ESTIMATION OF RUNOFF AND SEDIMENT YIELD USING SWAT MODEL: THE CASE OF KATAR WATERSHED, RIFT VALLEYLAKE BASIN OF ETHIOPIA.

M.Sc. Thesis

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Hawassa University, Ethiopia

ESTIMATION OF RUNOFF AND SEDIMENT YIELD USING SWAT MODEL: THE CASE OF KATAR WATERSHED, RIFT VALLEY LAKE BASIN OF ETHIOPIA.

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ADVISOR APPROVAL SHEET

As thesis research advisors, I hereby certify that, I have read and evaluated the thesis prepared, Under our guidance, by Dulo Husen Washo entitled: "**Estimation of Runoff and Sediment yield using SWAT model: The case of Katar watershed, Rift Valley Lake Basin of Ethiopia**". I recommend that, it can be submitted as fulfilling thesis requirement.

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Major Advisor	Signature	Date

EXAMINERS' APPROVAL SHEET

As member of Board of Examiners of the M.Sc. Thesis Open Defense Examination, We certify that we have read evaluated the thesis prepared by Dulo Husen Washo entitled: **"Estimation of Runoff and Sediment yield using SWAT model: The case of Katar watershed, Rift Valley Lake Basin of Ethiopia".** We recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in **Hydraulic Engineering**

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STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the MSc degree, in Hydraulic Engineering at Hawassa University and deposited at the University library to be used as a reference material. It is not submitted anywhere else or to any other institution for the award of any academic degree, diploma or certificate, but use of it can be possible through borrowing from the University library under the rules and regulation of the library.

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LIST OF ABBREVIATIONS AND ACRONYMS

C	Clay
CL	Clay Loam
CUP	Calibration and Uncertainty Program
CN	Curve Number
CRV	Central Rift valley
DEM	Digital Elevation Model
NMA	National Meteorological Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FAST	Fourier Amplitude Sensitivity Test
GIS	Geographic Information System
HRU	Hydrologic Response Unit
LUC	Land Use Classification
MoA	Ministry of Agriculture
MoWIE	Ministry of Water, Irrigation and Electricity
MUSLE	Modified Universal soil loss Equation
PCP	Precipitation
RVLB	Rift Valley Lake Basin
SCRP	Soil conservation Research Project
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SW	Sub watershed
SWAT	Soil and Water Assessment Tool
SUFI2	Sequential Uncertainty Fitting Version 2
UTM	Universal Transverse Mercator
WXGEN	Weather generator International Water Management

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ABSTRACT

Estimating of runoff and sediment yield at watershed level is important for better understanding of hydrologic processes and identifying appropriate measures to combat erosion. In this study, Soil and Water Assessment Tool (SWAT) was used to calibrate and validate a hydrologic component on Katar river discharges at Habura gauging station and predict the stream flow of Katar watershed. The objective of the study was estimating the runoff and sediment yield for the Katar watershed using SWAT model. Sensitivity analysis, model calibration and validation were also performed to assess the model performance. From the result of Global sensitivity analysis, twelve(12) highly sensitive parameters were identified, and coefficient of determination (R^2*), Nash-Sutcliffe (ENS) and* percent bias (PBIAS) *were used as objective function to evaluate model calibration and validation on the monthly basis, and it could simulate runoff to a good level of accuracy. The results obtained were satisfactory for the gauging station (*R^2*= 0.80, ENS = 0.6 and PBIAS=0) for calibration and (*R^2*= 0.6, ENS = 0.55 and PBIAS=1.2) validation period. The simulated runoff and sediment yield of Katar watershed was quantified and also the utmost erodible part of the watershed was identified and prioritized. Among all sub-watersheds, nine (9) sub watersheds were more vulnerable to soil loss and potentially prone to erosion risk, which was out of range of tolerable soil loss rate (18 *$tha^{-1}yr^{-1}$*). Large area of watershed covered by Haplic Luvisols(high clay content) and agriculture is the dominant activities in area. The simulated mean of sediment yield and runoff loss from watershed for 26 years were 11 *$tha^{-1}yr^{-1}$* and 12.3 *m^3s^{-1}* respectively. The result of the study could help stakeholders to plan and implement appropriate watershed management strategies based prioritizations of severity of erosion. In conclusion, the SWAT model could be effectively used to predict runoff and sediment yield and result of the study could help different stakeholders to plan and implement appropriate interventions strategies in the Katar watershed.*

Keywords: *Katar watershed***,** *Runoff, Sediment yield, SWAT, SWAT_CUP, Calibration and Validation.*

1 INTRODUCTION

1.1 Background

More than 90% of the Highlands were once forested; today the percentage of forest cover is less than 4% (Hurni, Solomon, Amare, Berhanu, Eva, Brigitte, Zeleke, (2010). 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 (Bobe, 2004). Another report by the Soil Conservation Research Project (SCRP, 1985) of Ethiopia indicated that the rate of soil loss in extreme cases ranges from 0 to 300 t $ha^{-1}yr^{-1}$ with an average loss of 70 t $ha^{-1}yr^{-1}$, which is beyond the concept of any tolerable soil loss. Taddese (2001) also indicated that 1.5 million tons of soil has been lost in the Ethiopian highlands each year, which also has resulted in a significant loss of grain from the country's annual harvest. As a result of soil erosion, poverty and food insecurity are concentrated in rural areas (MoARD 2010).

The extensive deforestation has led to severe soil erosion and increased land degradation throughout the Ethiopian Highlands, particularly in Katar watershed area. The loss of 20 billion tons of soil per year is not only degrading the environment but also affecting the economic viability of countries (Richard, 2009). The highlands have been experiencing severe soil erosion due to intensive farming on steep land, population growth, overgrazing, deforestation, improper land management systems, lack of appropriate soil and water conservation measures and rugged terrain and fragile soil in the study area (Amsalu and De Graaff, 2006).

In the Ethiopian highlands, deforestation for crop production, cultivation of marginal lands and overgrazing are the major factors that dramatically increased the vulnerability of agricultural lands to rainfall-driven soil erosion (Addis, 2016).The intensive cultivation and deforestation for crop production increased in Katar watershed and as a result huge amount of soil losses from the study area and some areas under high and sever soil erosion. Increasing soil erosion, resulting sedimentation have a major impact on the Ziway Lake (Ayenew, 2004). Hence, a clear understanding of runoff, sediment transports and the ability to accurately predict the erosion processes are essential for appropriate watershed management. SWAT model is a suitable model that is used for estimating runoff and sediment loss, and provided information for the sustainable development of the land and water resources of the study watershed.

1.2 Statement of the problem

Land cover change is massively and rapidly taking place, as elsewhere in the Ethiopian Central Rift Valley (CRV) (Dadi, 2016), and CRV is one of the environmental vulnerable areas in the country. Katar watershed situated in CRV and the area is currently under heavy pressures associated with the increasing population (Jansen, 2007), climate change (Zeray, 2006) as well as the intensification of agricultural development activities were increased in the watershed.

In Katar watershed, land cover is rapidly changed to agricultural land, improper land management, deforestation of forest, overgrazing and population pressure is increasing from time to time (Tibebe, D.; Bewket, W. (2011)). Katar watershed is a part of Ethiopia highlands, soil degradation is at an alarming rate due to erosion by water and intensive agricultural activities on undulating slopes without any conservation mechanisms, as a result huge amount of productive soil losses from the study area, which can affect health of hydrological process within the watershed. The soil in some parts of sub watershed is highly eroded, due to fragile ecosystem and inherent erodible nature of the soils. As the result of rapid soil degradation and massive soil erosion from this watershed, and some parts of this watershed is already taken out of cultivation due to land dissected by gully(a) and significant masses of soil are washed away from the watershed(b) as illustrated in Figure1. Soil erosion by water not only reduced the productivity of the land in this watershed, but also causes severe siltation in reservoir, mainly ziway lake.

So, it is very important to assess the runoff and sediments transport from the watershed (the spatial distribution of sediment yield and runoff loss in the catchment) and develop sediment yield loss map in the area before formulation of any soil and water conservation strategies, which are essential for land and water management and sustainable food production. The is not studied in depth in the Katar watershed. The total amounts of sediment yield annually leaving the watershed is not easily quantified manually for remote and inaccessible areas; particularly for Katar watershed.

In reality it is not possible to conserve all areas under the threat of erosion because of the financial constraints. Most recently, watershed management is an approach followed by the government of Ethiopia in the form of mass mobilizations to protect soil from erosion in particular and to reverse land degradation in general (Desta et al. 2005; Gete 2006; Nigussie et al. 2012). In order to reverse soil erosion, several efforts have been exerted since the 1970s (Bekele and Holden 1998; Menale et al. 2009; Nigussie et al. 2012). However, past soil conservation efforts did not bring significant changes to the ongoing soil degradation problems (Bekele and Holden 1998; Menale et al. 2009). Whereas, dramatic reduction has been made in arresting soil erosion (Gashaw, T.; Tulu, T.; Argaw, M,.2017), the approach has not been supported with intervention prioritizing techniques that identify highly susceptible erosion prone areas. Identification of erosion-prone areas using a distributed physical model that estimates soil erosion rates with sufficient accuracy will be important for implementing appropriate erosion control practices (Shimelis, B.D.; Melesse, 2015). The Katar watershed is one of the central highland basin in the Rift Valley region of Ethiopia where soil erosion is rampant. Hence, to solve this, there is a need to identify the most erosion prone areas in the watershed, so that effective conservation measures can be taken.

Therefore, to address the above situation, watershed management is one of the most important approaches, which helps to reduce land degradation, increase vegetation cover, and productivity of the watershed. Thus way, SWAT is imperative model for estimation of sediment yield and runoff losses from the watershed.

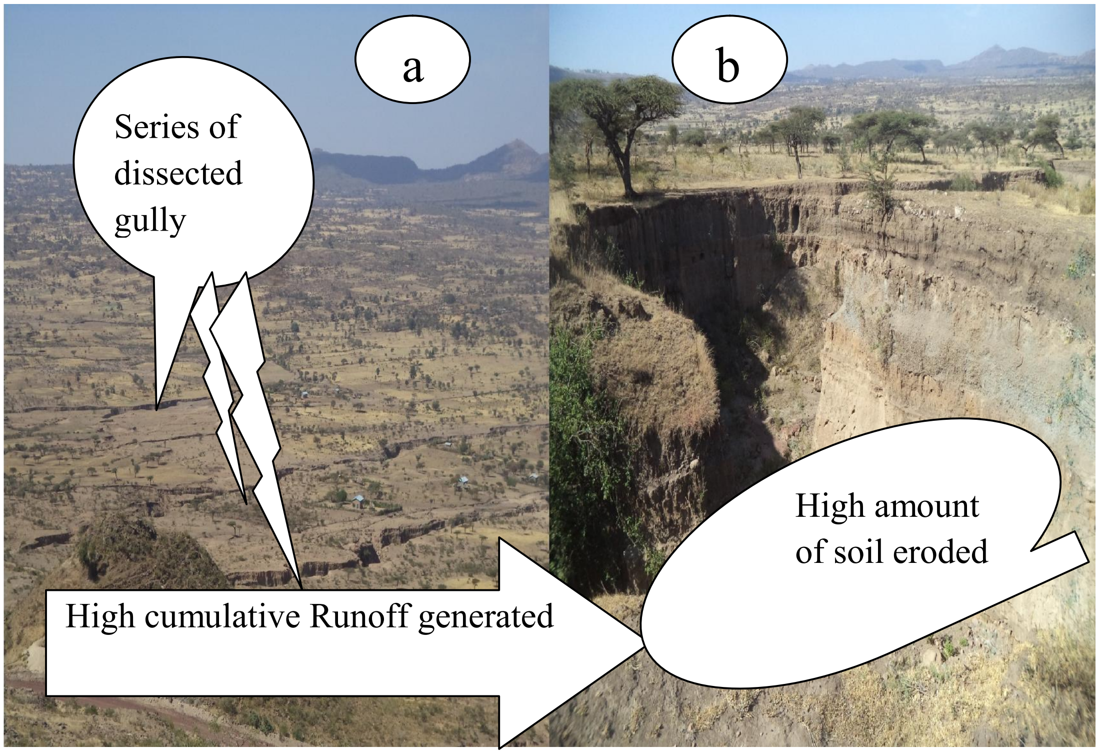

Figure 1. The series dissected of gully formation (a) and high amount of soil loss(b) from Hetosa Woreda (2017).

1.3 Objectives

1.3.1 General objectives

- To estimate the runoff and sediment transport for the Katar watershed using SWAT model

1.3.2 Specific objectives

- To estimate simulated runoff and sediment transported from watershed
- To categorize the watershed in terms of soil erosion rate and runoff potential and identify the most erodible sub catchment.

1.4 Research questions

The study addressed the following research questions:

1. Which sub-catchment is more erodible?

2 LITERATURE REVIEW

2.1 Watershed

Watershed or catchment is an area of land that drains water, sediments and dissolved materials at some common water outlet, *i.e.,* stream, river, or lake. The required point of analysis, or where the flows, or design criteria might be required which defines downstream lowest point of a watershed. Therefore, lowest most location at the downstream is referred to as a point of interest for analysis purpose. Most of the lakes in the Rift Valley of Ethiopia are located at the bottom end of large drainage basins to receive maximum water-collecting potential (Halcrow, 1989). Watershed activities can directly affect reservoir health and stability and because of this linkage with watershed activities; understanding of complex interactions between aquatic and terrestrial systems become an important aspect of lake management. This leads to evaluation of the watershed to develop criteria for effectively handling the problems associated with watershed-linked, reservoir water quality and quantity (Nyssen, 2003).

2.2 Factors affecting soil erosion

Several factors influence soil erosion; which include climate, soil, topography, and vegetation and management practices. 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.

2.2.1 Soil type

Few soil properties, which affect soil erodibility, include soil texture, drainage condition, soil depth, structural integrity and organic content (Gebreyesus and Kirubel 2009; Prasannakumar et al. 2012). The vulnerability of soil to erosion, known as its erodibility, is a result of these four properties that act to either influence infiltration (the movement of water into the ground) or to resist soil detachment and transport by rainfall and runoff. Each type of soil has its own inherent susceptibility to the forces of erosion, in large part because of chemical composition and organic matter content. The soil resistance to erosion depends in part on topographic position, slope steepness and the amount of disturbance created by man, for example during tillage, the properties of the soil are the most important determinants. Although large-grained materials are easily detached by raindrop splash or flowing water, they are not easily transported.

The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have smaller infiltration capacities. Soil permeability refers to a soil's ability to transmit air and water. Soils with high permeability rates reduce runoff by allowing more water to infiltrate. Well-graded gravels and gravel sand mixtures typically have high permeability rates and are less susceptible to erosion from rainfall and surface runoff. The infiltration capacity depends further more on the moisture content prevailing in a soil at the onset of a rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated (Finkel and Sergerros, 2005). 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

2.2.2 Erosivity

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. 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). The two important rainfall variables that determine storm erosivity are rainfall amount and rainfall intensity. Rainfall intensity provides a measure of erosion per unit rainfall, which multiplied by rainfall amount, provides an estimate of total erosivity for the storm.

The frequency, intensity, and duration of rainfall and the size of the area on which the precipitation falls are fundamental factors in determining the amount of runoff produced. Frequent and intense storms, especially those of longer duration, pose a serious erosion risk. Seasonal changes in temperature, as well as variations in rainfall, help to define the high erosion risk period of the year. In area where rainfall is adequate with good distribution and mild air temperature, people prefer to grow crops and keep livestock i.e. to undertake settled mixed agriculture (Lahmeyer and Yeshi-Ber consult, 2004).

2.2.3 Topography

Topographic features that influence erosion are slope, size and shape of a watershed and aspect of a mountain. There are three factors of a slope affecting erosion, namely steepness, length, and curvature of a slope. 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). Runoff velocity and effective depth of interaction between surface soil and runoff is increased with increase in slope.

Investigation on experimental plots has shown that steep slope plots yield more runoff than those with gentle slopes. Some researchers, for instance (Bobe, 2004) indicated that soil erosion increases exponentially with increase in slope gradient.

2.2.4 Vegetation Cover and Management

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. Vegetation Cover and Management also have a direct link to soil erosion. Vegetation covers play an important role in hindering the erosion process more significant is the effect the vegetation has on the infiltration capacity of the soil. The root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving more time to infiltrate and to evaporate (Troch, 2003).

Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. Close growing plants catch raindrops and keep them from hitting the soil directly. It has a greater impact on erosion than any other single factor. Materials in contact with the soil surface reduce erosion more effective than a canopy. Cover in contact with the soil surface also absorbs much of the flow’s eroding and transporting force, which greatly reduces erosion. However, forests usually contain protective ground cover in the form of leaf or needle mulch. Not only do ground covers intercept raindrops and keep them from detaching soil particles, but these covers also prevent soil compaction, which restricts infiltration of water into the soil. With greater infiltration there is less runoff.

Changes of land use and land cover through the expansion of agricultural land at the expense of forest and woodlands have been the major causes of soil erosion in the area (Ayenew, 2004 and Meshesha, 2010) and have exacerbated the effects of the seasonal high rainfall and steep terrain.

2.3 Impact of Land Use on Water Resource

2.3.1 Land use impact on hydrologic regime

With regard to the hydrologic regime, impacts on surface and ground water resources can be distinguished. Impacts of land use practices on surface water can be divided into (i) impacts on the overall water availability or the mean annual runoff, and (ii) impacts on the seasonal distribution of water availability. With regard to groundwater, the effect of the land use on groundwater recharge has to be examined.

2.3.2 Mean surface runoff

The impact of land use on the mean runoff is a function of many variables, the most important being the water regime of the plant cover in terms of evapotranspiration (ET), the ability of the soil to hold water, and the ability of the plant cover to intercept moisture. A change of land cover from lower to higher ET will lead to a decrease in annual stream flow. Conversely, a change from higher-ET plants to lower-ET plants will increase the mean surface runoff reduction in forest cover increases water yield (Calder, 1998). Increasing water yield from changing plant cover does not necessarily increase water availability downstream.

2.3.3 Peak flow/floods

Peak flows can increase as a result of a change in land use if the infiltration capacity of the soil is reduced, for example through soil compaction or erosion, or if drainage capacity is increased. Peak flow may increase after trees are cut down (Bruijnzeel, 1990). Relative increases in storm flow after tree removal is smallest for large events and largest for small events. As the amount of precipitation increases, influence on storm flow of soil and plant cover diminishes (Bruijnzeel, 1990).

Conversely, peak flows may decrease as a result of an increased soil infiltration capacity. In larger basins, effects of land use practices on peak flow are offset due to time lag between different tributaries, different land use and variations in rainfall (Bruijnzeel, 1990). In larger watersheds, this de-synchronization effect can lead to a reduction in peak discharge, although overall storm flow increases due to land use changes in individual sub watersheds (Brooks, 1991).

2.3.4 Groundwater recharge

The groundwater recharge may be increased or decreased as a result of changing land use practices. The major driving forces are the ET of the vegetative cover and the infiltration capacity of the soil. Groundwater recharge is often linked with dry-season flows, as groundwater contributes much of the river discharge during the dry season. The water table may rise as a result of decreased evapotranspiration, e.g. following logging or conversion of forest to grassland for grazing. Recharge may also increase due to an increased infiltration rate, e.g. through afforestation of degraded areas (Tejwani, 1993). In contrast, the water table may fall as a result of decreased soil infiltration, e.g. through non-conservation farming techniques and compaction (Tejwani, 1993). And also, heavy grazing may lead to reduced infiltration and groundwater recharge (Chomitz and Kumari, 1996). Likewise, groundwater recharge can be reduced as a result of planting of deep rooting tree species, e.g. eucalyptus (Calder, 1998).

2.4 Land use land cover change

LULC has a substantial impact on the hydrological compartment since land use and land cover change has become a central component in current strategies for managing natural resources and monitoring environmental changes (Zubair, 2006). Land use land cover change (LULCC) can be easily observed in forestry on a global scale, the largest change in terms of land area, and arguably also in terms of hydrologic effects, is from deforestation and afforestation. Deforestation, rapid land use change for farming and overgrazing are likely to affect the hydrologic regime of the rift lakes (Tenalem Ayenew, 2007).

For different parts of Ethiopia, land cover changes were studied from small scale to large scale, e.g. Zeleke and Hurni, 2001 (north-western Ethiopia) Bewket, 2003; Belay, 2002 (north Ethiopia); Kassa, 2003 (north-eastern Ethiopia); Mekuria, 2005 (south-western Ethiopia) and Mengistu, 2009 (southern Ethiopia). All these studies show that agricultural land has expanded at the expense of natural vegetation, including forests, grazing land and shrub lands. In many parts of the highlands of Ethiopia, agriculture has gradually expanded from gently sloping land into the steeper slopes of the neighboring mountains (Mengistu, 2009). As a result of runoff from rainfall, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill, and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in reservoirs or down watershed. Removal of vegetation increase runoff, the increase in runoff has been found to be proportional to the area of vegetation removed. The other factor that affects hydrologic compartment is agriculture.

2.5 Description of SWAT Model

SWAT is a river basin scale, a continuous time, a spatially distributed model 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, 2005). SWAT can analyze both small and large watersheds by subdividing the area into homogenous parts. As a physically-based model, SWAT use hydrologic response units (HRUs) to describe spatial heterogeneity in terms of land cover, soil type and slope within a watershed. The SWAT system embedded with-in geographic information system (GIS) that can integrate various spatial environmental data including soil, land cover, climate and topographic features. Currently SWAT is imbedded in an ArcGIS interface called ArcSWAT. It is computationally efficient, in recent years, SWAT (Soil and Water Assessment Tool) model developed by (Neitsch, 2005) has gained international acceptance as a robust interdisciplinary watershed modeling.

SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman, 2005). Applications of SWAT have expanded worldwide over the past decade, especially in the US and Europe (Arnold and Allen, 1999), in developing countries (Chekol, 2007) and specifically in Ethiopia (Eyob, 2010).

2.6 Overview of hydrological modeling

Many hydrological and soil erosion models are developed to describe the hydrology, erosion and sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of sediments.

2.6.1 Runoff modeling

Surface runoff estimation is of immense important as it directly affects any planning (Schwab, 2002). Tripath, (2002) indicated that watershed parameters such as size of the catchments, slope, soil type, land use/land cover, vegetation with in channels, and storage capacity of the watershed area 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.

2.6.2 Hydrologic model

Hydrological modelling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling (Lenhart, 2002).Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. Without going into too much detail, deterministic hydrologic models can be classified into three main categories (Cunderlik, 2003).

1. Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 2000).

2. Semi-distributed models. Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. There are two main types of semi-distributed models: 1) kinematic wave theory models (KW models, such as HEC-HMS), and 2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 2000). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin.

3. Distributed models. Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

2.7 Empirical description

The Simulation of the hydrology of a watershed is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water and sediment loadings to the main channel in each sub watershed. The second division is routing phase of the hydrologic cycle that will be defined as the movement of water and sediments through the channel network of the watershed to the outlet. In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SWT = SWo + \sum_{i=0}^{t}(Rday - Qsurf - Ea - Wseep - Qqw)i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 1}$$

In which SWt is the final soil water content (mm), SWo is the initial soil water content on day i (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), and Qgw is the amount of return flow on day i (mm).

2.7.1 Surface Runoff Volume

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. The SCS curve number method used to estimating surface runoff (SCS 1972). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. In this study, the SCS curve number method is used to estimate surface runoff. The method is an empirical model, which is based on the following equation:

$$\mathrm{Qsurf} = \frac{(Rday \quad Ia)2}{(\mathrm{Rday} - \mathrm{Ia} + \mathrm{s})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq.2$$

Where: Qsurf is the accumulated runoff or rainfall excess (mm H2O), Rday is the rainfall depth for the day (mm H2O), Ia 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:

$$S = 25.4\left(\frac{1000}{CN} - 100\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots\ldots\ldots . \mathrm{Eq.\,3}$$

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

$$\mathrm{Qsurf} = \frac{(Rday - 0.2s)2}{(\mathrm{Rday} + 0.8\mathrm{s})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq.4$$

Runoff only occur when Rday > Ia. The detailed and complete descriptions about CN are given in the SWAT theoretical documentation (Neitsch ,2002).

The initial value of the retention parameter defined as S=0.9*Smax. The SCS curve number is a function of the soil’s permeability, land use and antecedent soil water conditions. SCS defines three antecedent moisture conditions:

- I – dry (wilting point),
- II – average moisture, and
- III – wet (field capacity).

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 will be used to predict sediment loss. SWAT will calculates the peak runoff rate with a modified rational method.

$$\mathrm{Qsurf} = \frac{\mathrm{CIA}}{3.6} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . Eq. 5$$

Where: qpeak: is the peak runoff rate (m3/s),

C: is the runoff coefficient,

i- is the rainfall intensity (mm/hr),

A- is the sub basin area (km2) and

3.6 is a unit conversion factor.

2.7.2 Sediment component

SWAT calculates the soil erosion and sediment yield with the Modified Universal Soil Loss Equation (MUSLE), (Williams and Berndt, 1977).

$$Sed = 11.8(Qsurf * qpeak * Ahru)0.56 * KUSLE * CUSLE * PUSLE * LSUSLE * CFRG..Eq.6$$

In which sed is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume (mm /ha), qpeak is the peak runoff rate (m3/s), area hru is the area of the HRU (ha), KUSLE is the soil erodibility factor (0.013 metric ton m2 hr/ (m3-metric ton cm), CUSLE is the cover and management factor, PUSLE is the support practice factor, LSUSLE is the topographic factor and CFRG is the coarse fragment factor.

In general, the processes like generation and transport of runoff and sediment from watersheds included in Surface hydrologic modeling. The design of conservation structures was required for estimation of runoff and sediment transport to reduce the ill effect of sedimentation. This effort is enhanced by the use of physically based computer simulation models (SWAT) technique, which helps in identifying most vulnerable erosion prone areas and selecting appropriate management practices for the study area based on topography and other important parameters.

3 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location and Topography

Katar watershed covers 3326.86 square kilometers (km^2) is part of the Ziway Shala sub basin of main Ethiopia Rift valley. This internal drainage basin located in the central part of the Main Ethiopian Rift Valley. Geographically it is located between $7^{0}21'33"$ - $8^{0}9'53"$ North latitude and $38^{0}53'57"$- $39^{0}24'46"$ East longitude. Katar River and its tributaries drain from south east highland area to North West and enter Lake Ziway. Topographically, Katar catchment shows a well pronounced variation with the altitude ranging from around 1644m.a.s.l near Lake Ziway (at the outlet) to about 4171m.a.s.l, on the high volcanic ridges along the eastern watershed (Kaka and Galama Mountain).

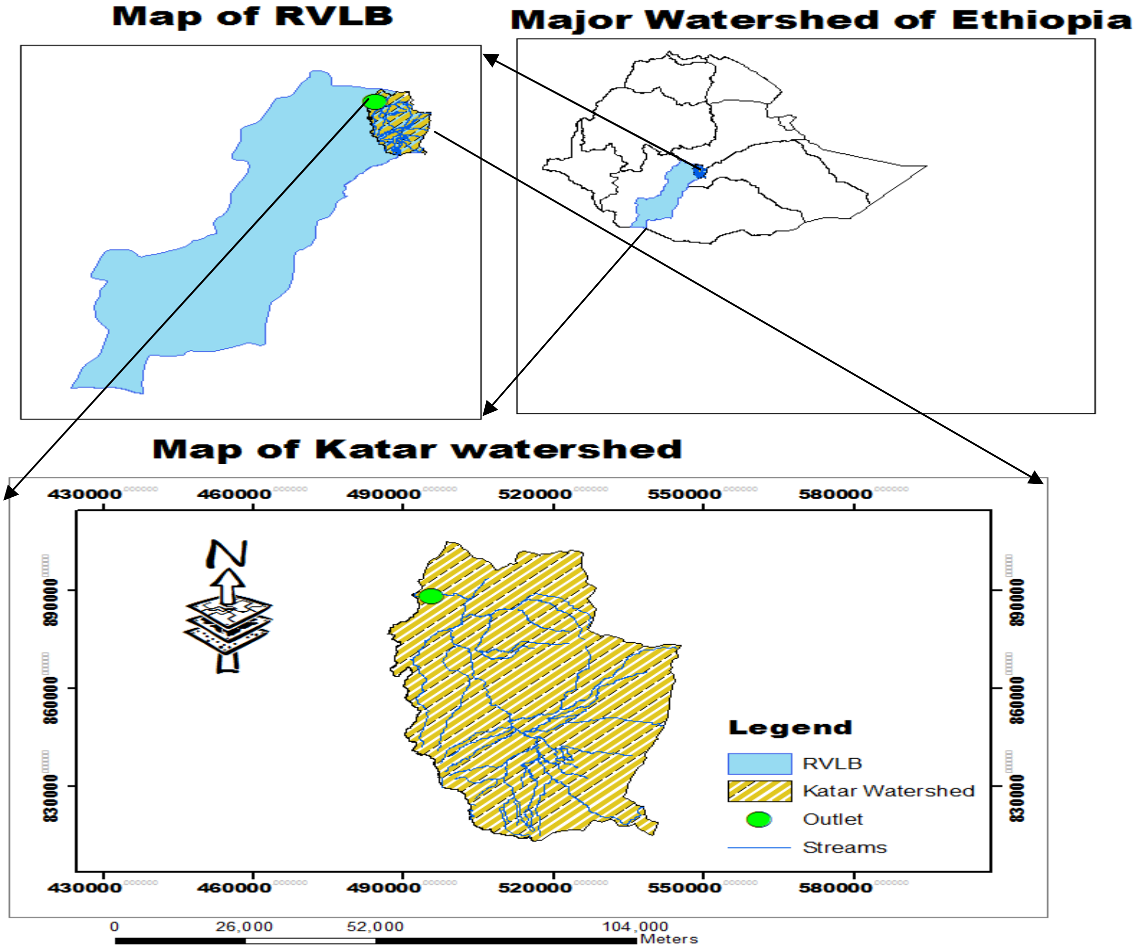

Figure 2. Map of Study Area (source: MOWIE, 2007 master plan)

3.1.2 Climate

The climate of Katar watershed is dry to sub-humid or humid climate. The lowland area surrounding the lake is arid or semi-arid and the highlands are sub dry humid to humid (Tenalem, 2007; Wolter, 2007). According to the statistical analysis of the climatic data, the climate of the study area can be categorized as semi-arid to sub-humid type with a mean yearly rainfall ranging from 744.8mm to 1046.0 mm, and with a mean yearly minimum and maximum temperature ranging from 7.3°C to 13.8°C, and from 19.0°C to 28.1°C respectively.

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

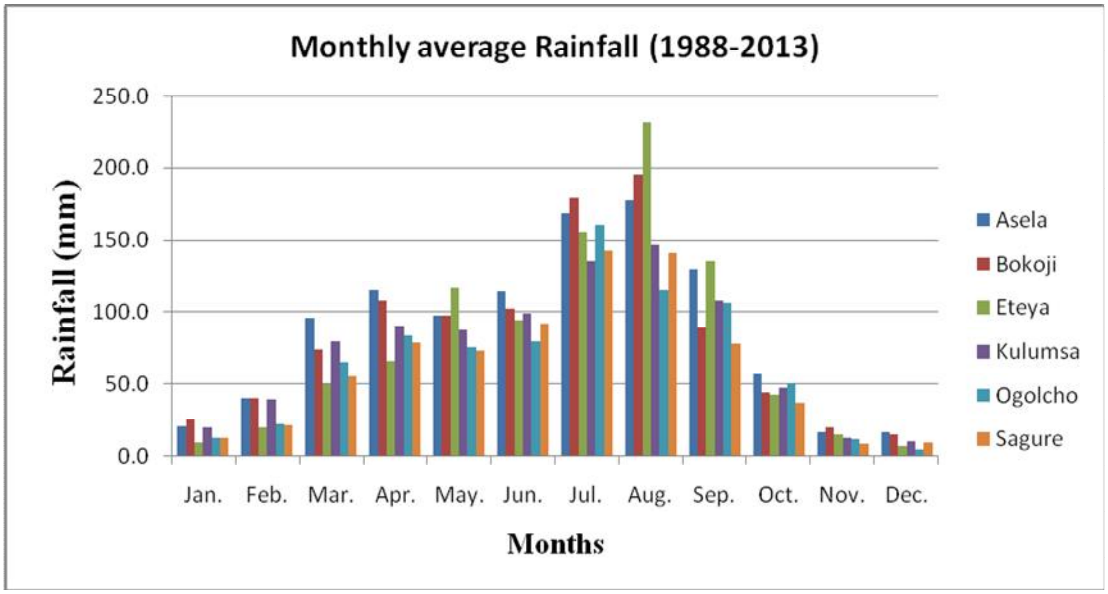

Figure 3. Mean monthly rainfall of selected station at Katar watershed from 1988-2013 (source: NMA)

3.1.3 Hydrology

Katar River is the biggest perennial river starting from Arsi high lands (Kaka and Galama Mountain) and flowing towards the northwest and finally joins the lake. It is the largest tributary of Lake Ziway with a catchment has a common boundary with the Awash River Basin in the north and with Wabi-Shebele River Basin in the south west. The daily observed stream flow data was obtained at the outlet (Habura) of the watershed, for 26 (1988-2013) years from Hydrology Department of Ministry of Water, Irrigation and Electricity for Katar River feeding to Lake Ziway. The daily discharge data of station for Katar River was not completed. However, some of the missing daily discharge data were filled using linear regression equation between the downstream and the upstream gauge for Katar river discharge relation. Then, after missed data were filled, the stream flow data used for calibrating and validating the model.

