steep slope and have heavy clay to sandy soil type and used by agricultural activity to forest cover. Though some of the sub watersheds are found in steep slopes, soil loss rate was very small because of the afro alpine and forest land cover reduce the runoff power. Hence measures should be taken for this area is keeping the natural balance. Accordingly forests and fro alpine vegetation should be treated as an area closures in order to protect the devastation by human and livestock.

Table 5.7 Priority class of sub watersheds

<i>No.</i>	<i>Soil Loss Rate</i>	<i>Priority class</i>	<i>Sub watersheds</i>
1	> 11 t/ha/yr	High	3, 4, 5 and 8
2	Between 5 and 11 t/ha/yr	Moderate	1, 6, 9, 13 and 20
3	< 5 t/ha/yr	low	2, 7, 10, 11, 14, 15, 16, 17, 18, 19 and 20

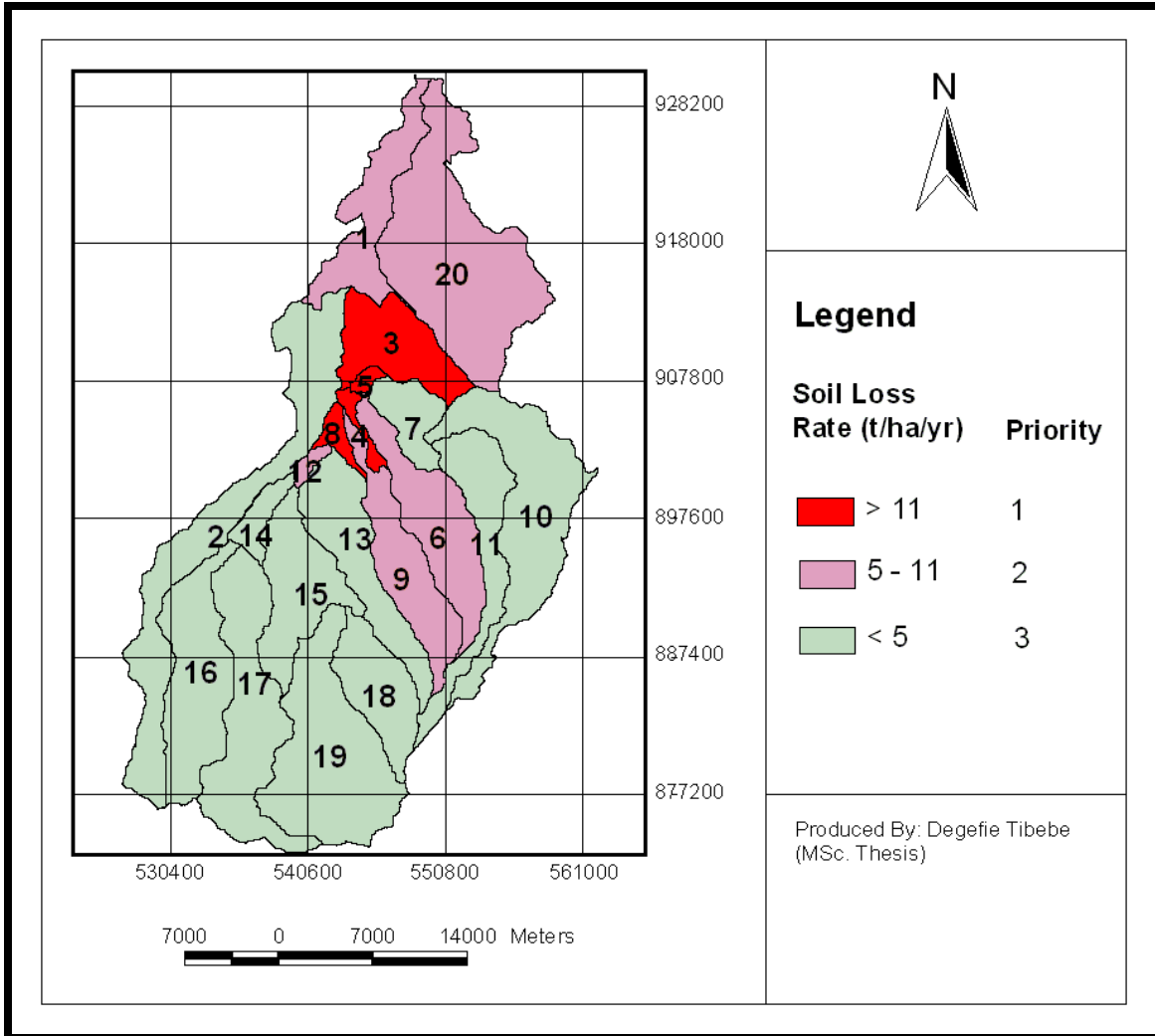


Figure 5.15 Prioritization of kelete sub watersheds

6. Conclusions and Recommendations

The following conclusion can be drawn from this study:

- SWAT model integrated with GIS and Remote Sensing is helpful in analyzing the soil loss and runoff spatially and temporally. Hence it facilitates conservation planning, project planning, and soil erosion inventories and for formulating regulation at watershed level. This will be helpful for planning where and when appropriate conservation measures should be taken because it can give a possibility of dividing a watershed into sub-watersheds that is easy to handle in terms of financial and technical aspects for development activity.
- SWAT model is capable enough for simulating runoff and soil loss even without calibrating. But for the best result, calibration is a must.
- As the analysis showed that surface runoff was higher on those sub-watersheds which were characterized by heavy clay soils like Chromic Vertisol and Eutric Cambisol, agricultural land use system and slope gradient greater than 25%.
- The temporal variation of the runoff amount showed that an upward trend was observed. This can be correlated with the rainfall condition of the area. As the rainfall analysis showed that an upward trend was observed. The correlation coefficient between the rainfall and runoff was 0.87. This was a strong and positive correlation.
