JIMMA UNIVRSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
HYDRAULIC ENGINEERING PROGRAM

STREAM FLOW AND SEDIMENT YIELD MODELING (CASE STUDY: ANGER WATERSHED)

A thesis Submitted to the School of Graduate studies of Jimma University in partial fulfillment of the requirement for the degree of Master of Science in Hydraulics Engineering

By

Zeleke Werke

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DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING

HYDRAULIC ENGINEERING STREAM MASTERS OF SCIENCE PROGRAM

STREAM FLOW AND SEDIMENT YIELD MODELING (CASE STUDY: ANGER WATERSHED)

BY: ZELEKE WERKE FAJIGO

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ABSTRACT

Proper planning and management of water resources is vital for wise utilization and sustainable development of the resource. Runoff from the upstream of the watershed and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development in the watershed. An understanding of the hydrological response of a river basin would help to resolve potential water resources problems associated with floods, droughts. The objective of this study was to simulate stream flow and sediment yield of Anger watershed for proper management of the basin.

The Soil and Water Assessment Tool (SWAT) was used to model the hydrology of the basin with dataset including soils, land use/cover, digital elevation model, flow and meteorological data from National meteorological stations. The model was calibrated and validated against measured flow. The values of model for the annual water yields of Anger watershed at the outlet are 2032.61mm, with the total annual rainfall of 2726.6mm. Out of this 50% of the water yield was from surface runoff, 47% of the water yield was from Groundwater, 2% of the water yield was from lateral flow contribution to the stream flow and 1% of the flow was lost through transmission. Finally the results show that the average runoff coefficient is 0.24, in Anger watershed contributes an annual water yields of 3.97 BCM and the model simulation output annual average suspended sediment yield was53.017T/HA

The study showed that monthly stream flow, sediment yield and other hydrologic components in Anger watershed was predicted by the Soil and Water Assessment Tool (SWAT) hydrologic model with very good values of model performance evaluation parameters. The Soil and Water Assessment Tool (SWAT) model was calibrated from 1987 to 2000 and validated from 2001 to 2004. Both, calibration and validation results, showed a good match between measured and simulated flow. Both coefficient of determination (R^2) and Nash- Sutcliffe simulation efficiency (NSE), were 0.75 and 0.71 for both calibration and validation respectively. This shows good performance of the SWAT model on monthly time step.

***Key words**: Stream flow, Sediment yield, SWAT model*

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LIST OF ABBREVIATIONS

AGNPS	Agricultural Non-Point Source
ANSWERS	Areal Nonpoint Source Watershed Environmental Response Simulation
AV-SWAT	Arc View integrated Soil and Water Assessment Tool
BCM	Billion Cubic Meter
CN	Curve Number
CREAMS	Chemical, Runoff, and Erosion from Agricultural Management System
DEM	Digital Elevation Modal
ENMA	Ethiopian National Meteorological Services Agency
EPIC	Erosion Productivity Impact Calculator
ESCO	Soil Evaporation Compensation factor
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GSE	Geological Survey of Ethiopia
GPS	Global Position System
HRU	Hydrologic Response Unit
MUSLE	Modified Universal Soil Loss Equation
MOWE	Ministry of Water and Energy
NMSA	National Metrological Service Agency
SOM	Soil Organic Matter
SURQ	Surface Runoff
SWAT	Soil Water Assessment Tools
USLE	Universal Soil Loss Equation
USDA-ARS	US Department of Agriculture – Agriculture Research Service
USDA	US Department of Agriculture
WHAT	Web-based Hydrograph Analysis Tool
WMO	World Meteorological Organization
WWDSE	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1 Back Ground

Management of natural resources in catchments has gained significance internationally over the last ten years. Particularly development cooperation has increasingly focused on the issue with the aim to protect and sustain resources of a particular area and at the same time make these resources utilizable for the population

Proper planning and management of water resources is vital for wise utilization and sustainable development of the resource. The total renewable surface water resources of Ethiopia are estimated at 122 BCM (billion cubic meters) per year from 12 major river basins, and 22 lakes. Renewable groundwater resources are estimated to be about 2.6 BCM (The World Bank, 2006).

Ethiopia has huge potential resources which includes total of 122 billion cubic meters of surface water, 2.6 billion cubic meters of groundwater resources and 3.7 million hectare of potentially irrigable land that can be used to improve agricultural production and productivity (Awulachew et al., 2007; MOWR, 2002).