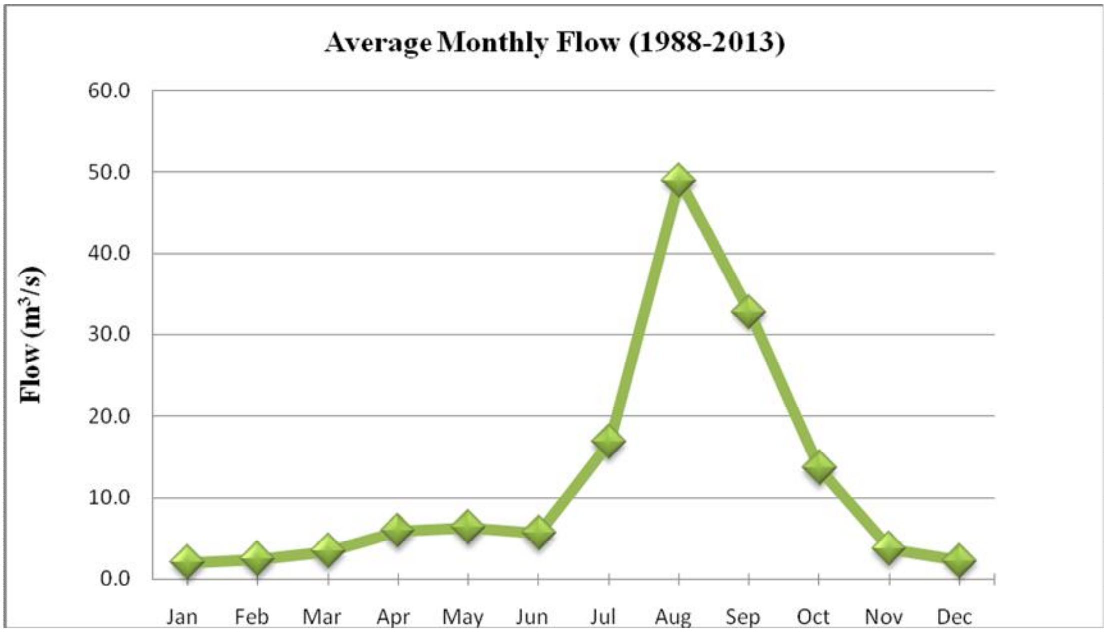

Figure 4. Mean monthly River flow of Katar watershed from 1988-2013 (source: MOWIE)

3.2 Filling of Missing Meteorological data

Among meteorological data collected from National Meteorological Agency (NMA), rainfall data is the most important and had missing value at most meteorological station of watershed. Hence, the Normal Ratio Method (NRM) was used to fill the missing data of rainfall stations. This method was important for this watershed since the differences in annual rainfall between most of the stations exceed 10% and the existence of large elevation difference among the stations. This approach enabled to estimate missing data by weighing the observation at n‘gauges by their respective annual average rainfall values and can be adopted by using the following equation (Garg, 2005):

$$px = \frac{Nx}{N}\left(\Sigma\frac{Pn}{Pi}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . Eq.7$$

Where:

Px = Estimated precipitation

Nx = the mean annual rainfall for the station with missing data (mm),

Pn =Daily precipitation depth at the adjacent stations of n number

Pi = Average annual precipitation of adjacent stations

N = Total number neighboring stations

3.2.1 Data consistency

To check the change in magnitude of rainfall data for stations, Double Mass -Curve(DMC) analysis was used to check whether the existence was inconsistency in rain - gauge stations in Katar watershed. The missing data were first estimated, and then consistency analysis was applied. The cumulative rainfall data of a specific station is plotted against the cumulative average rainfall of the remaining stations. After plotted the cumulated rainfall data versus average rainfall data was shown a good relation, but for Ogolcho and Bokoji stations shown inconsistency (Figure 5) and this two station corrected and plotted again (Figure 6). After data corrected, all the stations are internally consistent at each stations (Figure 6). The observed gauging stations data shown that, the collected data is homogeneous. The results of the consistency analysis are plotted in figure 6.

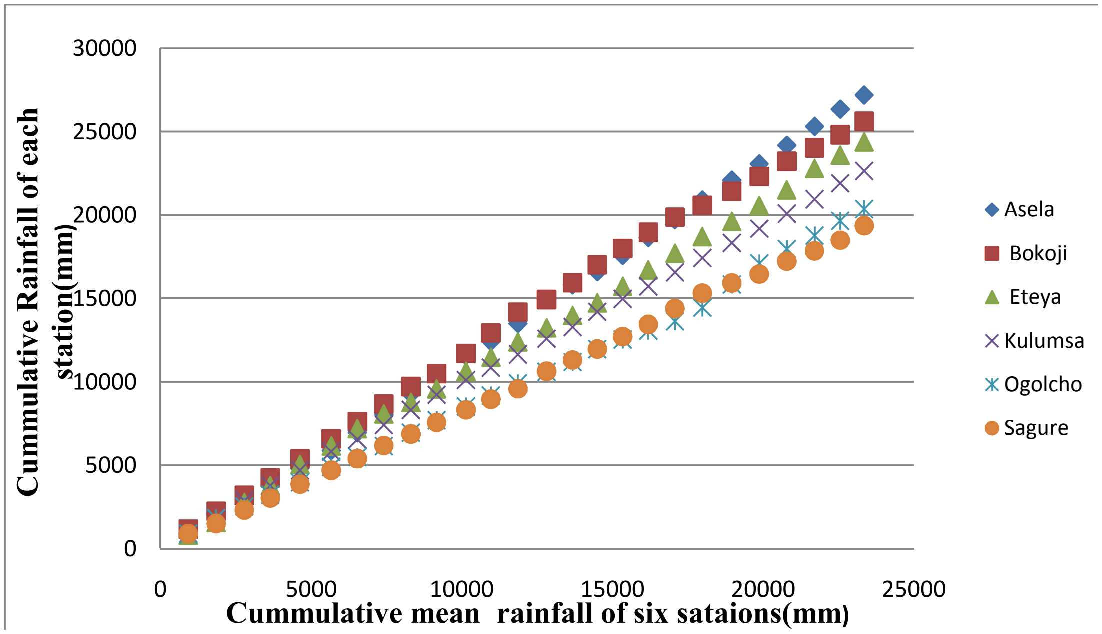

Figure 5. Double Mass Curve for the Stations of Katar Watershed before corrected consistency (Source: NMA)

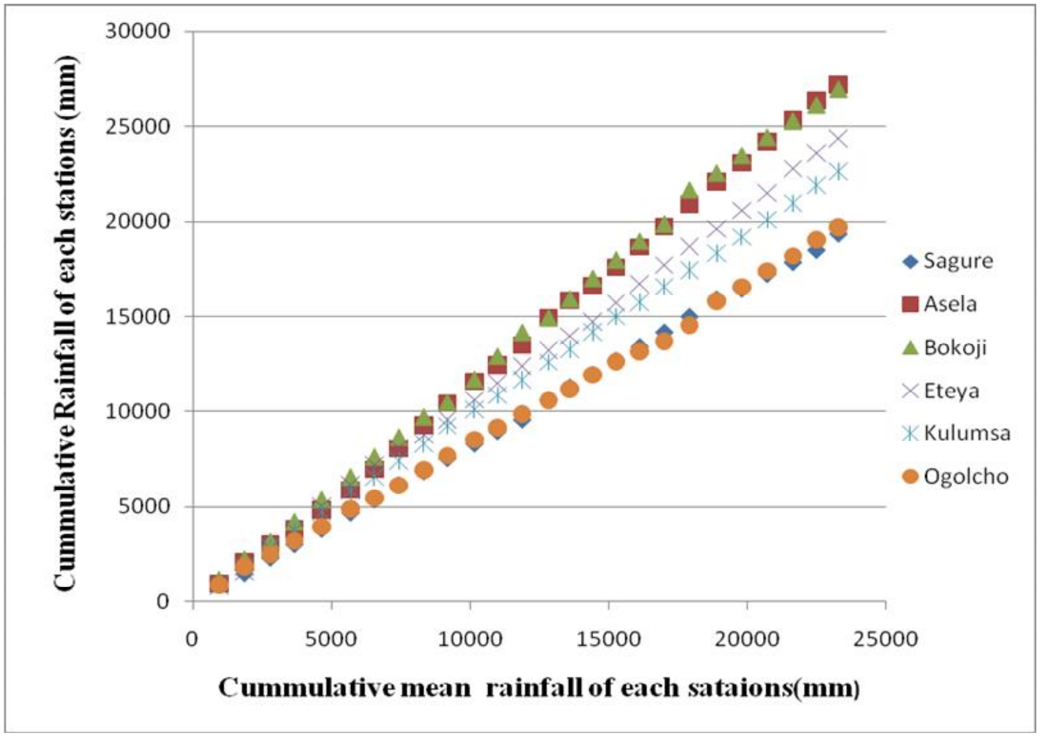

Figure 6. Corrected Double Mass Curve for the Stations of Katar Watershed (Source: NMA)

3.3 Model Inputs

The most important spatial information needed were: Digital Elevation Model (DEM), land use or land cover and a soil.

3.3.1 Digital Elevation Model

Topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. DEM 30mx30m resolution was obtained from MOWIE and the area was delineated using this spatial resolution. The DEM was used to delineate the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient and slope length, and stream network characteristics such as channel slope, length and width were derived from the DEM (Figure 7). Then, watershed delineation activity was finalized by calculating the geomorphic sub-basin parameter.

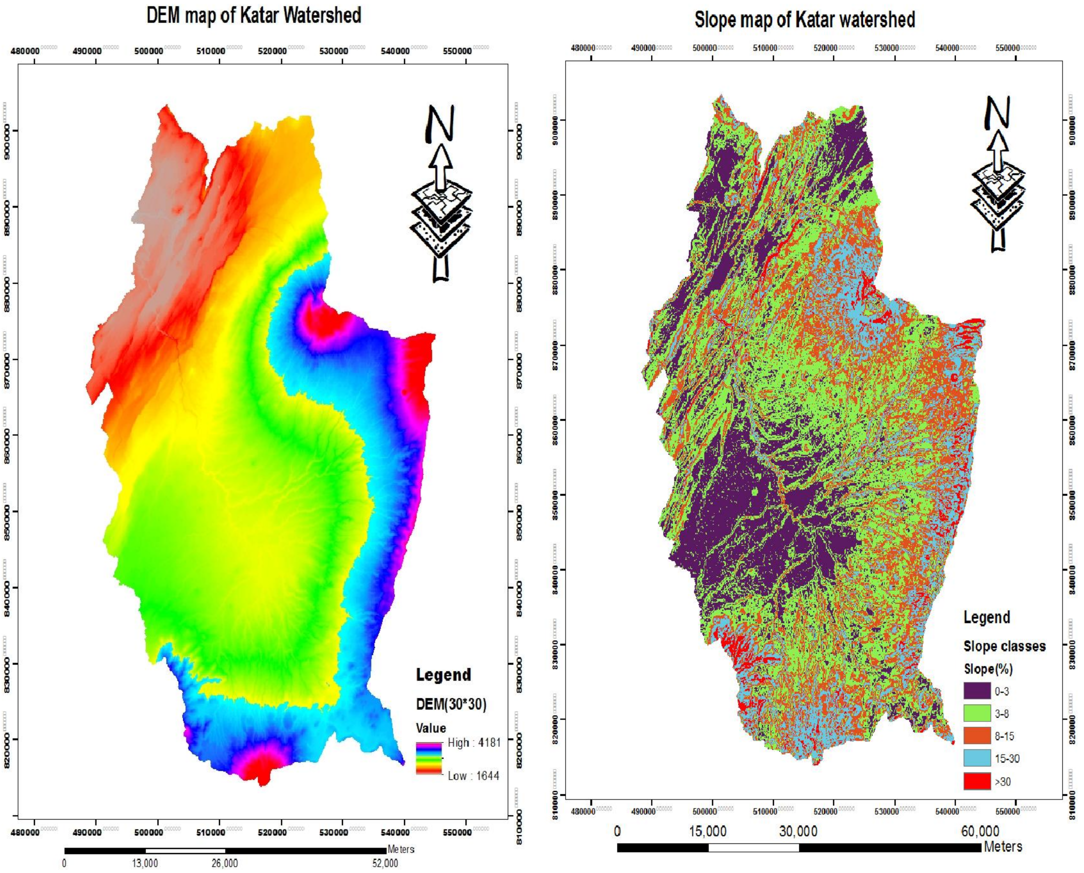

Figure 7. Digital Elevation Model(left) and slope classes (right)(Source: MOWIE,2007)

During the creation of HRU, the slope was classified into the reasonable range. Accordingly, for this work to minimize complexity and use manageable data and also considering the steepness of the area, the slope was classified into five classes based on MOARD (2005). These are: 0-3%, 3-8%, 8-15%, 15-30%, and above 30%. The results indicated (Table 1) that, more area of watershed covered by a slope ranges from 3-8, 0-3 and 8-15% which account an area of 136425.12 ha (41.01 %), 76226.09 ha (22.91 %) and 80812.36 ha (24.29 %) of the total watershed area respectively. That is flat to the gentle slope and rolling plain dominate the watershed; and steep hilly, very steep slopes, ridges and mountains (>30%) covered an area of 4541.36 ha (1.37 %) of the total watershed.

Table 1. Slope classes and the area occupied in ha and percent (%) of the study area after HRUs definition

Slope range (%)	Kater Watershed		
	Land form	Area (ha)	Area Coverage (%)
0-3	Flat or almost flat	76226.09	22.91
3-8	Gentle slopping, undulating plain	136425.12	41.01
8-15	Rolling plain	80812.36	24.29
15-30	Hilly plain	34681.18	10.42
>30	Steep hilly, very steep slopes, ridges and mountains	4541.36	1.37
Total		**332686 .11**	**100**

3.3.2 Land Use/land cover

Katar watershed covered an area of 3326.86 km^2, which resulted in 35 sub watersheds with 181 HRUs. The land use land cover data were acquired from the Rift Valley lake Basin Master plan 2007 in the form of shape files. The ten (10) land use land covers were identified for this study area (Table 2).

Table 2 . Original Land use/ land cover types and their SWAT code in the study area

Original Land Use	**SWAT Code**
Intensively Cultivated	AGRC
Moderately Cultivated	AGRL
Exposed surface	EXPS
Grassland	PAST
Shrub land	RNGB
Forest	FRST
Urban Area	URBN
Afro-Alpine	FRSE

Marshland	WETL
Water	WATR

The dominant land use land cover of study area after HRUs definition was as follows; Intensively Cultivated land, Moderately Cultivated land, Exposed Surface, Grassland, Shrub land, Forest and Afro Alpine Green Vegetation. According to the land use land cover data; major part of the watershed was covered by Intensively Cultivated land which account about 263287.83 ha (79.14 %) of watershed area, and the lowest part of watershed covered by forest land which account about 291.80 ha(0.09%) of watershed area from the whole watershed (Table 3).