- According to this study, runoff was the erosive agent rather than rainfall. This can be strengthened by the statistical analysis of rainfall versus soil loss and runoff versus soil loss. The result showed that soil loss was strongly and positively correlated with runoff rather than rainfall. Its value was 0.72.
- The soil loss analysis showed that some sub-watersheds are characterized by high soil loss rates beyond the tolerable limit that was set for a tropical area. Most of them are categorized by moderate to low soil loss rates. The principal responsible factors for the higher soil loss rates were slope gradient, type of

soil and land use/land cover. Accordingly, the slope gradient greater than 30% which is steep slope, heavy clay soil and agricultural land use system with poor conservation were the responsible factors for higher soil loss rate.

- Ameliorative measures should be recommended based on the type and severity of the problems. Whenever natural resource management and conservation works are planned, the area should be treated based on the severity of erosion problem, which is the base for prioritization of sub watersheds. In this study, sub watersheds 3, 4, 5 and 8 are under high priority. The measures should be taken for these sub watersheds as follows:
 - For slope gradient > 30% , area closure and reforestation activity are recommended
 - For heavy clay soils like Chromic Vertisol and Eutric Cambisol, agricultural activity should be practiced with runoff and soil loss decreasing methods. Some of these conservation methods are BBF, Furrow, and Tied-ridge.

Hence, there is an urgent need for resource conservation work based on the priority given in this study

- To have a better result spatial and temporal analysis of land use/ land should be incorporated. Therefore future study should incorporate this.

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Websites used for additional information and software downloads

<http://www.brc.tamus.edu/swat/avswat.html> [Accessed 12 December 2006]

Appendixes

Appendix 1: Crop Parameters-SWAT

Crop Parameters used by the SWAT model

1 AGRL 4 Agricultural Land-Generic true
 33.50 0.45 3.00 0.15 0.05 0.50 0.95 0.64 1.00 2.00 30.00 11.00 0.0199 0.0032 0.0440
 0.0164 0.0128 0.0060 0.0022 0.0018 0.250 0.200 0.005 4.000 0.750 8.500 660.000
 36.000 0.050