Although there is a universal perception that Ethiopia has adequate water resources, the spatial and temporal occurrence of these resources within a watershed should be properly known for proper planning and management to be effective.

Despite these potential resources base, agricultural production are lowest in some parts of the country attributed from unsustainable environmental degradation mainly reflected in the form of erosion and loss of soil fertility (Demel, 2004).Under the prevalent rain fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the high lands coupled with climate variability have aggravated the incidence of poverty and food insecurity (Awulachew et al., 2007).

Sheet and rill erosion are by far the most widespread kinds of accelerated water erosion and principal cause of land degradation in the country and their combined effect significantly affect agricultural production and productivity (Contable, 1984).The loss of nutrient-rich top soil by water leads to loss of soil quality and hence reduced crop yield.

Soil erosion by water and its associated effects are therefore recognized to be severe threats to the national economy of Ethiopia .Since more than 85% of the country‘s population depends on agriculture for living; physical soil and nutrient losses lead to food insecurity (Luelseged, 2005).

Rapidly increasing population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use rights (grazing and woody biomass resources), cultivation of marginal and steep lands, overgrazing, and other social, economic and political factors have been the driving force to a series of soil erosion in the basin (BCEOM, 1998; MoARD, 2004).

Sediment degrades water quality, and carries soil- adsorbed polluting chemicals. Sediment deposition in irrigation canals, stream channels, reservoirs, water conveyance structures, reduces their capacity and would require costly operation for removal (Foster, 1982).

Sediment deposition along the river channel causes flooding in the surroundings the processes of erosion, entrainment, transportation and deposition of sediments in a river catchment are complex. The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the forces generated by flowing water. Once a particle has been detached, it must be entrained before it can be transported away. Both entrainment and transport depend on the shape, size and weight of the particle and the forces exerted on the particle by the flow. When these forces are diminished to the extent that the transport rate is reduced or transport is no longer possible, deposition occurs.

Sediment is transported in suspension, as bed load rolling or sliding along the bed and interchangeably by suspension and bed load. The nature of movement depends on the particle size, shape, and specific gravity in respect to the associated velocity and turbulence. Under some conditions of high velocity and turbulence, e.g. high flows in steep-gradient mountain streams; cobbles are carried intermittently in suspension. Conversely, silt size particles may move as bed load in low-gradient, low -velocity channels, e.g. drainage ditches.

Sediment may cause severe damages depending on the amount, character, and place of deposition. Deposits that occur on floodplains create numerous types of damages to crops and developments. The deposition of sediment in drainage ditches, irrigation canals, and in navigation and natural stream channels creates serious problems in loss of services and cleanout costs.

The deposition of sediment in our natural stream channels has greatly aggravated floodwater damages. The deposition of sediment in channels decreases the channel capacity and the flood-carrying capacity. This results in higher and more frequent overflows (Foster and Meyer 1977, Wischmeier and Smith 1978).

The potential flood hazard is obviously the result of a potential water resource that needs to be developed. Runoff from the upstream of the watershed and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development in the basin.

If a watershed is not managed properly, then the natural resources will be degraded rapidly and therefore they cannot be used for betterment of human life. Proper management to use the excess flow will be an enormous input for various water resource projects in a basin in general and in Anger watershed in particular.

Models, therefore, will be a great tool both in predicting the amount of excess water leading to flooding as well as manage the shortage in case of drought and the use of simulation modeling, which is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g, river discharge, sediment concentration), is becoming attractive because direct measurement of parameters describing the physical system is time consuming, costly, tedious, and often has limited applicability (Abbaspour, Vejdani, &Haghighat, 2007). The problem with obtaining measured data becomes worse when the watershed under consideration is very large; hence the use of simulation models becomes mandatory.

1.2 Problem Statement

Water resources play a crucial role in the economic development of the developing countries with plentiful of water resources like Ethiopia. The region's explosive population growth and resulting new demands on limited water resources require efficient management of existing water resources and building new facilities to meet the challenge. In water resources management system, it is well known that to combat water shortage issues, simulating stream flow is crucial. Stream flow modeling is vital importance to flood mitigation and water resources management and planning.