Table 3. Area coverage by each land use/Land cover type of the study area after the definition of HRU

	Katar Watershed	
Major land use	**Area (ha)**	**Area (%)**
Intensively Cultivated	263287.83	79.14
Moderately Cultivated	38590.62	11.60
Exposed surface	1399.97	0.42
Grassland	2395.03	0.72
Forest	291.80	0.09
Afro-Alpine Green Vegetation	9177.65	5.76
Shrub-land	7543.21	2.27
Total	**332686.11**	**100**

3.3.3 Soil data

The soil physical and chemical characteristics play a large role in determining the movement of water within the HRUs. Soil data were obtained from Rift Valley Lakes Basin (RVLB) integrated resource development master plan study project (MOIWE, 2007). And also some SWAT soil parameters were calculated by using Pedo Transfer Function (PTF) developed by Saxton and Rawls (2006). From this distribution of soil type, Haplic Luvisol(LVh) covered more area (56.43%) of the study watershed (Table 4). This soil type contain 48.1% of clay, 30.9% of silt and 21% of sand, and clay soil is the dominant soil in the study watershed (Table 4). The least soil type is Eutric Cambisols (CMe) and contain 44% clay, 30% silt and 26% of sand. From the watershed, 150.61ha (0.05%) of land covered by water body.

Table 4. Distribution of soil type in the Katar Watershed

Types of Soils	Area (ha)	Area (%)	Textural Distribution/Composition		
			Sand (%)	Silt(%)	Clay %)
Eutric Cambisols (CMe)	7.70	0.00	26.0	30.0	44.0
Rhodic Nitisols(NTr)	105574.19	31.73	37.8	31.8	30.4
Vitric Andosols(ANz)	19313.71	5.81	39.0	38.4	22.6
Eutric Vertisol(VRe)	19897.31	5.98	18.6	38.5	42.9
Haplic Luvisol(LVh)	187742.59	56.43	21.0	30.9	48.1
Total	**332535.5**	**99.95**			

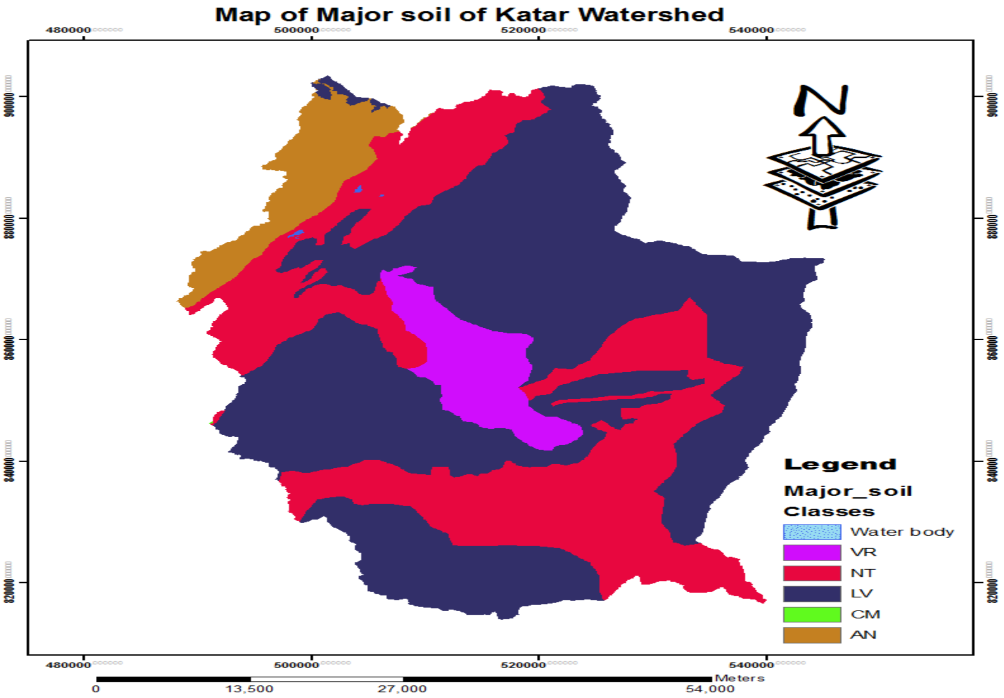

Figure 8. Major soil map of the study area (Source: MOWIE, 2007 master plan)

The identified dominant soil types of the study area as illustrated in Table 5. From this, Halpic Luvisols(LVh) is the dominant soil type covered an area of 194399.93 ha (58.43 %) and Eutric Vertisols (VRe) the least soil type covered an area of 13597.25 ha (4.09 %) of watershed from the total area of the study watershed (Table 5).

Table 5. Major soil types and area coverage (ha, %) of the study area after HRUs definition.

	Katar Watershed	
Major Soil Types	**Area (ha)**	**Area (%)**
Vitric Andosols(ANz)	20111.75	6.05
Rhodic Nitisols(NTr)	104577.18	31.43
Halpic Luvisols(LVh)	194399.93	58.43
Eutric Vertisols(VRe)	13597.25	4.09
Total	**332686.11**	**100**

3.3.4 Meteorological data

SWAT model needs daily measured weather data which includes daily precipitation, minimum and maximum temperature, wind speed, solar radiation and relative humidity. Daily meteorological data were obtained from National Meteorological Agency (NMA) for the stations of: Asela, Eteya, Ogolcho, Kulumsa, Bokoji and Sagure from 1988 to 2013. After missed data were filled, minimum and maximum temperature and rainfall on daily basis were prepared and organized using the Microsoft Excel program and formatted as text file type, which is the required format by SWAT model.

3.4 Methodology

3.4.1 Model set-up

The Arc SWAT interface was used for the setup and parameterization of the model. A digital elevation model (DEM) was imported into the SWAT model. The watershed was delineated manually in order to extract the area of interest. Look up tables were prepared and uploaded to the model for land use land cover and soil for reclassification according to SWAT coding convention. The land use land cover and soil maps of the study area were overlaid to obtain a unique combination of land use, soil and slope within the sub watershed to be modeled.

In this study, the minimum threshold area required to discreted the sub watershed into homogeneous HRUs was selected as 20%, 20% and 10% threshold levels used for the land use, soil and slope respectively in combinations with multiple HRU were used. These threshold levels were set to eliminate minor land uses and soil and slope classes in each sub watershed. So that a maximum of 10 HRUs with unique land use/soil/slope combinations would be created in each sub watershed, as recommended in the SWAT user manual (Neitsch et al., 2002). The overlaid of land use, soil and slope maps resulted in the definition of 181 HRUs were identified, which are unique combinations of land use, soil type and slope. Then, after HRUs analysis finished, weather data of principal station was loaded to link them up with the corresponding files already created for this purpose. Before link data, data were prepared in txt format required by the model. After loading all the necessary input data and generating all the required database files.

3.5 Hydrologic response unit analysis

After watershed delineation, sub watersheds were subdivided into small hydrologic response units (HRUs) that have unique land use, soil and slope. The threshold level set for land use, soil and slope were used to define the number of HRUs in the watershed. Each HRU's represent a homogeneous combination of characteristics of land use, soil type and slope classes (Neitsch, 2011).

3.6 Sensitivity analysis

The sensitivity analysis for this study area was done using Global sensitivity analysis methods. Model Sensitivity analysis is the step where the uncertainties of the modeling process, could be evaluated and prioritized for the inclusion into the calibration process. It can be categorized into four classes.

Table 6.Sensitivity analysis index (Source: Lenhart, 2002)

Class	Index (I)	Sensitivity
I	|I|≥1.00	Very high
II	0.2≤|I|<1.00	High
III	0.05≤|I||<0.2	Medium
IV	0≤|I|<0.05	Small to neglible

3.7 Calibration and validation of the SWAT model

The observed stream flow data collected at Habura gauging station used for calibration and validation of the model in this study. SWAT simulation was executed for a total of period of 26 years, which included 1990-2005 as the calibration period and 2006–2013 as the validation period. SWAT model parameter adjustment was performed only during the calibration period and the validation process was performed by simply executing the model for the different time period using the previously calibrated input parameters. Santhi, Srinivasan, Arnold, and Williams (2006) pointed out that there is no formal optimization procedure that can be used to calibrate SWAT model. Based on suggestion by Neitsch et al. (2002), the model calibration process was performed manually by adjusting the most sensitive hydrologic related parameters and comparing the model result with measured stream flow data. This procedure continued until the acceptable calibration statics.

3.8 Model performance evaluation

The performance of the model was evaluated by assessing the correlation between simulated and observed values. SWAT-CUP 20012 version was used to calibrate the model using Sequential uncertainty fitting (SUFI ver2) (Abbaspour et al., 2007). In this study, during both calibration and validation periods, the goodness of-fit between the simulated and measured runoff was evaluated using the coefficient of determination (R^2), percent difference or percent bias (PBIAS) and the Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe,1970). The R^2, ENS and PBIAS value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause *et al*., 2005). The closer the model efficiency is to 1 and PBIAS value close to 0% is best and the more accurate the model. According to SWAT developers (Santhi, et al., 2001) they assumed an acceptable calibration for hydrology at a PBIAS < ±25%, $R^2 > 0.6$ and ENS > 0.5. To decide the accuracy of the model the value of each index obtained by the model were compared with the value of hydrologic model performance ratings.

Table 7. General performance evaluation for stream flow on monthly time step (Moriasi et al., 2007 and Nash et al., 1970):

	Objective functions		
R^2	ENS	PBIAS	Performance Rating
$0.7< R^2< 1.00$	0.75 <ENS≤1.00	PBIAS<±10%	Very Good
$0.6 < R^2< 0.7$	0.65 <ENS≤0.75	±10% < PBIAS <±15%	Good
$0.50 < R^2 <0.6$	0.50 <ENS≤0.65	±15% < PBIAS <±25%	Satisfactory
$R^2 <0.50$	ENS ≤0.50	PBIAS≥±25%	Unsatisfactory

The R^2 is the magnitude of the linear relationship between the observed and the simulated values, and calculated as:-

$$R^2 = \left\{ \frac{\sum_{i-1}^{n} (O_i - \bar{O})\,(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2}\,\sqrt{\sum_{i=1}^{n} (S_i - \bar{S})^2}} \right\}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 8}$$

Where: Oi is the observed flow, Si is the modeled flow, and O is the mean of the observed flow and *S* is of the simulated flows.

The Nash–Sutcliffe efficiency proposed by Nash and Sutcliffe (Nash et.al,1970) is related to the deviation from unity of the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values. The normalization of the variance of the observation series results in relatively higher and lower values of NSE in catchments with higher and lower dynamics, respectively

$$\text{ENS} = 1 - \left[\frac{\sum_{i=1}^{n} (Q_m - Q_s)^2}{\sum_{i=1}^{n} (Q_m - Q_s)^2} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 9}$$

Where: Q_m is the observed flow, Q_s is the simulated flow of the simulation.

The percent difference or percent bias (PBIAS) describes the tendency of the simulated data to be greater or smaller than the observed data values over a specified period (usually the entire calibration or validation period). A value close to 0% is best, with lower values indicating satisfactory model simulation

$$\text{PBIAS} - \frac{\sum_{i=1}^{n} (Qm - Qs) * 100}{Qm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 10}$$

Where Q_m is the observed flow, Q_s is the simulated flow of the simulation and $\bar{Q}$ is average stream flow.

4 RESULTS AND DISCUSIONS

4.1 Sensitivity Analysis

4.1.1 Sensitive parameters for stream flow

Sensitivity analysis was carried out before calibrating the model to save time during calibration. The identification of critical model parameters affecting the model prediction was done by sensitivity analysis. Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. According to the result, from the global sensitivity analysis fifteen hydrologic parameters (Table 8) were selected based on Lenhart (2002) to compute the sensitivity of the streams' flow. Those parameters were: Saturated hydraulic conductivity of soil layers (SOL_K), Average slope steepness (HRU_SLP), Base flow alpha factor(days) (ALPHA_BF), SCS runoff curve number (CN2), Manning's "n" value for overland flow (OV_N), Moist bulk density (SOL_BD), Groundwater "revap" coefficient(GW_REVAP), Depth from soil surface to bottom (SOL_AWC), Maximum Canopy storage (CANMX), Plant uptake compensation factor (EPCO), Threshold water depth in shallow aquifer (mm) (GWQMN), effective hydraulic conductivity in the main channel (CH_K2), Groundwater delay(days) (GW_DELAY), Surface runoff lag coefficient (SURLAG) and Soil evaporation compensation factor (ESCO).

Table 8. Parameters used for sensitivity analysis

SWAT Parameters	Descriptions	t-Stat	Rank
Sol_K	Saturated Hydraulic conductivity	-100.00	1
GWQMN	Threshold water depth in shallow aquifer (mm)	50.00	2
HRU_SLP	Average slope steepness	-30.00	3
CN2	SCS runoff curve number	-28.00	4
GW_DELAY	Groundwater delay(days)	20.00	5
SOL_AWC	Depth from soil surface to bottom	12.00	6
ESCO	Soil evaporation compensation factor	-3.50	7
ALPHA_BF	Baseflow alpha factor(days)	-3.50	8
EPCO	Plant uptake compensation factor	2.50	9
SOL_BD	Moist bulk density	2.50	10
CANMX	Maximum Canopy storage	-1.50	11
CH_K2	effective hydraulic conductivity in the main channel	-1.50	12
OV_N	Manning's "n" value for overland flow	0.00	13
SURLAG	Surface lag time	0.00	14

GW_REVAP	Groundwater "revap" coefficient	0.00	15

Based on Lenhart et al. (2002), the top twelve highly sensitive parameters were identified and ranked based on the t-Stat as shown in Table 8. The sensitivity of the parameter decreases with increasing ranking number value and therefore, the three parameters at the bottom of the table were negligible to sensitive. These three parameters were zero (0) sensitivity index and did not affect stream flow. The top twelve highly sensitive parameters were the most driven parameters of stream flow. These highly sensitive parameters were as follows; saturated hydraulic conductivity of soil layers (SOL_K), Threshold water depth in shallow aquifer (mm) (GWQMN), Average slope steepness (HRU_SLP), SCS runoff curve number (CN2), Groundwater delay(days) (GW_DELAY), Depth from soil surface to bottom (SOL_AWC), Soil evaporation compensation factor (ESCO), Baseflow alpha factor(days) (ALPHA_BF), Plant uptake compensation factor (EPCO), Moist bulk density (SOL_BD), Maximum Canopy storage (CANMX), effective hydraulic conductivity in the main channel (CH_K2) (Table 9). Therefore, attention were given to most twelve highly sensitive parameters during model calibration.

4.2 Model Performance Evaluation

4.2.1 Stream flow calibration

Calibration of stream flow has been performed depending on observed flow measurements. The main target was to calibrate the model and predict the runoff at the outlet (Habura).Final adjusted calibrated parameters and fitted values for stream flow as shown below(Table 9).

Table 9. Final calibrated parameters and fitted values for stream flow

SWAT Parameters	Descriptions	Range	Initial Value	Final Calibrated Value
CN2	SCS runoff curve number		*	0.0012
CANMX	Maximum Canopy storage	0-10	0	8.62
HRU_SLP	Average slope steepness	0-1	0	0.05
OV_N	Manning's "n" value for overland flow	0.01-30	0.03	5.02
SOL_BD	Moist bulk density	0.85-2.5	0.85	2.5
Sol_K	Saturated Hydraulic conductivity	0-2000	0	5.52
SOL_AWC	Depth from soil surface to bottom	0-1	0	0.175
CH_K2	effective hydraulic conductivity in the main channel	0.01-500	0.01	23.44

EPCO	Plant uptake compensation factor	0-1	0	1
GW_REVAP	Groundwater "revap" coefficient	0.02-0.2	0.02	0.062
ALPHA_BF	Baseflow alpha factor(days)	0-1	0	0.00
GW_DELAY	Groundwater delay(days)	0-500	0	41.5
GWQMN	Threshold water depth in shallow aquifer (mm)	0-5000	0	533

* SWAT default parameters and SWAT driven parameters were used, and some parameter values obtained from the different study in Ethiopia

After adjusting the highly sensitive parameters manually, calibration was then performed by using SUF-2 set up during the periods of 1990-2005 (1988 and 1989 was used as a “warm-up” year). Statistical criteria should be used during the calibration process to check if estimates are in acceptable ranges. The result of simulation was evaluated with the observed and found correlation coefficient R^2=0.8, Nash–Suttcliffe simulation efficiency NSE=0.6 and percent difference or percent bias (PBIAS) =0 is best for the calibration period as shown in (Table 10). A best fit trend line was applied to each scatter plot, and the resulting line equation used to quantify model performance.