2 AGRR 4 Agricultural Land-Row Crops true
 39.00 0.50 3.00 0.15 0.05 0.50 0.95 0.70 2.50 2.00 25.00 8.00 0.0140 0.0016 0.0470
 0.0177 0.0138 0.0048 0.0018 0.0014 0.300 0.200 0.007 4.000 0.750 7.200 660.000
 45.000 0.050

3 FRSD 7 Forest-Deciduous false
 15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50 30.00 10.00 0.0015 0.0003 0.0060
 0.0020 0.0015 0.0007 0.0004 0.0003 0.010 0.001 0.002 4.000 0.750 8.000 660.000
 16.000 0.050

4 FRSE 7 Forest-Evergreen false
 15.00 0.76 5.00 0.15 0.70 0.25 0.99 0.99 10.00 3.50
 30.00 0.00 0.0015 0.0003 0.0060 0.0020 0.0015 0.0007 0.0004 0.0003
 0.600 0.001 0.002 4.000 0.750 8.000 660.000 16.000 0.050

5 FRST 7 Forest-Mixed false
 15.00 0.76 5.00 0.05 0.05 0.40 0.95 0.99 6.00 3.50 30.00 10.00 0.0015 0.0003 0.0060
 0.0020 0.0015 0.0007 0.0004 0.0003 0.010 0.001 0.002 4.000 0.750 8.000 660.000
 16.000 0.050

6 PAST 6 Pasture false
 35.00 0.90 4.00 0.05 0.05 0.49 0.95 0.99 0.50 2.00 25.00 12.00 0.0234 0.0033 0.0600
 0.0231 0.0134 0.0084 0.0032 0.0019 0.900 0.003 0.005 4.000 0.750 10.000 660.000
 36.000 0.050

7 RNGB 6 Range-Brush false
 34.00 0.90 2.00 0.05 0.10 0.25 0.70 0.35 1.00 2.00 25.00 12.00 0.0160 0.0022 0.0200
 0.0120 0.0050 0.0014 0.0010 0.0007 0.900 0.003 0.005 4.000 0.750 10.000 660.000
 39.000 0.050

2 URMD Residential-Medium Density
 0.380 0.300 0.240 0.180 225.000 0.750 550.000 232.000 7.200

Appendix 2: Weather Generator Parameters-SWAT

Weather generator (WGEN) parameters used by the SWAT model

<i>Legend of the parameters used in the weather generation</i>		
	Symbol	Symbol Description
A	TMPMX	Average or mean daily maximum air temperature for month (°C).
B	TMPMN	Average or mean daily minimum air temperature for month (°C).
C	TMPSTDMX	Standard deviation for daily maximum air temperature in month (°C).
D	TMPSTDMN	Standard deviation for daily minimum air temperature in month (°C).
E	PCPMM	Average or mean total monthly precipitation (mm H ₂ O).
F	PCPSTD	Standard deviation for daily precipitation in month (mm H ₂ O/day).
G	PCPSKW	Skew coefficient for daily precipitation in month.
H	PR_W1	Probability of a wet day following a dry day in the month.
I	PR_W2	Probability of a wet day following a wet day in the month.
J	PCPD	Average number of days of precipitation in month.
K	SOLARAV	Average daily solar radiation for month (MJ/m ² /day).
L	DEWPT	Average daily dew point temperature in month (°C).
M	WNDVAV	Average daily wind speed in month (m/s).

STATION	WLATITUDE	WLONGITUDE	WELEV	RAIN_YRS	TMPMX1	TMPMX2
Dhera	8.33	39.31	1775.00	20.00	27.60	28.80
Dixis	8.05	39.58	2750.00	20.00	26.50	27.40
Kulumsa	8.01	39.20	2180.00	20.00	23.20	23.80
Sire	8.27	39.44	1980.00	20.00	29.20	29.60