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. Many farmers in Ethiopian highlands cultivate sloped or hilly land, causing topsoil to be washed away during the torrential rains of the rainy season. The rains also leach the highland soils of much fertility. `

In most parts of Ethiopia the high intensity rainfall occurs when the cultivated land has low cover. With the fast growing population and the density of livestock in the basin, there is pressure on the land resources, resulting in even forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation. High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation & maintenance and shortening lifespan of water resources infrastructure.

At the same time, the sediment deposition in the reservoirs and irrigation systems downstream lead to serious reduction in reservoirs storage capacities and hence leading to hydropower generation problems, banks flooding and ultimately negatively impact on the socioeconomic lives of the users, environment and ecosystem in general. Moreover, the sedimentation in the irrigation systems leads to water shortage and irritation management difficulties. On the other hand, sediment deposition on the bed of the river course raise the bed level, hence leads to flood risks and loss of human lives and their properties. Therefore this study may fill the gap of quantifying stream flow and sediment yield in the Anger watershed.

1.3 Objective of the Study

1.3.1 General Objective

The main objective of this research is to simulate stream flow and sediment yield of Anger watershed

1.3.2 Specific Objectives

1. To estimate the runoff and sediment yield of the Anger river basin outlet.
2. To calibrates and validates the model for stream flow.
3. To assess the water potential yield of Anger watershed.

1.4 Significance of the Study

Water resources planning and management efficacy is subject to capturing inherent uncertainties stemming from climatic and hydrological inputs and models. Stream flow modeling and water allocation decision making, fundamentally contain uncertainties arising from assumed initial conditions, model structure, and modeled processes. Accounting for these propagating uncertainties remains a formidable challenge and to extend hydro-meteorological information of the study area that helps decision makers to manage water resources for irrigation, water supply purposes beneficial to the community of the basin Therefore stream flow modeling and the Sediment yield will play great role to handle problems in the basin.

1.5 Scope of the Study

This study attempt on stream flow and sediment yield modeling of Anger watershed to know water potential of the watershed for future development and to help policy makers to focus on soil erosion protection measures.

1.6 Research Questions

- How to estimate the Runoff and sediment yield of the Anger watershed?
- How to calibrate and validate the model for stream flow?
- What is the water potential of Anger watershed?

2. LITERATURE REVIEW

2.1 General

Mankind has always been concerned to comprehend and subsequently control the processes of the hydrologic cycle. Many hydrologic phenomena are extremely complex, and thus, they may never be fully understood during the past, the processes of the hydrologic cycle were only conceptualized, and causes and effects were just described in relatively simple relations. Nowadays, however, the state of knowledge and technology makes it possible to even understand rather complex processes of the hydrologic cycle by means of executing a model on the computer. (Anderson & Woessner, 1992) attempted to define in such a way that model is a simplified representation of a complex system. The purpose of model is to replace reality, enabling measuring and experimenting in a cheap and quick way, when real experiments are impossible, too expensive, or too time-consuming (Eppink, 1993).

2.2 Hydrology

Hydrology is that natural science that is concerned with the occurrence, properties, distribution, and movement of water in the natural and man-made environment. As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evaporated or it may slowly make its way to the surface water system via underground paths.

2.2.1 Hydrologic Cycle

Water on earth exists in a space called the hydrosphere which extends about 15km up into the atmosphere and about 1 km down into the lithosphere, the crust of the earth. Water circulates in the hydrosphere through the maze of paths constituting the hydrologic cycle.

The hydrologic cycle is the central focus of hydrology. The cycle has no beginning or end, and its many processes occur continuously. Water evaporates from the oceans and the land surface to become part of the atmosphere; water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

In a global sense, the occurrence, distribution and movement of water in the natural environment can be visualized through a cyclic process known as the hydrologic cycle. Estimating the total amount of water on the earth and in the various processes of the hydrologic cycle has been a topic of scientific exploration since the second half of the nineteenth century. However, quantitative data are scarce, particularly over the oceans, and so the amounts of water in the various components of the global hydrologic cycle are still not known precisely.

2.2.1.1Precipitation

The term precipitation denotes all forms of water that reach the earth from the atmosphere .The usual forms are rainfall, snowfall, hail, frost and dew. Of all these, only the first two contribute significant amounts of water. Rainfall being the predominant from of precipitation causing stream flow, especially the flood flow in a majority of rivers.

2.2.1.2 Surface Runoff

Surface Runoff or overland flow is flow that occurs along a sloping surface using daily or sub daily rain fall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each hydrologic response units (HRUs).