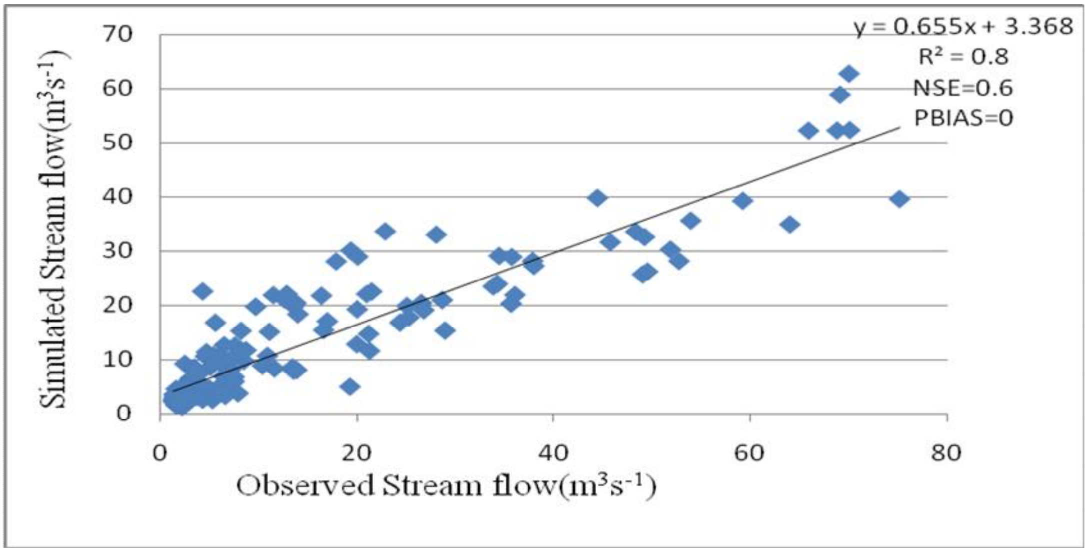

Figure 9. Comparison between observed and simulated stream flow for calibration period (1990-2005).

Calibration resulted of the correction coefficient (R^2),Nash–Suttcliffe simulation efficiency (NSE) and percent difference or percent bias (PBIAS) were 0.8, 0.6 and 0 respectively (Figure 9 and Table 10), and shown a good agreement between measured and simulated monthly stream flow according to Moriasi (2007) and Nash–Suttcliffe simulation efficiency (1970). The model is calibrated satisfactorily to simulate monthly stream flow adequately and statistical evaluation revealed a good correlation, efficiency and percent difference or percent bias between the measured and simulated values. The R^2 =0.8, ENS=0.6 and PBIAS=0 value indicated that the model predicted well and the simulated runoff and observed runoff close to each other though the overall prediction of the model (Table 10). The results fulfilled the requirements suggested by Santhi et al.(2001) for PBIAS< ±25%, R^2 >0.6 and ENS>0.5. In general, the model performs well in predicting the runoff from Katar watershed.

Table 10. Calibration results of average monthly observed and simulated flow

Parameter	Calibrated (1990-2005)
R^2(coefficient of determination)	0.8
NSE(Nash-Sutcliffe model efficiencies)	0.6
PBIAS (percent Bias)	0

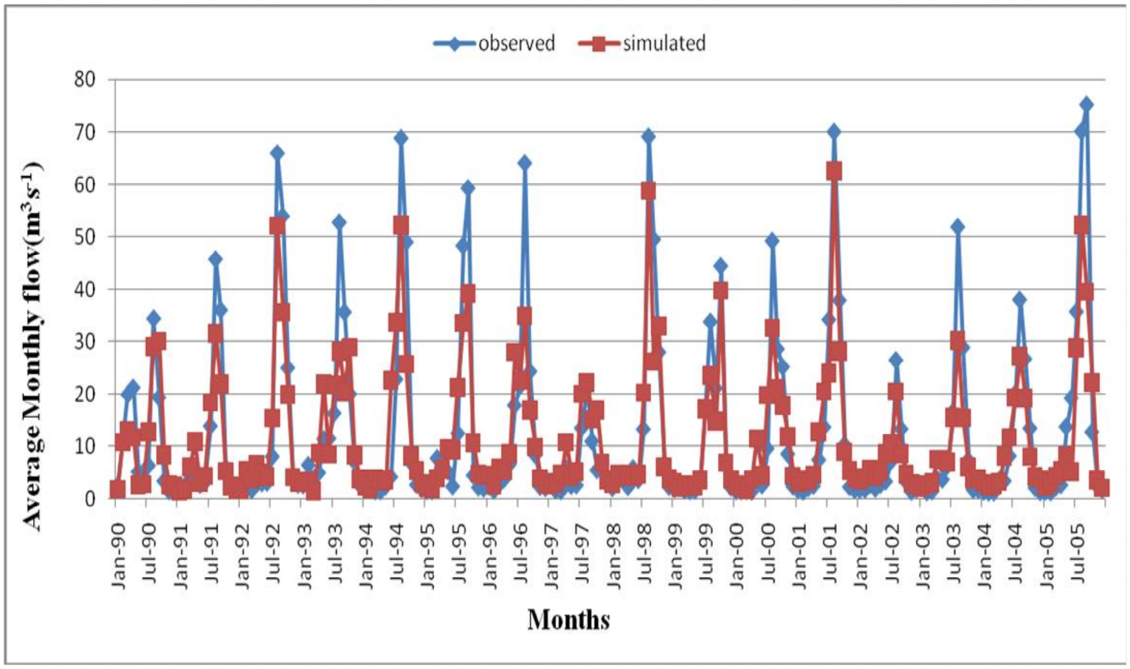

Figure 10. Simulated and observed monthly stream flow during calibration period (1990–2005)

4.2.2 Stream flow Validation

Stream flow validation was conducted to ensure the validity of the calibration process from 1st, 2006 to December 31, 2013. Validation procedures for a 8 years period (2006-2013) shows that the value is acceptable for simulated and observed stream flow (Figure 11 and

Table 11). The R^2, ENS and PBIAS were found to be 0.67,0.55 and 1.2 respectively (Figure 11 and Table 11), which shows a good correlation with the gauged stream flow. This ensures that the simulated flow follows the same trend with the gauged stream flow in the time serious. The Nash-Suttcliffe (1970) simulation efficiency; however, was found to be 0.55, which is acceptable as this value is more than 0.5. The results fulfilled the requirements suggested by Santhi et al.(2001) for PBIAS< ±25%, R^2 >0.6 and ENS>0.5. In general, the model performs well in predicting the runoff from Katar watershed. A best fit trend line was applied to each scatter plot, and the resulting line equation was used to quantify model performance.

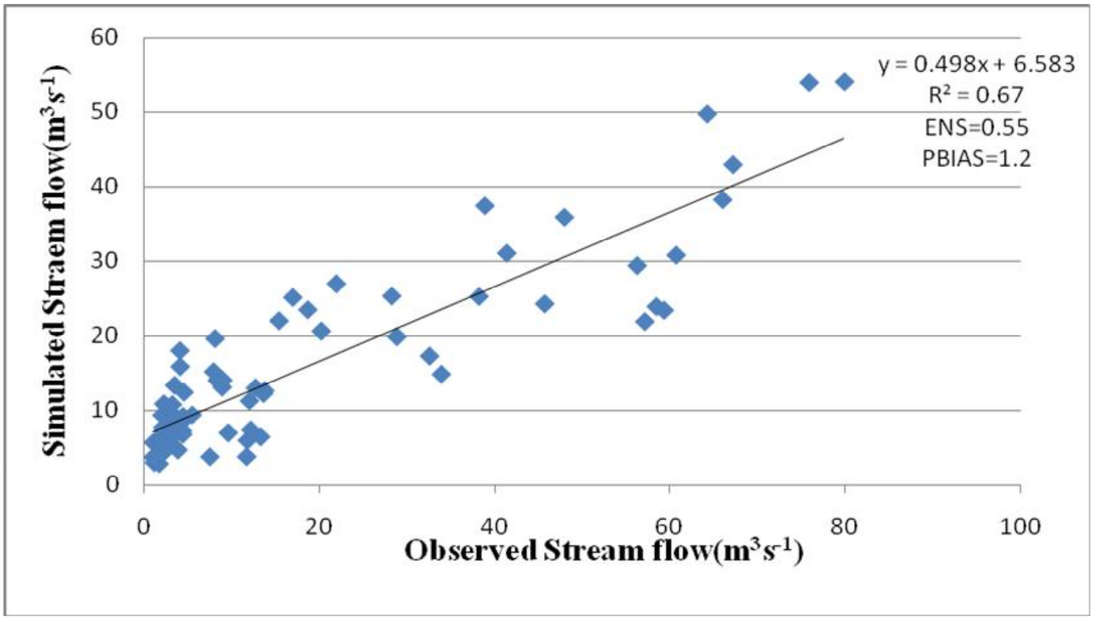

Figure 11 Comparison between observed and simulated surface runoff flow for validation period (2006-2013).

Table 11 Validation results of average monthly observed and simulated flow

Parameter	Calibrated (2006-2013)
R^2(coefficient of determination)	0.67
NSE(Nash-Sutcliffe model efficiencies)	0.55
PBIAS (percent Bias)	1.2

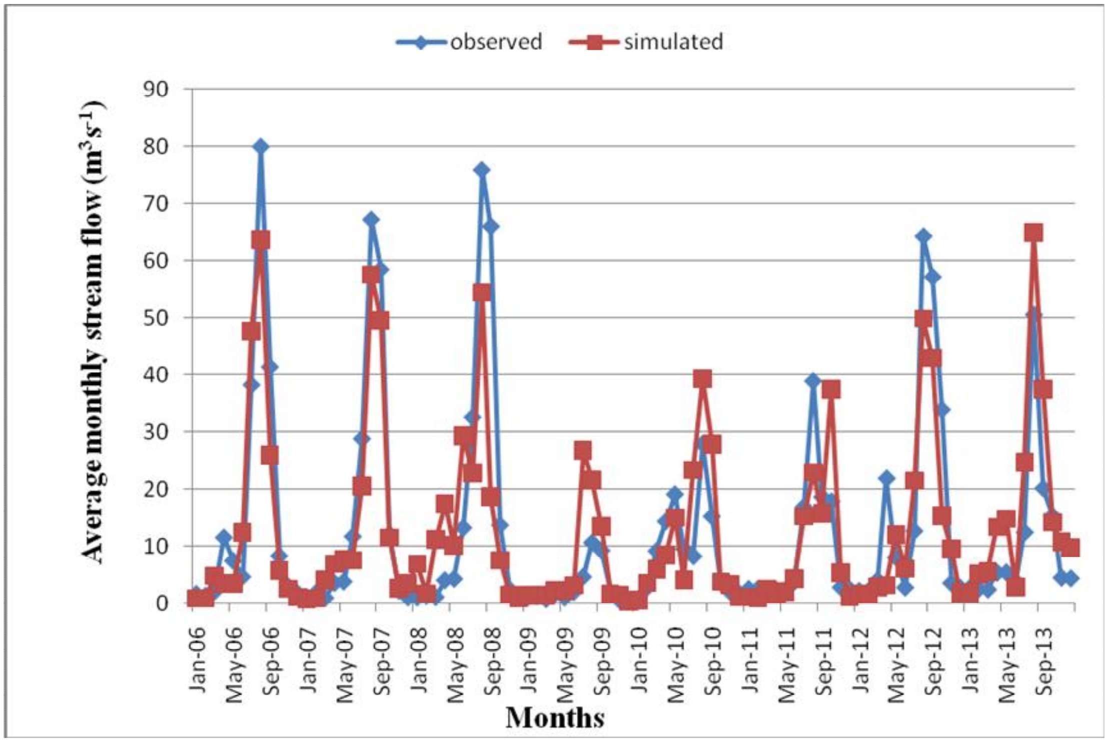

Figure 12 Simulated and observed monthly stream flow during Validation period (2006–2013)

4.3 Simulated Runoff and Sediment yield of Katar watershed

The runoff was simulated for 26 years on monthly basis. According to this result, the simulated mean annual sediment and runoff losses were 11 $tha^{-1}yr^{-1}$ and 12.3 m^3s^{-1} from the watershed respectively (Table 12). The soil loss was mainly from Luvisols and agricultural land use, this soil was dominated by clay soil, and clay soil have low infiltration. Similar results were reported by (GIRDC, 2010), who stated that clay dominant soils are characterized by well to moderately drained; deep to very deep; dark brown; friable moist; very sticky to sticky and very plastic to plastic wet. Thus, high surface runoff and sediment yield transported from this soil type because of less infiltration, poor land cover and land management. Thus way, high amount of sediment and runoff losses from this watershed.

Table 12 The annual simulated sediment and Runoff loss from each sub watershed

Sub watershed	Annual Sediment loss $tha^{-1}yr^{-1}$	Annual Runoff(m^3s^{-1})	Area(ha)	Area (%)
1	1.4	0.8	7543.20	2.27
2	1	0.5	646.93	0.19
3	1.8	0.6	202.81	0.06
4	17	19.9	6708.00	2.02
5	0.1	0.9	67.60	0.02
6	29	32.6	33913.00	10.19
7	1.1	0.8	6192.00	1.86
8	1.3	7.8	7457.60	2.24
9	2.2	10.6	10221.00	3.07
10	3.3	2.0	6147.50	1.85
11	2.6	2.0	340.58	0.10
12	21.1	20.8	20199.00	6.07
13	15.9	15.8	1642.10	0.49
14	5.4	4.6	10424.00	3.13
15	19.6	18.7	11277.00	3.39
16	10.2	15.4	13505.00	4.06
17	2.7	2.0	7303.60	2.20
18	1	1.6	11362.00	3.42
19	10.1	24.9	9414.70	2.83
20	36.8	38.5	8667.60	2.61
21	12.4	22.2	4767.20	1.43
22	25.4	24.9	7864.10	2.36
23	3.9	3.1	20411.00	6.14
24	32.8	29.9	9050.10	2.72
25	26	17.6	487.76	0.15
26	4.5	4.6	14598.00	4.39
27	3.9	3.1	15600.00	4.69
28	5.3	5.5	5148.90	1.55
29	0.3	0.5	291.80	0.09
30	5.1	5.5	612.70	0.18
31	19.9	10.9	7121.30	2.14
32	37.6	39.1	13538.00	4.07
33	6.5	13.8	6939.10	2.09
34	8.9	14.6	23569.00	7.08
35	9.5	15.5	29451.00	8.85
Total	**11**	**12.3**	**332686.11**	**100**

4.4 Spatial distribution of sediment yield and runoff in Katar watershed

Assessing the soil formation rates of an area is vital for the evaluation of soil loss rate and the potential of soil regeneration once soil erosion is substantially reduced. The degree of erosion hazard in the Katar sub-watersheds were reclassified in to four (Table 13) different erosion hazard classes based on Getachew et.al, (2017).

Table 13. Sediment yield losses and Severity classes of Katar Watershed

Annual soil loss(tha^{-1}yr^{1})	Sub watershed	Severity classes	Area(ha)	Area (%)	Severity Ranks
0-11	1,2,3,5,7,8,9,10,11,14,16,17,18,19,23,26,27,28,29,30,33,34,35	Low	207450.02	62.360	4
11-18	4,13,21	Moderate	13117.30	3.940	3
18-30	6,12,15,22,25,31	High	80862.16	24.304	2
30-37.6	20,24,32	Very high	31255.70	9.396	1

The range of tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to 18 tha^{-1}yr^{-1} (Hurni, 1985). According to this study, 9 out of 35 sub-watersheds estimated that annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate (>18 tha^{-1}yr^{-1}) (Figure 13 and Table 12,13). This fact shows how far soil erosion is a serious threat to the study area. So, identification of erosion prone/ hotspot areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield and prioritize problem-oriented and site specific watershed management efforts. Prioritization map was then prepared based on erosion hazard in Figure 13. According to prioritization map, sediment loss categorized into four (4) classes, such that 0-11,11-18,18-30 and 30-37.6tha^{-1}yr^{-1}.