TMPMX3	TMPMX4	TMPMX5	TMPMX6	TMPMX7	TMPMX8	TMPMX9	TMPMX10
30.10	30.10	29.30	32.50	26.70	26.10	27.40	32.40
28.40	28.50	29.60	30.80	28.30	28.20	28.00	27.90
24.90	24.70	24.50	23.60	21.30	21.00	21.40	22.80
33.20	33.60	35.30	30.80	29.90	31.00	31.30	29.60

TMPMX11	TMPMX12	TMPMN1	TMPMN2	TMPMN3	TMPMN4	TMPMN5	TMPMN6
28.20	27.60	12.60	13.60	15.00	15.70	15.00	15.20
27.40	26.70	13.60	14.50	15.80	17.30	17.10	17.40
22.90	22.80	8.30	9.70	10.90	11.90	11.80	11.10
28.70	28.00	11.30	12.80	14.90	15.60	15.00	17.50

TMPMN7	TMPMN8	TMPMN9	TMPMN10	TMPMN11	TMPMN12	TMPSTDMX1	TMPSTDMX2
14.40	14.30	14.10	13.50	12.00	11.90	1.06	1.92
16.50	15.90	15.90	14.90	13.60	13.40	1.91	2.04
11.10	10.90	10.50	10.50	8.80	7.90	1.50	1.90
16.20	16.50	16.50	13.20	10.10	11.10	2.10	2.80

TMPSTDMX3	TMPSTDMX4	TMPSTDMX5	TMPSTDMX6	TMPSTDMX7	TMPSTDMX8	TMPSTDMX9	TMPSTDMX10
1.24	1.34	1.30	1.40	1.50	0.80	0.80	0.90
1.77	1.22	1.61	0.86	1.23	1.99	1.74	1.68
1.80	1.80	1.00	1.40	1.40	1.50	1.50	1.60
2.00	2.20	1.90	2.20	2.10	2.00	3.20	1.20

TMPSTDMX11	TMPSTDMX12	TMPSTDMN1	TMPSTDMN2	TMPSTDMN3	TMPSTDMN4	TMPSTDMN5	TMPSTDMN6
1.00	0.70	1.62	2.18	0.73	1.06	0.82	0.73
1.67	1.67	1.25	1.36	1.31	1.30	1.67	1.18
1.90	1.50	1.30	1.20	0.70	0.80	0.80	0.70
1.50	1.40	5.10	4.80	4.30	3.70	4.20	3.50

TMPSTDMN7	TMPSTDMN8	TMPSTDMN9	TMPSTDMN10	TMPSTDMN11	TMPSTDMN12	PCPMM1	PCPMM2
0.93	1.06	0.89	0.95	0.84	0.86	17.50	31.40
1.37	1.18	1.15	1.04	1.12	1.36	33.50	72.80
0.60	0.60	0.60	0.80	0.90	1.20	19.50	51.10
3.50	3.00	2.67	3.80	5.00	5.30	7.10	12.90

PCPMM3	PCPMM4	PCPMM5	PCPMM6	PCPMM7	PCPMM8	PCPMM9	PCPMM10
53.00	43.00	67.30	48.40	134.50	151.90	75.30	35.60
92.40	119.60	57.80	56.90	153.70	162.70	108.80	47.90
82.10	80.40	85.50	80.20	128.70	133.10	106.90	33.20
50.70	78.30	43.13	63.90	145.20	135.50	116.50	13.30

PCPMM11	PCPMM12	PCPSTD1	PCPSTD2	PCPSTD3	PCPSTD4	PCPSTD5	PCPSTD6
23.50	13.10	9.46	18.36	19.40	16.40	25.90	16.60
15.90	8.60	45.01	50.00	50.00	49.53	49.70	31.27
12.20	11.50	15.50	20.40	32.70	25.20	19.50	16.90
5.50	8.50	4.05	4.75	5.24	5.75	3.88	3.55

PCPSTD7	PCPSTD8	PCPSTD9	PCPSTD10	PCPSTD11	PCPSTD12	PCPSKW1	PCPSKW2
27.73	25.70	21.90	16.30	15.10	8.70	2.34	0.91
50.00	43.20	49.04	50.00	35.17	26.67	8.73	6.07
21.30	19.26	16.73	17.73	8.33	9.50	6.70	5.40