2.2.1.3 Infiltration

Infiltration is the process of water penetrating from the ground surface into the soil. Many factors influence the infiltration rate, including the condition of the soil surface and its vegetative cover, the properties of the soil, such as its porosity and hydraulic conductivity, and the current moisture content of the soil.

2.2.1.4 Lateral Sub Surface Flow

Lateral sub surface flow or inter flow is stream flow contribution which originates below the surface but above the zone where rocks are saturated with water.

2.2.1.5 Ground Water

Groundwater is water saturated zone of earth materials under pressure greater than atmospheric, which is positive pressure. Subsurface and groundwater outflow occur when subsurface water emerges to become surface flow in a stream or spring.

2.2.1.6 Return Flow

Return flow, base flow is the volume of stream flow originating from groundwater.

2.2.1.7 Evaporation

Evaporation is the process in which a liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy.

2.2.1.8 Evapotranspiration

The processes of evaporation from the land surface and transpiration from vegetation are collectively termed evapotranspiration.

2.2.1.9 Transmission Losses

Transmission losses are losses of Surface flow via leeching through the streambed. This type of loss occurs in ephemeral or intermittent streams where groundwater contribution occurs only at certain times of the year, or not at all.

2.2.2 Hydrologic System

A hydrological system is defined as a set of physical, chemical and/or biological processes acting upon input variables to convert them into output variables (Dooge, 1968). In this definition a variable is understood to be a characteristic of the system, which may be measured, assuming different values when measured at different times. A parameter is a quantity characterizing the hydrological system and which is usually assumed to remain constant in time.

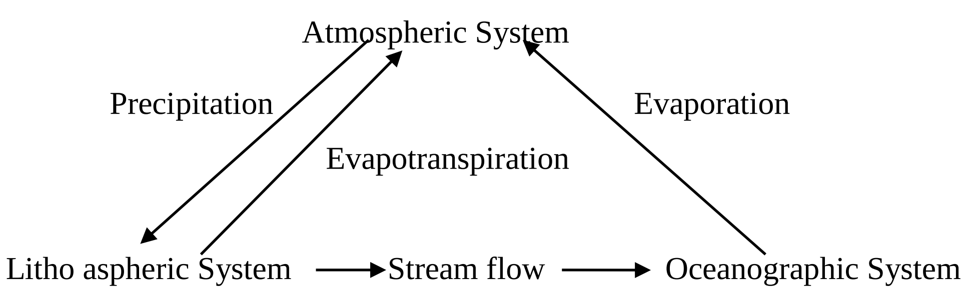
Hydrologic system is common in engineering analysis to represent the different components of the hydrologic cycle as components of a complex system.

2.2.2.1 System

System isa set of interconnected parts or components that form a whole:

- Have some structure or organization
- Have functional relationships

Hydrologic System



Hydrologic system

•Subsystems:

- Atmospheric (meteorology)
- Lithoaspheric (hydrology)
- Oceanographic (oceanography)

•Processes:

- Evaporation/Evapotranspiration
- Precipitation
- Stream flow

2.3 Sediment Yield

Ethiopia, often referred to as the water tower of East Africa, is dominated by mountainous topography, and the rainfall-runoff processes on the mountainous slopes are the source of the surface water for much of Ethiopia (Derib,2009), and thus, understanding the rainfall-runoff processes is critical to controlling erosion and enhancing agricultural productivity.

2.3.1 Soil Erosion

Soil erosion, soil loss, and sediment yield are terms with distinct meanings in soil erosion processes. Soil erosion is the gross amount of soil moved by drop detachment or runoff.

Soil loss is the soil moved off a particular slope or field. Sediment yield is the soil loss delivered to a point under evaluation.

Soil erosion by water is one of the most important land degradation problems and a critical environmental hazard in worldwide (Eswaran et al. 2001). Specially, accelerated erosion due to human-induced environmental alterations at global scale is causing extravagant increase of geomorphic process activity and sediment fluxes in many parts of the world (Turner et al. 1990).

The process of soil erosion involves detachment, transport and subsequent deposition (Meyer and Wishamejer, 1969). Sediment is detached from soil surface both by the raindrop impact and the shearing force of flowing water. The detached sediment is transported down slope primarily by flowing water, although there is a small amount of down slope transport by raindrop splash also (Walling, 1988). Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. The majority of the sedimentation of rivers in the basin occurs during the early period of the rainy season and peaks of sediment are consistently measured before peaks of discharge for a given rainy season (Steenhuis et al.,2009).