According to this study, sub watershed 6,12,15,20,22,24,25,31,and 32 were categorized under high and very high soil loss and covered 33.7% of watershed in the study area (Figure 13 and Table 13). The area which was high soil erosion (24.304 %) generated covered large area than very high (9.396 %) from the study area. The soil losses from these sub watershed is greater than maximum tolerable soil loss rate (>18 tha^{-1}yr^{-1}) and high surface runoff generated from these sub watershed and identified as erosion prone area in Katar watershed (Figure 13 and Table 13). The main reason for generating more runoff and sediment was because of land degradation, poor land cover, improper land management (lack of soil and water conservation) and cultivating undulating slope without conservation. The acceptable soil loss that can maintain the economy and a high level of production (Wischmeier and Smith 1978; FAO 1986; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 tha^{-1}yr^{-1}(Renard et al. 1996, Foster et al., 2002). But the soil loss from these sub watershed is above this range and the area is more vulnerable to soil loss. Thus, the soil losses above maximum rate reduced the production and productivity of the soil and economy of the study area. These sub watershed dominated by intensively cultivated land (79.14%), Haplic Luvisols(58.43%) (clay dominant soil which is poor infiltration) and also undulating slope (3-8%)(41.01%). Hence, agriculture and luvisols are the more dominant of land use and soil respectively and this may cause for soil erosion in the study area. Erosion is more aggravated on wide range of agricultural land uses, and susceptible to structure deterioration with tillage and the Katar watershed dominated by wide range of agricultural activities. These factors were responsible for aggravating the soil loss and facilitated the surface runoff to wear out the top soil in a higher rate from watershed.

Among 35 sub watershed, 3 sub watershed (4,13 and 21) were fallen under moderate soil losses, which were given moderate priority class and the annual soil loss from these sub watershed were ranges from 11 to 18 $tha^{-1}yr^{-1}$ (Table 13). This study agreed with the study of Hurni (1985), who stated that range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia was found from 2 to 18 $tha^{-1}yr^{-1}$. Hence, the soil losses from 3 sub watershed ranges in tolerable soil loss rate. But the result from the three sub watershed above acceptable soil loss that can maintain the economy and a high level of production (Wischmeier and Smith 1978; FAO 1986; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 $tha^{-1}yr^{-1}$(Renard et al. 1996, Foster et al., 2002) and also above the range of soil formation rate in the study area ranges from 6-10 $tha^{-1}yr^{-1}$ (Hurni, 1983). These sub watersheds were dominated by moderately gentle slope, agriculture and clay loam soil (moderate infiltration capacity). This may the causes for high amount soil losses. Hence soil type, topography and agricultural activity is the principal factor for the sediment loss and surface runoff.

Twenty three (23) sub watersheds were fallen under low soil loss rate < 11 $tha^{-1}yr^{-1}$ (Table 13 and Figure 13). The area classified under low soil loss rate is covered large area (62.36%) of watershed. The result was agreed with the result of FAO(1986) and Gebreyesus and Kirubel (2009), who state that the acceptable soil loss that can maintain the economy and a high level of production (Wischmeier and Smith 1978; FAO 1986; Gebreyesus and Kirubel, 2009) ranges from 5 to 11 $tha^{-1}yr^{-1}$(Renard et al. 1996, Foster et al., 2002). Also, soil formation rate in the study area ranges from 6-10 $tha^{-1}yr^{-1}$ (Hurni, 1983). Thus, this study agreed with above two authors; because the result of the study was within acceptable range (0-11 $tha^{-1}yr^{-1}$). The soil losses from this area classified under low soil loss rate. These sub watershed dominated by flat to steep slope, moderate agricultural activity, forest, Grassland, Range-Brush, Shrub land and Afro alpine Green Vegetation land cover. However, higher/steep slopes are found along the boundaries of the watersheds and had less impact on the soil loss, because of land cover (Afro Alpine Green Vegetation, forest, grass land, shrub land and etc) and so runoff power reduced (more infiltration) and soil erosion reduced. Cebecauer and Hofierka (2008) and Starchi, (2013) also observed that land cover has a significant influence on soil erosion. A report from China (Luo, 2014) indicated that, land with lower vegetation cover implying the extent of soil erosion and high amount of surface runoff generated. Similarly, a Nigerian study by (Oruk, 2012) reported greater soil erosion in lands with poor vegetation cover. Hence, land cover took a lion share in reducing soil erosion and runoff potential by increasing infiltration capacity. Thus way, the amount of soil losses from this sub watershed is below tolerable soil loss limit. Even though, the risk of soil loss is less in this sub watershed, measurement should be undertaken to keep the natural balance.

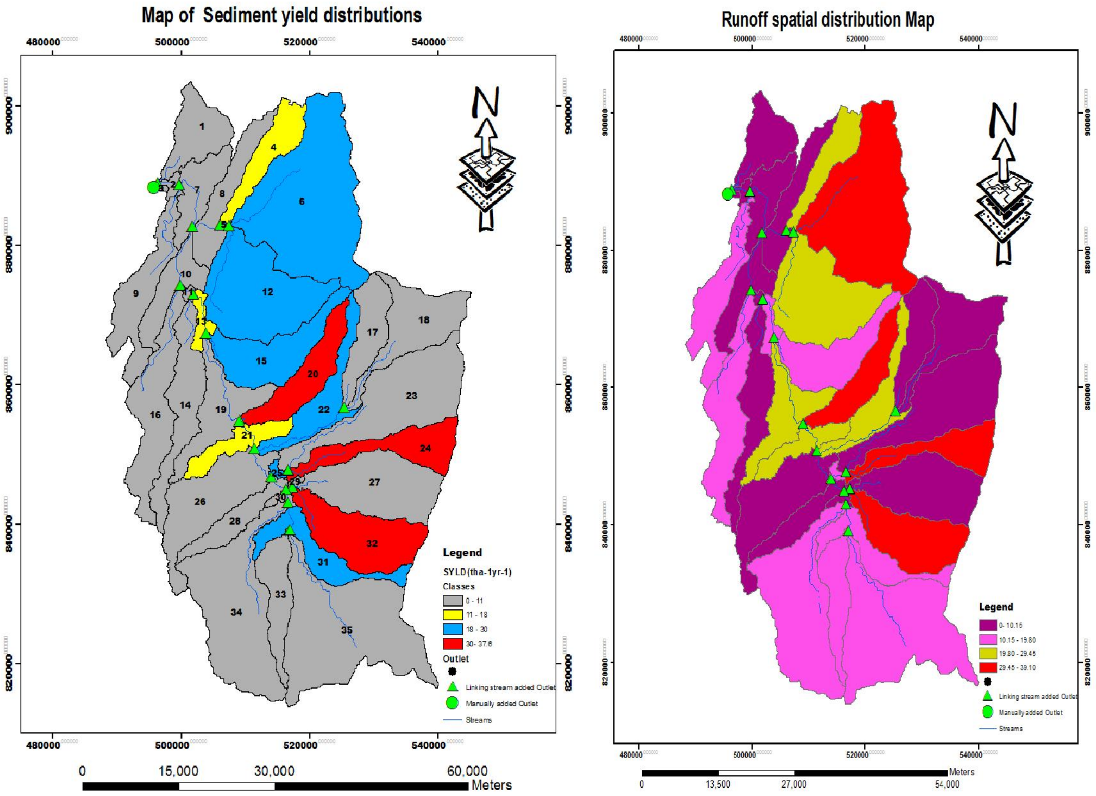

Figure 13. Map of sediment loss (left) and Runoff (right) of Katar watershed

The above map results indicated that converting grasslands and forest to agricultural crops is results in increased runoff volumes, increased sediment yields, and decreased base flow. The main reason for more runoff and sediment losses were; because of poor land cover, improper land management and cultivating undulating slope without conservation measures as a result more sediment yield and runoff loss generated. These changes will cause significant sediment yield loss, depleting soil nutrients, sedimentation of reservoirs (mainly lake ziway), and increase flooding of low-lying areas at the downstream.

In Generally, agricultural practice without conservation measure will aggravate the runoff processes in the study area. On flat slopes deposition of sediments is the major constraint that can affect the down watershed and hydrology of watershed, and this constrains can be improved by applying integrated watershed management.

4.5 Prioritization for intervention planning

Because of resource limitations, implementing of soil conservation measures or watershed management in the entire watershed at a time is impractical. Thus, prioritization of intervention areas based on the severity and risks of soil erosion is imperative. The Katar watershed was classified and ranked into four priority classes indicated in Table 13 and Fig.13. Hence, based on the results, sub watershed 6,12,15,20,22,24,25,31 and 32 were hotspot erosion area and prioritized for intervention (Table 13 and Fig.13). The total area that experienced soil erosion rate above the maximum tolerable erosion limit of 18 t ha-^{1} yr-^{1}(Hurni, 1985) is 112117.86 ha, and covered 33.7% of the entire watershed. Reasonable assessment of soil erosion is the core of any decision making. On those selected (high and very high sediment and runoff loss Table 13) hotspot erosion areas, the required treatments may include practicing strip planting, terracing ,soil bund, contour farming, check dam and leaving crop residue on the field and these treatments were reduced the effect of surface runoff velocity and sediment transport capacity. This structures should be practices in all land use of Katar watershed in generally, particularly on agricultural land use (intensively cultivated land). The check dam mainly practiced on gully formation area (Figure 1).

In order to achieve food security, poverty reduction and environmental sustainability in the country reversing soil erosion is a high priority (Bewket and Teferi, 2009; Abate, 2011). Also similar studies stated that, undertaking soil conservation measures based on the given priority is a better option as also suggested by Bewket and Teferi (2009), Abate (2011), Amare et al. (2014) and Gizachew (2015) for their respective study sites. Therefore, priorities for intervention will be focused on high and very high soil eroded sub watershed to keep natural balance and minimized the effects siltation at downstream. of the study area

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

The SWAT model was calibrated from 1990 to 2005 and validated from 2006 to 2013 on a monthly basis to examine its applicability for simulating flows of Katar watershed. Fifteen (15) parameters were tested for sensitivity analysis and out of these, twelve (12) parameters were highly sensitive for calibration of study area. The average monthly simulated stream flows were compared with the average monthly observed values using graphical and statistical methods. The calibration processes considered sensitive parameter for the stream flow to evaluate the degree of agreement between measured and simulated monthly stream flow. The SWAT-CUP SUF_2 model performance criteria for flow simulation resulted (R^2= 0.8, NSE = 0.6, and PBIAS=0) for calibration and (R^2= 0.67,NSE = 0.55 and PBIAS=1.2) for validation periods, respectively. The results showed a good agreement between the measured and simulated average monthly stream flows during the calibration and validation periods. The SWAT model performed well in predicting the stream flow from the study watershed and the results were acceptable..

The variation of simulated sediment yield is more sensitive to the land use land cover, soil type and topography dominating the area, as a result it had meaningful contribution to sediment yield and surface runoff. Identifying and prioritizing erosion susceptible areas for intervention is quite essential for this study area. According to reclassification, soil loss classified into four depending on severity classes. The classification area in terms of soil erosion was as follows; 62.36% low, 3.94% moderate, 24,303 % high and 9.396 % very high soil erosion. The main causes of soil losses that categorized under high and very high was because of land degradation, poor land cover, improper land management(lack of soil and water conservation). These are the major causes for more erosion.

According to this study, 9 sub watershed (6,12,15,20,22,24,25,31 and 32) were identified and more susceptible to soil erosion, because of the soil loss is greater than tolerable soil loss limit in the study area, and more attention has to be given to this area than other sub watershed. Thus, to overcome this problems watershed management strategies (soil and water conservation measures) should be used based on the severity classes to reduce soil erosion and watershed management is an advantageous for the area of high and high very soil erosion and undulating slope of this study watershed. The soil losses from these sub watersheds had onsite fertile soil loss and off site heavy sedimentation at downstream (Lake Ziway). Hence, treatment of watershed should be undertaken for those sub watershed fallen under high and vey high erosion (Figure 13 and Table 13).

Generally, it is important to give due attention for appropriate watershed development, at least for high and very high soil erosion area and this area need immediately took a measurement to reduce this vital resource from erosion. The result of the study could help different stakeholders to plan and implement appropriate watershed management strategies in the study area and protect the downstream from the effect flooding, sedimentation and keep the natural balance of watershed. The model developed could be used in prediction model to take appropriate measures in advance. In conclusion, the SWAT model could be effectively used to predict runoff and simulated sediment.

5.2 Recommendations

The sub watersheds 6,12,15,20,22,24,25,31 and 32 were categorized under high and very high soil loss and the soil loss greater than tolerable soil loss limit (>18t/ $tha^{-1}yr^{-1}$) and high surface runoff generated from these sub watershed; from the total watershed area. The area should be treated by using intervention strategies based on the severity of erosion problem. On those selected (high and very high sediment and runoff loss Table 13) hotspot erosion areas, the required treatments will be practicing strip planting, terracing ,soil bund, contour farming, check dam and leaving crop residue on the field to reduce runoff volume and sediment transport capacity. From the watershed, 1.37 % of the area can have a slope more than 30%, which is danger the area if the natural cover is disturbed. In this slope range no need of conducting any agricultural activities, rather the area should be protected and conducting rehabilitation or applying watershed management strategies in this area.

There is a lot of work to improve in the future for this study area regarding suspended sediment data at outlet. Therefore, responsible bodies should give due attention to took sampling of sediment at the time of flow measurement for further testing the model. The model could be further tested for calibration and validation of sediment yield when suspended sediment data is available.

Therefore, appropriate watershed management policies be put in place in order to promote a more sustainable environment, and future study will be focused on further analysis of the impacts of climate and land use change as well as management scenarios on the stream flow flows and sediment yield in the study watershed.

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APPENDEXIES

Table 1. Distribution of dominant soil type, land use and cover and slope for each sub watersheds of the study area after HRUs definition

Sub-basins	SWAT code	Dominant soil	Dominant slope (%)	Area (ha)	Area (%)
1	RNGB	ANz	3-8	3496.72	46.36
2	AGRL	ANz	0-3	1185.08	74.13
3	AGRL	ANz	0-3	166.43	82.06
4	AGRC	NTr	3-8	1622.26	24.18
5	AGRL	NTr	3-8	14.49	21.43
6	AGRC	LVh	3-8	11195.14	33.01
7	AGRL	ANz	0-3	2976.01	48.06
8	AGRL	NTr	3-8	3955.35	53.04
9	AGRL	ANz	0-3	3772.67	36.91
10	AGRL	NTr	3-8	2071.12	33.69
11	AGRL	LVh	15-30	130.55	38.33
12	AGRC	LVh	3-8	9458.44	46.83
13	AGRC	NTr	3-8	276.06	16.81
14	AGRC	LVh	0-3	6419.97	61.59
15	AGRC	LVh	3-8	4553.14	40.38
16	AGRC	LVh	3-8	2924.15	21.65
17	AGRC	LVh	3-8	2824.63	38.67
18	FRSE	LVh	8-15	2812.92	24.76
19	AGRC	LVh	0-3	5422.14	57.59
20	AGRC	LVh	3-8	3249.41	37.49
21	AGRC	LVh	0-3	2703.86	56.72
22	AGRC	LVh	3-8	3502.83	44.54
23	FRSE	LVh	8-15	3393.48	16.63

24	AGRC	LVh	3-8	1810.93	20.01
25	AGRC	VRe	0-3	337.76	69.25
26	AGRC	LVh	0-3	11918.60	81.65
27	AGRC	NTr	3-8	5638.61	36.15
28	AGRC	LVh	0-3	2495.75	48.47
29	FRST	VRe	15-30	245.67	84.19
30	PAST	LVh	0-3	295.85	48.29
31	AGRC	NTr	3-8	2639.82	37.07
32	AGRC	NTr	3-8	6014.05	44.42
33	AGRC	NTr	3-8	3358.51	48.40
34	AGRC	LVh	3-8	5396.30	22.90
35	AGRC	NTr	3-8	9587.08	32.55

Appendix I: Soil Parameters in SWAT Database for Each Soil Layers in the Watershed

Soil Parameters in SWAT Database for Each Soil Layers in the Watershed

Soil Name:	Eutric Cambisols (CMe)			
Soil Hydrologic Group:	B			
Maximum rooting depth(mm) :	1300			
Texture	C			
Layers	1	2	3	4
Depth (mm)	150	300	450	1300
Bulk Density Moist (g/cm3)	1.5	1.44	1.46	1.06
SOL_AWC (mm/mm)	0.13	0.15	0.14	0.10
SOL_CBN (weight %)	0.60	1.5	0	0
SOL_K (mm/hr)	2.23	5.36	1.47	0.44
Clay (weight %)	35.6	28.5	38.4	75.5
Silt (weight %)	24.4	44.3	41.4	11.5
Sand (weight %)	38	27.2	27.2	13
Rock Fragments (weight %) (Optional)	0	0	0	0
Soil Albedo (fraction)	0 .397	0.21	0	0
USLE_K	0.15	0.14	0.17	0.11
SOL_EC (ds/m)	1	0	0	0