7.65	8.67	3.59	3.89	1.63	1.25	16.98	6.28
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PCPSKW3	PCPSKW4	PCPSKW5	PCPSKW6	PCPSKW7	PCPSKW8	PCPSKW9	PCPSKW10
0.73	2.10	1.17	0.64	0.48	0.28	-0.22	3.18
3.63	4.40	5.12	4.69	2.66	2.87	2.91	6.93
3.70	3.30	3.50	2.70	2.30	1.90	2.10	3.50
6.12	5.92	7.89	4.88	3.42	4.00	3.98	6.08

PCPSKW11	PCPSKW12	PR_W1_1	PR_W1_2	PR_W1_3	PR_W1_4	PR_W1_5	PR_W1_6
3.39	3.20	0.09	0.08	0.15	0.21	0.10	0.28
9.00	6.65	0.07	0.26	0.30	0.40	0.47	0.69
7.60	10.30	0.09	0.23	0.31	0.31	0.46	0.61
12.13	12.38	0.06	0.45	0.37	0.50	0.26	0.51

PR_W1_7	PR_W1_8	PR_W1_9	PR_W1_10	PR_W1_11	PR_W1_12	PR_W2_1	PR_W2_2
0.68	0.33	0.19	0.03	0.00	0.26	0.00	0.06
0.67	0.22	0.48	0.17	0.02	0.00	0.18	0.17
0.65	0.75	0.30	0.02	0.00	0.03	0.00	0.42
0.44	0.30	0.38	0.19	0.00	0.14	0.50	0.27

PR_W2_3	PR_W2_4	PR_W2_5	PR_W2_6	PR_W2_7	PR_W2_8	PR_W2_9	PR_W2_10
0.22	0.22	0.17	0.27	0.58	0.75	0.77	0.05
0.60	0.63	0.49	0.76	0.95	0.44	0.38	0.00
0.44	0.32	0.27	0.46	0.60	0.77	0.52	0.08
0.61	0.58	0.40	0.59	0.86	0.89	0.67	0.53

PR_W2_11	PR_W2_12	PCPD1	PCPD2	PCPD3	PCPD4	PCPD5	PCPD6
0.33	0.00	2.00	3.00	4.00	6.00	8.00	9.00
0.00	0.00	2.00	4.00	7.00	7.00	6.00	6.00
0.17	0.00	4.00	5.00	12.00	13.00	14.00	17.00
0.33	0.00	1.50	3.20	4.30	5.40	4.80	5.00

PCPD7	PCPD8	PCPD9	PCPD10	PCPD11	PCPD12	RAINHHMX1	RAINHHMX2
13.00	15.00	10.00	4.00	2.00	1.00	77.10	55.90
11.00	12.00	11.00	5.00	5.00	2.00	73.00	52.20
21.00	25.00	20.00	10.00	3.00	2.00	17.70	34.90
11.04	13.00	10.40	4.70	1.20	1.00	89.40	53.20

RAINHHMX3	RAINHHMX4	RAINHHMX5	RAINHHMX6	RAINHHMX7	RAINHHMX8	RAINHHMX9	RAINHHMX10
66.60	125.00	55.00	49.00	67.00	60.00	36.70	28.00
70.00	62.00	62.00	47.50	62.20	60.90	52.20	92.50

45.90	45.80	57.40	47.50	38.90	31.50	43.19	23.22
52.70	58.10	60.60	31.78	54.50	82.40	31.30	36.80

RAINHHMX11	RAINHHMX12	SOLARAV1	SOLARAV2	SOLARAV3	SOLARAV4	SOLARAV5	SOLARAV6
27.80	23.30	21.00	22.00	22.00	22.00	22.00	21.00
53.70	30.20	21.00	22.00	21.00	21.00	20.00	19.00
19.90	10.90	18.00	20.00	19.00	19.00	20.00	19.00
28.10	23.20	18.00	20.00	19.00	19.00	20.00	19.00