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster and Meyer 1977, Wischmeier and Smith 1978). Spatial and temporal information on runoff, soil erosion, and sediment yield of a catchment can provide a useful perspective on the availability of water, rate of soil erosion, and soil loss in the catchment. The dynamics of the processes of soil erosion and sediment yield are influenced by the spatial and temporal characteristics of the input variables affecting them and by controls exerted by the land surface. The controls related to land surface include elevation, soil, vegetation cover, and underlying geology.

The major classification of erosion type is by erosive agents, wind or water, which causes the erosion. The main types of erosion are rill erosion, sheet erosion and gully erosion. The sheet and rill erosion classification is based on a concept of progressive erosion severity. Sheet erosion, which is a uniform removal of soil from the surface, is assumed to be the first phase of the erosion process, and sheet erosion rates are assumed to be low. As erosion becomes increasingly sever, rill erosion is assumed to begin. Rill erosion progresses to gully erosion, which produces deeply incised channels.

2.3.2 Factors Affecting Soil Erosion

Several factors influence soil erosion; which include climate, soil, topography, 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. 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).

Soil erosion by water is also a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. As (Stern ,1990) put when the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport.

The erodibility of the soil also affects soil erosion. The erodibility of the soil refers to the resistance of the soil to both detachment and transport by the eroding agent. (Hudson, 1996) defines erodibility as the specific property of soil, which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances.(Wischemeier and Smith, 1978) established a regression equation for the parameters to estimate soil erodibility (K). Soil erodibility increases with increasing silt plus very fine sand content of the soil.

It decreases with increasing clay and organic matter content. According to (Mainam, 1999) soil aggregate stability and infiltration rates can be affected by aggregate size and bulk density, soil texture and soil structure. (Teklehaimanot, 2003) indicated that high aggregate densities generally are related with high clay content and increased aggregate strength. The other factor that contributes to soil erosion is soil sealing. Soil sealing is the formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling, or sedimentation, which is relatively impermeable to air and water (Bergsma et al, 1996). It is due to the effect of raindrop on bare soil, which results in reduction of infiltration; and increase in runoff and the potential for the soil erosion.

Vegetation Cover and Management also have a direct link to soil erosion. Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. The canopy intercepts raindrops, and if it is close to the ground, water dripping off the leaves has much less energy than unhindered raindrops (Wischmeier and Smith, 1978).

Materials in contact with the soil surface reduce erosion more effective than a canopy. No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy. Besides, such materials slow the runoff, which increases the flow depth.

2.3.3 Overview of Soil Erosion and 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.

2.3.4 Soil Erosion Model

Erosion modeling is based on understanding of the physical laws of landscape processes that occur in the natural environment. Erosion models can provide a better understanding of natural phenomena such as transport and deposition of sediment by overland flow and allow for reasonable prediction and forecasting. Many different models have been proposed to describe and predict soil erosion by water and associated sediment yield. They vary considerably in their objectives, time and spatial scales involved.

The models available in the literature for sediment yield estimation can categorized in to two main groups:

(1) Physical process based models and

(2) Empirical models

Physical process based models are intended to represent the essential mechanisms controlling erosion process by solving the corresponding equations. These models are the synthesis of individual components that affect the erosion processes and it is argued that they are highly capable to assess both the spatial and temporal variability of the natural erosion processes. The physical based models include AGNPS (Young .et al.1987), ANSWERS (Beasley et al., 1980), WEPP (Nearing et al., 1989) and SHE (Abbott etal., 1986; Wick and Bathurst, 1996). Physical based models are expected to provide reliable estimates of the sediment yield. However, these models have the major drawback, since they require many parameters related with each processes as these models are organized in physical-based sub-models related to hydrology, hydraulics, meteorology and soil mechanics. As a result, the number of input parameters for some of the models may be as high as 50, as for instance in the case of the WEPP model (Nearing et al., 1989).

Therefore, the practical application of these models is still limited because of uncertainty in specifying the values of the model parameter and also due to the differences between the scales of application that is a catchment versus field (Hadley et al., 1993).The application of physical based models in many areas is further limited due to lack of data set required for the model simulation.