Soil Name:	Rhodic Nitisols(NTr)		
Soil Hydrologic Group:	B		
Maximum rooting depth(mm)	1200		
Texture	CL		
Layers	1	2	3
Depth (mm)	300	700	1200
Bulk Density Moist (g/cm3)	1.5	1.5	1.57
SOL_AWC (mm/mm)	0.12	0.13	0.14
SOL_CBN (weight %)	0.68	1	0
SOL_K (mm/hr)	2.16	4.4	4.5
Clay (weight %)	36	30	25.2
Silt (weight %)	23.6	31.1	40.8
Sand (weight %)	40.4	38.9	34
Rock Fragments (weight %) (Optional)	0	0	0
Soil Albedo (fraction)	0.38	0.30	0
USLE_K	0.15	0.15	0.17
SOL_EC (ds/m)	1	0	0

Soil Name:	Vitric Andosols(ANz)			
Soil Hydrologic Group:	A			
Maximum rooting depth(mm) :	2000			
Texture	L			
Layers	1	2	3	4
Depth (mm)	150	850	1000	2000
Bulk Density Moist (g/cm3)	1.5	1.6	1.65	1.36
SOL_AWC (mm/mm)	0.13	0.12	0.14	1.14
SOL_CBN (weight %)	1.8	0.9	0	0
SOL_K (mm/hr)	21.3	13.2	21.69	0.95
Clay (weight %)	15.6	18.9	8.2	47.4
Silt (weight %)	36.3	33.7	49.8	33.7
Sand (weight %)	48.1	47.4	42	18.9
Rock Fragments (weight %) (Optional)	0	0	0	0
Soil Albedo (fraction)	0.17	0.32	0	0
USLE_K	0.14	0.165	0.19	0
SOL_EC (ds/m)	1.0	0	0	0.16

Soil Name:	Eutric Vertisol(VRe)		
Soil Hydrologic Group:	D		
Maximum rooting depth(mm) :	1450		
Texture	C		
Layers	1	2	3
Depth (mm)	200	650	1450
Bulk Density Moist (g/cm3)	1.58	1.35	1.58
SOL_AWC (mm/mm)	0.13	0.14	0.16
SOL_CBN (weight %)	0	2.90	0
SOL_K (mm/hr)	5.45	3.34	4.43
Clay (weight %)	60.8	39.7	20.4
Silt (weight %)	38.7	33.2	47.6
Sand (weight %)	4.5	27.1	23.0
Rock Fragments (weight %) (Optional)	0	0	0
Soil Albedo (fraction)	0	0.18	0
USLE_K	0.27	0.12	0.19
SOL_EC (ds/m)	1	0	0

Soil Name:	Haplic Luvisol(LVh)				
Soil Hydrologic Group:	A				
Maximum rooting depth(mm) :	2000				
Texture	C				
Layers	1	2	3	4	5
Depth (mm)	150	360	630	1100	2000
Bulk Density Moist (g/cm3)	1.39	1.53	1.18	1.18	1.45
SOL_AWC (mm/mm)	0.14	0.13	0.12	0.11	0.13
SOL_CBN (weight %)	0	0	0	0	0
SOL_K (mm/hr)	1.29	3.03	0.82	0.54	1.28
Clay (weight %)	42.3	30	62.5	64.8	40
Silt (weight %)	40.6	36.5	25.9	20.5	32
Sand (weight %)	17.1	33.5	11.7	14.7	28
Rock Fragments (weight %) (Optional)	0	0	0	0	0
Soil Albedo (fraction)	0	0	0	0	0
USLE_K	0.18	0.17	0.16	0.14	0.16
SOL_EC (ds/m)	1.0	0	0	0	0

Appendix II: Meteorological and Hydrological Data Tables

Table 3. Bokoj total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1988	12.9	36.5	85	201.3	52.7	79.5	184.6	272.8	103.4	129.6	8.3	5	1171.6
1989	20.2	46.2	98.3	155.6	82.8	87.1	172.9	155	67.2	101.1	11.6	80	1078
1990	4.1	102	108.1	146.9	38	60.4	155.1	222	72.8	8.5	17.2	3.3	938.4
1991	5.3	68.5	140.9	30.9	81.1	123.3	197.2	267.9	97.4	8.9	0.9	30.2	1052.5
1992	112.9	91.2	39.4	130.1	54.7	116.9	164.3	216	36.1	126.7	52.4	13.1	1153.8
1993	55.2	99.4	2	148.9	175.8	123.9	163.8	222	138.2	50.3	3.5	3.2	1186.2
1994	0.8	0	37.6	128.2	50	168	246.5	274.7	95.7	6.3	38.6	5	1051.4
1995	0	41.4	94.2	151.8	73.4	50.1	181.7	230	157.2	17.5	1.2	32.4	1030.9
1996	58.7	12.3	140.2	55.5	154.3	124.9	229.2	158.3	86.1	35	3.1	5.9	1063.5
1997	20.2	20	39.5	82.1	110.7	82.8	217	118.5	48.7	30.3	4.1	1.5	775.4
1998	0	47.1	260.4	176.5	8.6	83.5	215.4	226	157.4	16.8	6.6	6.3	1204.6
1999	44.4	62.9	65	110.6	199.4	171.8	215.7	177.7	32.5	74	58.3	14.9	1227.2
2000	73.6	100.5	124	148.1	242.3	68.1	128.4	155.9	122	42.5	26.8	14.5	1246.7
2001	4.6	0	10.6	17.7	135.5	183.8	177.8	110.8	66.4	3.5	36.7	11.6	759
2002	24.1	1.6	98.1	117.9	194.8	106.3	208.5	148.6	38.8	55	4.9	2	1000.6
2003	4.5	61.5	52.3	142.2	108.7	210	138.3	234.4	62.6	49.1	0.9	14.4	1078.9
2004	2.5	40.7	206.9	123.1	117.9	100.7	67.4	179.6	60.3	44.8	3.2	23.2	970.3
2005	9.7	58.2	54.3	110.1	83.9	105.8	215.6	174.5	93.7	69.9	2.8	15.5	994
2006	9.7	9.1	68.2	95.9	48.3	95.1	186.3	253	114.6	17.2	14.3	0	911.7
2007	1.5	6.3	14.7	17.4	49	112.3	160.5	135.5	58.2	64.6	77.6	1.3	698.9
2008	77.8	0.1	30	25.1	30.8	44.9	228.2	171.8	138.6	56.6	1.4	42.4	847.7
2009	32	111.5	93.9	91.7	49.4	47.7	162.2	129.8	102.2	5.9	11.5	43.1	880.9
2010	32.2	6.6	16.8	72	187.9	98.3	219.7	137.9	96.1	7.7	37.5	0	912.7
2011	0	0	25.3	104.5	61.5	77	107.7	260.3	131.8	22.3	11.5	2.8	804.7
2012	17.8	4.5	9.3	106.2	62.2	63	155.9	215.7	72.9	48.8	37.8	3.8	797.9
2013	17.7	4.3	9.4	106.1	62.2	62.9	155.8	215.8	72.6	49	37.8	0	793.6
Mean	**24.7**	**39.7**	**74.0**	**107.6**	**96.8**	**101.9**	**179.1**	**194.8**	**89.4**	**43.9**	**19.6**	**14.4**	**985.8**

Appendix Table 4.Eteya total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1988	4.8	16.3	25	87.7	39.3	97	98.9	218.4	182.4	35.9	2.4	5.9	814
1989	5.9	0	14	36.6	50.3	97.1	99	218.4	182.2	35.9	3	36	778.4
1990	2.7	127.9	31.9	110.6	26.6	96.1	265.1	259.1	190.6	57	14.5	5.8	1187.9
1991	7	21.6	137.9	65.8	108.5	73.7	171	245.4	151.6	22.9	0	5.8	1011.2
1992	29.7	19.2	28.8	61.6	102.1	132.1	170	392.8	196.7	80.5	18.6	28	1260.1
1993	77.7	39.4	0	91.1	132.6	131.2	186.2	181.4	140	127.5	0.7	11.6	1119.4
1994	0	0	11.8	81.9	76.9	219.7	241.9	153.6	147.2	45.5	46.3	6	1030.8
1995	0	29.4	87.5	93.4	84.6	120.8	154.4	211.8	63.2	33.3	0	5.8	884.2
1996	11.2	0	0	31.3	86.5	206.8	45.6	211.8	63.2	33.3	0	0	689.7
1997	11.1	0	0	31.3	86.4	155.1	219.8	161.3	81.7	67.7	0	0	814.4
1998	11.1	11.5	116.6	82.5	37.4	11.1	210.6	328.8	198.6	14.3	0.2	27	1049.7
1999	24.2	24.3	15.3	45.7	72.5	96.8	165.2	238.7	62.6	96.8	0	4.3	846.4
2000	6	52.4	0.4	58	172.4	31	200.3	267.7	66.9	35.6	31.3	0	922
2001	0	0	21.3	53.8	145.6	30.8	139	282.7	141.1	2.3	2.5	13.8	832.9
2002	11.2	0	32	96.4	141.1	74.4	97.2	150.3	113.3	13.9	12	1.7	743.5
2003	0	23.5	57.3	91.9	133.3	77.5	132.2	118.9	88	33.5	0	1.9	758
2004	2.6	26.1	110.9	52.8	155.9	88.7	137.1	236.1	141.1	40	0	0	991.3
2005	2.4	26.1	111.1	52.8	155.9	88.8	137.1	236.2	141.3	40	0	0	991.7
2006	2.7	26.2	110.9	53.1	156.1	88.6	137.1	236.1	141.1	40	0	0	991.9
2007	2.5	26.1	110.9	52.8	155.8	88.8	137.2	236.2	141.1	40	0	6.6	998
2008	2.6	0	0.8	52.9	156.1	88.6	137.3	236.1	141.1	40	66.7	0	922.2
2009	2.6	17.7	0	52.7	155.9	88.8	137.2	236.1	141	40	66.7	0	938.7
2010	2.6	17.1	101.1	52.7	155.9	60.2	206	163.9	97.3	12	66.7	3.7	939.2
2011	1	3.1	101.1	63.9	193.1	82.4	217	316.4	291.4	28.6	0	0	1298
2012	0	0	25.3	104.5	61.5	77	107.7	260.3	131.8	22.3	11.5	2.8	804.7
2013	17.8	4.5	24.3	53.6	193.1	35.8	83.1	215.7	72.9	48.8	37.8	3.8	791.2
Mean	**9.2**	**19.7**	**49.1**	**65.8**	**116.7**	**93.8**	**155.1**	**231.3**	**135.0**	**41.8**	**14.7**	**6.6**	**938.8**

Table 5: Kulumsa total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1988	64.2	79.3	25	112.3	81.8	84.7	148.1	124.2	125.5	76.2	0	0.1	921.4
1989	0.2	50.4	69.9	177.9	25	132.4	115.9	180	86.8	31.6	5	41.2	916.3
1990	0	160.6	105.7	141.8	40.1	99.7	190.2	138.9	122	23.9	5.5	0.9	1029.3
1991	10.4	45.2	204.3	34.4	92.8	67.2	190	144	112.4	10.8	0	12.1	923.6
1992	26.5	96.2	4.5	89.4	28.4	70	121.8	187.4	119.8	106.6	53	14.5	918.1
1993	23.5	72	12.9	150.4	247	53.4	128.1	148.1	173.4	80.4	1.7	30.8	1121.7
1994	0	13	34.5	66.7	42.8	161.3	120.1	133.6	105.6	1.1	32.9	15.4	727
1995	0	34.1	164	140.3	64.8	79.3	120	142.1	74.3	2.2	0	45.8	866.9
1996	42	3.5	133.3	58.9	181.4	138	114.5	114.3	104.4	1.3	3.5	0	895.1
1997	6.4	0	218.2	112.7	35.3	115.5	134.5	108.6	61.2	93.5	25.7	0	911.6
1998	27.8	26.9	51.8	69.1	91.7	84.1	78	186.6	119.8	106.1	35	0	876.9
1999	5.4	1.1	73	25	61	103.5	111.8	110.3	71	184.5	0	0	746.6
2000	0	0	0.4	74.6	146.6	158.3	150.9	82.9	120.1	34.8	27.3	1.6	797.5
2001	0.5	22.4	186.1	12.2	189	147.5	98	179.2	86.9	10.9	6.2	0	938.9
2002	102.9	68.4	50	72.3	52.9	58.5	46.2	164.8	44.3	1.6	0	38	699.9
2003	18.3	42.6	98.5	148.7	29.2	126.1	132	207.9	82.5	18.5	0.6	0	904.9
2004	52.8	1.5	25.6	104.4	29.8	115.8	119	97.4	156.1	79.6	1.8	2.8	786.6
2005	53.1	44.9	84.6	128.8	73	66	65.6	104.4	89.3	19.2	25.8	0.3	755
2006	5	16	93.6	131.4	61.9	82.2	161.6	106.5	82.2	76.1	2	6.5	825
2007	27.4	59.6	49.4	71.5	155.3	142.4	149.5	96.4	79.8	20.2	6.6	6.6	864.7
2008	2.9	0	0.2	42	84.4	133.1	167.2	223.8	106.1	78.2	66.7	0	904.6
2009	20.3	17.7	35.5	50.2	62.3	58.8	158.5	253.6	95	68.3	0.9	28.3	849.4
2010	4.5	127.4	101.1	112.6	74.5	118.3	149	83.4	122.2	3.5	3.5	3.7	903.7
2011	8.4	25.6	133.3	58.1	119.2	38.9	139.5	169	175.9	0	4	0	871.9
2012	0	0	30.1	109.3	72.5	64.8	198.1	253.1	159.2	55.5	0	13.3	955.9
2013	0	0	82.4	36.1	130.3	56.3	203.5	76	114.9	36	0	0	735.5
Mean	**19.3**	**38.8**	**79.5**	**89.7**	**87.4**	**98.3**	**135.1**	**146.8**	**107.3**	**46.9**	**11.8**	**10.1**	**871.1**

Table 6: Ogolcho total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1988	0.7	53.4	9.1	171.7	49.3	84.7	148.1	186.7	86.8	96.3	0	0.5	887.3
1989	0	45.5	137.4	91.6	10.8	204	176.9	135.9	134.1	27.7	0	6.2	970.1
1990	0	50.4	38.5	75.2	29.2	27.4	0.9	2.5	270.3	94.6	88.8	0	677.8
1991	3.1	56.7	145.8	89.9	43.6	37.4	198.4	55.5	55.5	9.7	0	9.1	704.7
1992	35.9	17.9	26.8	40.1	48	28.6	195.1	135.6	189.2	14.5	0	8.1	739.8
1993	30	27.2	32	170	136.9	21	206.1	132.9	90.8	81.4	0	0.4	928.7
1994	0	1.4	29.8	61.4	35.5	173	156.9	81.1	43.4	0	6.7	0	589.2
1995	0	0	64.3	161.9	15.8	59.3	106	114.6	68.6	31.5	0	31.6	653.6
1996	70.8	0.7	72.8	30.9	128.4	130.2	114.8	157.8	96.4	5.1	8.1	0	816
1997	19.8	0	146.7	105.2	29.6	62.5	159.2	63.6	97	59.1	4.5	0	747.2
1998	18.3	22.4	78.6	58.4	85.2	62.8	142.8	147.6	123.8	76.4	8.2	0	824.5
1999	0	22.4	49.4	2.8	35	91	100	94.9	79.2	174.2	0	0	648.9
2000	0	0	0	49.9	75	69.5	160.7	88.7	141.4	20.9	113.6	0	719.7
2001	0	4	123.4	10.7	100.3	90.6	155.4	157.8	45.1	12.3	0	4.1	703.7
2002	0.8	41.5	26.1	44.2	34.6	69.7	133.9	183.1	39.6	2	0	7.8	583.3
2003	6.1	58.1	90.8	86.5	33.4	94.6	176.6	95.8	91.5	3.4	0.2	38.5	775.5
2004	32.5	0	49.1	125.2	9.5	76.5	68.6	71.3	121.7	16.6	0	0	571
2005	42	6.4	55.4	103.9	42.9	35.1	67	55.4	121.8	16.6	4	0	550.5
2006	0.9	22.7	49.3	113.1	61.9	43.3	165.5	26.5	13.2	44.6	0	0	541
2007	0.5	13.5	51.3	47.9	107	184	132.3	112.5	124.2	46.3	0	0.6	820.1
2008	6.8	0	51.3	155.8	215.8	123.8	301.8	193.2	124.2	201	17.7	0	1391.4
2009	38.9	0	17.5	155.8	210.9	29.8	301.7	193.4	95	200.9	17.7	0	1261.6
2010	0	99.8	136.6	86.2	164	29.8	141.8	84	116	0	1.3	0	859.5
2011	13.8	14.6	84.3	0	164	113.5	172	81.7	133.8	0	32.3	0	810
2012	0	0	13.5	63.7	25	55.1	322.9	232.1	170.7	1.3	0	0	884.3
2013	0	0	96.5	68.4	69.3	65	149.2	100.1	81.4	75.2	1.8	0	706.9
Mean	**12.3**	**21.5**	**64.5**	**83.5**	**75.4**	**79.3**	**159.8**	**114.8**	**106.0**	**50.4**	**11.7**	**4.1**	**783.3**