SOLARAV7	SOLARAV8	SOLARAV9	SOLARAV10	SOLARAV11	SOLARAV12	DEWPT1	DEWPT2
20.00	21.00	21.00	21.00	19.00	21.00	15.40	12.40
16.00	17.00	18.00	21.00	21.00	20.00	7.40	6.40
16.00	18.00	16.00	19.00	20.00	19.00	7.40	6.40
16.00	18.00	16.00	19.00	20.00	19.00	15.00	12.40

DEWPT3	DEWPT4	DEWPT5	DEWPT6	DEWPT7	DEWPT8	DEWPT9	DEWPT10
11.30	15.50	14.40	15.20	16.00	16.50	16.00	9.50
9.70	10.50	7.80	12.30	12.80	13.30	12.30	12.80
9.70	10.50	7.80	12.30	12.80	13.30	12.30	12.80
11.30	15.50	14.40	15.20	16.00	16.50	16.00	9.50

DEWPT11	DEWPT12	WNDVAV1	WNDVAV2	WNDVAV3	WNDVAV4	WNDVAV5	WNDVAV6
7.20	8.10	2.97	2.72	2.87	2.70	2.64	3.33
6.80	7.00	2.97	2.72	2.87	2.70	2.64	3.33
6.80	7.00	1.81	1.75	1.85	1.52	1.76	1.30
7.20	8.10	2.97	2.72	2.87	2.70	2.64	3.33

WNDVAV7	WNDVAV8	WNDVAV9	WNDVAV10	WNDVAV11	WNDVAV12	XPR	YPR
3.23	2.49	1.36	1.37	2.01	2.66	534134.51	920709.66
3.23	2.49	1.36	1.37	2.01	2.66	564277.28	889790.13
1.45	1.16	0.87	2.06	2.06	3.18	522039.75	885328.00
3.23	2.49	1.36	1.37	2.01	2.66	554202.37	914685.01

Appendix 3: Soil Parameters-SWAT

Soil parameters used by the SWAT model

SNAM	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	SOL_Z1	SOL_BD1	SOL_AWC1
Eutric Regosol	1	B	320.00	0.01	0.00	320.0000	1.3700	0.0970
Vitric Andosol	1	A	1700.00	0.01	0.00	1700.0000	1.1000	0.0700
Eutric Cambisol	1	B	1320.00	0.01	0.00	1320.0000	1.3100	0.0960
Eutric Nitosol	1	B	2000.00	0.01	0.00	2000.0000	1.2800	0.1280
Eutric Gleysol	1	B	1820.00	0.01	0.00	1820.0000	1.2800	0.1620
Lithosol	1	A	320.00	0.01	0.00	320.0000	1.3700	0.0970
Chromic Luvisol	1	C	2200.00	0.01	0.00	2200.0000	1.1000	0.1090
Chromic Vertisol	1	B	1750.00	0.01	0.00	1750.0000	1.2000	0.1510

SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1	SOL_EC1	SOL_Z2
120.0000	1.2800	26.0000	34.0000	40.0000	30.0000	0.2000	0.1500	0.0000	0.0000
500.0000	3.5500	18.0000	20.0000	62.0000	20.0000	0.2300	0.1500	0.0000	0.0000
60.0000	2.0000	35.4400	36.0000	28.5600	20.0000	0.1000	0.1500	0.0000	0.0000
250.0000	2.1170	51.0800	34.0000	14.9200	15.0000	0.1000	0.1000	0.0000	0.0000
500.0000	2.5100	45.3600	31.2700	23.3700	15.0000	0.1500	0.1000	0.0000	0.0000
500.0000	1.5800	26.0000	34.0000	40.0000	30.0000	0.2000	0.1000	0.0000	0.0000
50.0000	1.7810	65.0800	26.0000	8.9200	20.0000	0.1000	0.1000	0.0000	0.0000
1000.0000	0.6340	36.0000	54.0000	10.0000	20.0000	0.2000	0.1000	0.0000	0.0000