Empirical models are like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991), Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984) and Agricultural Non-point Source Pollution Model (AGNPS) (Young et al., 1987) are examples of commonly used watershed models based on USLE methodology to compute soil erosion.

2.4 Hydrological Model

Hydrological modeling 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 et al. 2002).There are many classification schemes of hydrologic models, based on the method ofrepresentation of the hydrologic cycle or a component of the hydrologic cycle (source:(Cunderlik 2003)).

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. Two major types of hydrologic models can be distinguished.

- **Stochastic Models**. These models are black box systems, based on data and using mathematical and statistical concepts to link a certain input (as example rainfall) to the model output (for instance runoff). Commonly used techniques are regression, transfer functions, neural networks and system identification. These models are known as stochastic hydrology models.

- **Process-Based Models**. These models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. These models are known as deterministic hydrology models. Deterministic hydrology models can be subdivided into single-event models and continuous simulation models. There are various type of hydrological models are now a days available in public domain.

Hydrological models are tools that describe the physical processes controlling the transformation of precipitation to stream flows. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. The focus of these models is to establish a relationship between various hydrological components such as precipitation, evapotranspiration, and surface runoff, ground water flow and soil water movement (infiltration). Many of these hydrological models describe the canopy interception, evaporation, transpiration, snowmelt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated subsurface flow. These models range from simple unit hydrograph based models to more complex models that are based on the dynamic flow equations.

Simulation programs implementing watershed hydrology and river water quality models are important tools for watershed management for both applied and operational research purposes. A hydrological model represents the water cycle of a drainage basin and studies the response of this basin to climatic and physical conditions (Renaud, 2004). Three different categories of hydrological models can be distinguished: physically process based, empirical and statistically base. Physically process based models are described by mathematically formulated fundamental physical laws, where each basin is represented by a concept; a reservoir For instance. They are useful for inferring the distribution, magnitude, and past, present and future behavior of a process with limited observations (Hermance, 2003). These equations can relate the changes of water properties into the reach to those across the surface.

Empirical models are a synthesis and a summary of field or experimental observations. Their fundamental parameters are not compulsory physically related. Empirical models are based on defining important factors through field observation, measurement, experiments and statistical methods (Petter, 1992). They are useful in predicting the hydrology or soil erosion, but are site specific and require long-term data (Elirehema, 2001). Empirical models are the result of several years of research data and numerically evaluate the effects of climate, soil properties, topography and crop management (Stone, 2000).

Physically based models are based on knowledge of the fundamental processes and incorporate the laws of conservation of mass and energy (Petter, 1992). These physical processes vary both temporally and spatially. They consider the spatial and temporal changes of different factors (Jaroslav et al., 1996). Physically based distributed watershed models play a major role in analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds.

Statistically based models use many observations to estimate the behavior of watersheds and their interactions. They can be physically or empirically based. In addition to categorizing both soil erosion and hydrological models with respect to the way they are being synthesized, another distinction is the difference between distributed and global models. In distributed models, the watershed is one single entity and in global models, many units represent the variability of hydrological parameters on the surface. Spatial variability is handled by dividing a drainage basin into smaller geographical units, such as sub basins, land cover classes, elevation zones or a combination of them. The so called hydrological response units (HRUs) represent areas where the modeling has been simplified and where the hydrological response is supposed to be homogeneous.

In recent years, distributed watershed models are increasingly used to study alternative management strategies in the areas of water resources allocation, flood control, impact of land use change and climate change, and finally environmental pollution control. Many of these models share a common base in their attempt to incorporate the heterogeneity of the watershed and spatial distribution of topography, vegetation, land use, soil characteristics, rainfall and evaporation.

Some of the watershed models developed in the last two decades are CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), EPIC - Erosion Productivity Impact Calculator (Williams, 1995), AGNPS (Agricultural None Point Source model) (Young et al., 1989),

SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998) and HSPF (Hydrologic Simulation Program – Fortran) (Bicknell et al., 2001), ANSWERS (Areal on-point Source Watershed Environmental Response Simulation) (Beasley and Huggins, 1982), EROSION-3D (SCHMIDT, 1995), EUROSEM (European Soil Erosion Model)(Morgan et. al., 1997), WEPP (Water Erosion Prediction Project) (Foster and Lane, 1987) etc.