Table 7: Sagure total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1988	7.3	31.3	7	106.7	88	73.8	234	175.9	129.8	43	1.4	0	898.2
1989	0.6	19.6	51	79.9	6.3	94.1	104.7	107.2	94.6	23.1	6.6	28.4	616.1
1990	4.9	132.8	120.1	70.9	51.7	80.1	130.3	97.3	95.9	9.5	19.1	0	812.6
1991	4.8	26.2	104.2	16.1	29.7	76	136.5	181.9	122.6	6.5	0.4	5.5	710.4
1992	24.1	81.8	53.6	74.5	38.1	76.5	107.1	225.4	63.3	57.8	13.1	12.6	827.9
1993	10	34.6	21.7	165.4	130.5	60.5	103.3	165.4	77.8	67.5	0	0.2	836.9
1994	0	9.9	33.2	52.1	25.9	138.8	180.9	140.8	105.5	1.1	11.3	2.1	701.6
1995	0	16.9	37.8	114.4	46.6	56.4	248.7	160.9	68.2	13.1	0	10.3	773.3
1996	36.1	9.2	78.8	10	126.9	160.9	101.2	103.6	59.8	4	3.7	1.6	695.8
1997	31.7	0	39.7	104.1	47.5	44.3	170.6	119.6	67.2	49.8	18.2	0	692.7
1998	24.1	37	61.7	75.6	60.5	59.4	99.5	201.9	35.3	91.9	9.6	0	756.5
1999	6.5	2.2	17.7	29	52.2	58.3	206.7	87.4	90.3	91.2	0	2.2	643.7
2000	6.5	2.1	17.7	29	52.2	58.4	71.6	228.7	70	42.5	26.2	16	620.9
2001	0.4	4.8	100.8	148.1	213.4	118.5	179.9	213.2	48	12.5	5.7	1.6	1046.9
2002	21.4	8.6	120.7	35.8	109.3	116.1	106.9	86.4	43.7	6	0	23.1	678
2003	4.3	10.7	28.9	160.7	19.8	60.4	172.4	121.7	57.7	4.8	0.2	17	658.6
2004	19.3	0.7	58.1	93.5	89.5	154.8	114.2	89.9	75	32.6	8	8	743.6
2005	13.5	25	68.2	94.7	76	35.6	136.1	86.3	130.2	45.2	11.3	5	727.1
2006	6	21.5	54.7	64.5	155.7	130	173.5	160.7	87.3	84	0	20	957.9
2007	34.9	8.5	83.7	107.5	86.7	143.9	85.4	160.8	113.7	84.1	2.8	0	912
2008	0	0.1	15.7	36.4	57.5	68.4	173.4	154.7	54	24	28.6	1.8	614.6
2009	30.8	0	38.3	33.3	45.3	56.3	83.6	90.8	47.9	57.4	3.1	41.3	528.1
2010	16.9	46.6	53.8	91.6	82.2	94.8	170.9	117.5	72	3.4	5.6	16.4	771.7
2011	8.4	7	38.1	71.8	66.2	96	131.5	123.2	59.6	1.5	6.9	16.4	626.6
2012	0	0	29.8	93.6	37.5	157	128.7	95.4	77.1	7.2	11.6	1.3	639.2
2013	10.8	0.8	100.5	75.4	100.5	113.8	149.8	163.6	71.8	78.2	9.8	0	875
Mean	**12.4**	**20.7**	**55.2**	**78.3**	**72.9**	**91.7**	**142.4**	**140.8**	**77.6**	**36.2**	**7.8**	**8.9**	**744.8**

Table 8 : Asela total monthly precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov	Dec.	Annual
1988	14.1	52	8.8	68.8	51.1	112.1	218.3	168.2	148.1	66.5	0	0	908
1989	1.7	26.7	126.6	268.2	40.2	132.3	111.9	169.3	129.8	54.2	13.2	88.5	1162.6
1990	0	111.7	93	92.1	22.8	92.1	197.8	186.4	153.7	6.9	11.2	0	967.7
1991	0	42.4	142.3	34.4	57.6	117.6	178.8	149.1	39.1	1.5	1.2	20	784
1992	36	116.8	130.3	198.7	40	44.5	131.6	206.3	39	6.9	1.3	38.7	990.1
1993	13.2	22.3	20	150.8	181.1	50.4	129.9	166.3	150	172.8	0	0	1056.8
1994	0	0	138.9	44.5	83.8	205.8	249.7	164.5	178.1	5.5	0	3.5	1074.3
1995	0	0	23.2	122.4	153.8	92.7	122.9	212	164	97.8	22	69.5	1080.3
1996	69.8	16	171.7	155.9	156.5	193.9	163.3	142.7	133.9	31.5	1.9	4.3	1241.4
1997	18.7	36.8	91.9	214.5	49.8	160	196.6	98.2	99.2	130.2	57.7	1.3	1154.9
1998	27.3	60.6	48.2	94.9	72.6	109	192.4	266.5	135.5	131.3	3.5	0.3	1142.1
1999	0.2	0	49.8	33.4	45.1	83.5	189.4	120.5	104.2	218.5	11.7	0.9	857.2
2000	0	0	1.1	178.3	127.8	138.3	150.8	153.6	173.9	101.6	36	0.4	1061.8
2001	0	90.1	267.3	53.9	258.7	179.4	139.8	273.4	127.2	39.2	8.7	1.1	1438.8
2002	0	90.1	267.3	53.9	109.3	116.1	106.9	86.4	43.7	6	8.7	1.1	889.5
2003	7.1	53.9	85	62.8	35.8	120.4	68.9	204.9	76.2	9.2	0	55.3	779.5
2004	10.1	14.6	173.5	185.6	36.6	102.2	148.5	155.7	110.9	6.1	2	33.6	979.4
2005	60.9	0.1	38.3	118.2	44.9	103.5	149.7	171.3	161.5	158.1	21.1	49.6	1077.2
2006	90.8	22.4	117.7	129.7	182.2	76.3	132.1	151.9	122.8	14.5	41.4	1	1082.8
2007	90.8	22.4	117.7	129.5	92.6	141.6	209.4	178.2	120	45.6	0	11.6	1159.4
2008	23.8	78.1	26.1	123.4	175	131.1	230.1	205.9	138.2	48.8	13.6	0	1194.1
2009	5.8	1.4	26.1	32.7	127.3	93.4	203.7	238.3	144.6	56	56.9	0	986.2
2010	49.1	15.4	76.4	73.7	73.8	113.6	203.7	238.1	144.5	56.1	56.9	0	1101.3
2011	6.1	127.5	102.9	191.6	125.6	88.9	143.7	137.9	193.7	1	17.3	2.9	1139.1
2012	9.9	26	100.8	70	148.1	80.1	178.2	185.5	199.3	0	36.3	0	1034.2
2013	0	0.1	31.5	110.7	33.3	93.3	224.9	181.8	136.6	4.2	1.2	34.5	852.1
mean	**20.6**	**39.5**	**95.2**	**115.1**	**97.1**	**114.3**	**168.2**	**177.4**	**129.5**	**56.5**	**16.3**	**16.1**	**1045.95**

Appendix III: Weather Generator Statistic and Probability Values

Table 9. Statistical values for Kulumsa station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	22.98	24.36	24.96	24.66	24.67	23.40	21.31	20.93	21.54	22.59	22.70	22.30
TMPMN	8.29	9.20	10.35	11.32	11.03	10.53	10.55	10.46	9.99	10.41	8.85	8.03
TMPSTDX	1.87	2.09	2.14	2.17	2.05	1.79	1.81	1.37	1.36	1.54	1.61	1.66
TMPSTDMN	2.39	2.34	2.11	1.98	1.86	1.65	1.63	1.53	1.71	2.06	2.35	2.40
PCP_MM	19.33	38.78	79.53	89.66	87.42	98.31	135.06	146.79	107.33	46.95	11.83	10.07
PCPSTD	3.39	5.11	7.17	6.78	7.12	5.84	6.30	8.45	5.13	5.58	2.07	2.08
PCPSKW	8.81	5.94	4.93	3.51	5.81	3.08	2.03	5.06	2.89	6.68	7.48	10.56
PR_W1	0.07	0.10	0.18	0.29	0.23	0.45	0.67	0.61	0.50	0.09	0.04	0.05
PR_W2	0.47	0.55	0.60	0.57	0.64	0.63	0.72	0.75	0.77	0.62	0.49	0.44
PCPD	3.85	5.54	10.00	12.77	12.96	17.27	22.38	23.00	21.46	6.65	2.58	2.69
RAINHHMX	45.4	56.9	83.5	61	103	45.2	34.2	114.3	53.7	78.3	26.1	31.9
SOLARAV	21.17	21.56	22.64	23.21	22.89	19.74	14.58	15.84	21.66	24.69	24.34	22.41
DEWPT	9.77	10.37	11.78	11.9	11.1	10.85	12.32	12.5	11.39	10.08	9.26	8.96
WNDAV	1.35	1.41	1.53	1.61	1.64	1.47	1.31	1.26	1.18	1.30	1.35	1.28

Table 10. Statistical values for Asela station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	22.47	23.36	24.01	23.73	23.68	22.46	20.46	20.23	20.56	21.60	21.66	21.57
TMPMN	16.56	16.02	15.10	15.30	16.50	14.80	14.50	14.00	14.14	15.20	15.20	16.20
TMPSTDX	1.98	2.23	2.36	2.33	2.15	2.25	1.76	1.56	1.57	1.60	1.77	1.83
TMPSTDMN	2.29	2.28	1.63	1.28	1.30	1.22	1.22	1.09	1.13	1.78	2.16	2.39
PCP_MM	20.59	39.52	95.25	115.1	97.13	114.31	168.19	177.42	129.53	56.54	16.3	16.08
PCPSTD	3.29	5.05	7.96	8.77	6.71	6.51	7.53	8.12	6.28	6.38	2.75	3.29
PCPSKW	7.18	5.68	4.83	4.14	3.42	2.73	2.31	2.69	2.63	5.66	7.89	9.96
PR_W1	0.07	0.11	0.19	0.24	0.23	0.44	0.63	0.60	0.46	0.11	0.06	0.05
PR_W2	0.46	0.49	0.64	0.64	0.67	0.65	0.77	0.78	0.79	0.61	0.45	0.42
PCPD	3.58	5.58	11	12.85	13.27	17.46	23.46	23.77	21.85	7.42	3.23	2.5

Table 11. Statistical values for Bokoji station

Descriptions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	21.09	21.38	21.05	20.05	20.40	19.29	18.29	17.48	18.42	19.02	20.05	20.42
TMPMN	7.97	9.00	10.10	9.94	9.97	8.91	8.79	9.07	9.24	8.30	7.92	7.64
TMPSTDX	1.79	2.11	2.62	2.48	1.99	2.47	3.12	1.87	1.70	1.88	1.66	1.51
TMPSTDMN	2.79	2.58	2.37	1.98	2.31	2.38	1.92	2.28	2.70	2.85	3.08	3.02
PCP_MM	24.71	39.71	74.02	107.55	96.77	101.85	179.07	194.79	89.37	43.92	19.63	14.44
PCPSTD	3.34	4.53	6.09	6.55	7.07	5.84	6.71	6.64	5.25	3.86	2.50	1.86
PCPSKW	6.80	5.08	4.12	3.13	4.21	3.63	2.24	1.75	3.46	4.31	5.84	5.75
PR_W1	0.08	0.12	0.18	0.34	0.31	0.48	0.75	0.74	0.50	0.17	0.10	0.08
PR_W2	0.51	0.57	0.62	0.69	0.63	0.68	0.87	0.89	0.70	0.58	0.44	0.42
PCPD	4.42	6.58	10.31	16.62	14.92	18.77	27.27	27.88	19.92	9.92	5.00	4.08

Table 12. Statistical values for Ogolcho station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	28.27	29.20	29.87	29.02	29.22	28.59	25.93	25.56	26.52	27.44	28.72	28.51
TMPMN	13.13	13.19	13.99	14.16	14.26	14.41	14.17	14.06	14.04	13.35	13.35	13.24
TMPSTDX	2.83	2.98	2.36	3.30	3.21	2.47	2.76	2.44	1.83	2.92	1.86	1.68
TMPSTDMN	3.10	2.97	2.37	2.43	2.28	1.84	2.16	2.21	2.13	2.84	2.91	3.21
PCP_MM	12.34	21.48	64.47	83.48	75.42	79.32	159.79	114.78	105.95	50.45	11.73	4.11
PCPSTD	2.75	3.56	6.35	7.56	7.50	6.56	8.86	7.07	6.89	6.10	2.83	1.52
PCPSKW	9.68	6.34	4.22	4.35	5.77	3.99	2.81	3.15	3.78	6.25	12.92	19.02
PR_W1	0.04	0.07	0.16	0.19	0.19	0.29	0.47	0.39	0.40	0.10	0.04	0.02
PR_W2	0.35	0.41	0.50	0.52	0.51	0.49	0.58	0.56	0.61	0.51	0.30	0.24
PCPD	1.96	3.15	7.69	8.96	8.85	11.42	16.81	15.19	15.88	5.62	1.69	0.96

Table 13. Statistical values for Sagure station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	23.46	24.13	24.38	22.99	22.68	21.30	19.49	19.38	20.53	21.93	22.81	22.74
TMPMN	6.76	7.48	8.46	9.55	9.05	8.74	9.32	9.22	8.44	7.06	6.66	6.95
TMPSTDX	1.65	1.94	2.24	2.11	1.96	1.89	2.00	1.71	1.43	1.54	1.19	1.35
TMPSTDMN	3.15	2.61	2.19	1.86	1.76	1.48	1.43	1.58	1.63	2.40	3.23	3.47
PCP_MM	12.43	20.69	55.21	78.25	72.91	91.66	142.36	140.78	77.63	36.23	7.82	8.88
PCPSTD	1.69	2.54	5.27	5.55	5.92	5.65	6.00	5.42	4.76	3.07	1.24	1.58
PCPSKW	6.87	5.99	6.49	4.24	5.65	2.84	2.78	1.78	4.32	3.66	6.54	9.21
PR_W1	0.09	0.09	0.18	0.36	0.29	0.45	0.69	0.68	0.45	0.13	0.06	0.06
PR_W2	0.43	0.57	0.61	0.60	0.61	0.64	0.84	0.85	0.69	0.61	0.47	0.36
PCPD	4.23	5.42	10.19	14.58	13.81	17.38	25.96	26.38	18.85	8.42	3.04	2.69

Table 14. Statistical values for Eteya station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
TMPMX	19.78	20.28	20.13	19.35	19.54	19.67	17.91	17.82	18.17	17.76	18.45	18.93
TMPMN	6.04	6.75	7.48	8.32	8.27	7.89	7.95	8.05	7.76	6.72	5.84	6.09
TMPSTDX	1.95	2.20	2.17	2.30	2.01	2.02	2.29	1.98	2.01	1.93	1.65	1.56
TMPSTDMN	2.40	2.05	1.97	1.73	1.90	2.13	1.59	1.61	1.75	2.00	2.28	2.38
PCP_MM	9.21	19.71	49.08	65.82	116.75	93.80	155.12	231.32	134.98	41.83	14.65	6.56
PCPSTD	1.70	2.66	5.36	4.42	7.99	6.18	7.75	10.42	7.24	3.76	3.59	1.46
PCPSKW	9.20	5.66	5.91	3.10	3.94	3.63	3.06	2.69	2.83	4.12	13.01	11.91
PR_W1	0.06	0.09	0.12	0.27	0.33	0.36	0.53	0.64	0.44	0.13	0.04	0.05
PR_W2	0.43	0.58	0.62	0.62	0.63	0.60	0.73	0.80	0.72	0.60	0.46	0.45
PCPD	3.12	4.81	7.46	13.42	15.35	14.92	21.00	24.46	19.50	8.38	2.19	2.58