Many of these watershed models are applied for runoff and soil loss prediction (e.g. Morgan 2001, Srinivasan et al., 1998, Grønsten and Lundek-vam, 2006), water quality modeling (e.g. Belay Debele et al., 2006, Santhi et al., 2006, Abbaspour et al., 2007), land use change effect assessment (e.g. Sheng et al., 2003, Claessens et al., 2006; Wu et al., 2007) and climate change impact assessment (e.g. Anderson et al., 2006, Huang et al., 2005; Zhang et al., 2007).

Among the above mentioned models, the physically based distributed model SWAT is a well-established model for analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds. It is one of the watershed models for long term impact analysis.

2.4.1 Stream Flow Modeling

Accurate stream flow modeling that is used Water resources planning and management efficacy is subject to capturing inherent uncertainties stemming from climatic and hydrological inputs and models.

Stream flow modeling is critical in reservoir operation and water allocation decision making, fundamentally contain uncertainties arising from assumed initial conditions, model structure, and modeled processes.

2.4.2 Sources of Stream flow

The watershed, or catchment, is the area of land draining into a stream at a given location. To describe how the various surface water processes vary through time during a storm, suppose that precipitation of a constant rate begins and continue indefinitely on a watershed. Precipitation contributes to various storage and flow processes.

Initially, a large proportion of the precipitation contributes to surface storage', as water infiltrates into the soil, there is also soil moisture storage. There are two types of storage: retention and detention', retention is storage held for a long period of time and depleted by evaporation, and detention is short-term storage depleted by flow away from the storage location.

As the detention storages begin filling, flow away from them occurs: unsaturated flow through the unsaturated soil near the land surface, groundwater flow through saturated aquifers deeper down, and overland flow across the land surface. Channel flow is the main form of surface water flow, and all the other surface flow processes contribute to it. Determining flow rates in stream channels is a central task of surface water hydrology. The precipitation which becomes stream flow may reach the stream by overland flow, subsurface flow, or both (V. Chow 1959).

2.4.3 Stream Networks

In fluid mechanics, the study of the similarity of fluid flow in systems of different sizes is an important tool in relating the results of small-scale model studies to large-scale prototype applications. In hydrology, the geomorphology of the watershed, or quantitative study of the surface landform, is used to arrive at measures of geometric similarity among watersheds, especially among their stream networks. The quantitative study of stream networks was originated by Horton (1945).He developed a system for ordering stream networks and derived laws relating the number and length of streams of different order.

2.4.4 Stream Flow Rate

Stream flow is not directly recorded, even though this variable is perhaps the most important in hydrologic studies. Instead, water level is recorded and stream flow is deduced by means of a rating curve (Riggs, 1985). The rating curve is developed using a set of measurements of discharge and gage height in the stream, these measurements being made over a period of months or years so as to obtain an accurate relationship between the stream flow rate, or discharge, and the gage height at the gauging site.

2.5 SWAT Model and Its Application

SWAT model (Arnold et al., 1998) is a semi-distributed, continuous watershed simulator operating on a daily time step. It is developed with the joint effort with USDA and Texas University for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds.

The major components of SWAT include hydrology, Water supply, Water quality, weather, erosion, plant growth, nutrients, pesticides, land management, and stream routing. The robust application of SWAT model has extended all over the world because of its diversified application. Government agencies like EPA USDA uses SWAT for tracking environmental problems like water quantity, nutrient cycling and in stream process.

Wider application of SWAT is mostly in the government agency and research organization of USA and EU. SWAT model output often used indirectly as it has the flexibility of coupling with other models. A large number of climate and land use studies has been done all over the world with SWAT model for land use and climate change study.

Large scale European Projects also uses SWAT as a central hydrologic model frequently. Here is an example of SWAT model application in the Himalayan region for impact assessment of climate change.

It is applied in many parts of United States and many other countries (e.g. Bingner, 1996, Peterson and Hamlett,1998; Srinivasan et al., 1998; Arnold et al., 1998; Benaman et al., 2005, Heuvelmans etal., 2004; Bouraoui, 2005). A comprehensive review of SWAT model applications is given by Gassman et al., (2007).

The SWAT model is widely used in the United States and in some European countries to solve water management problems. It has been used for a variety of applications, including water balance calculation, sediment transport and stream-aquifer interaction Guen, (2005).

SWAT was integrated in GIS with Arc View 9.3. The different types of data required by the model were added, allowing the model to run. The calibration permitted the prediction of the behavior of the basin depending on different conditions. A study to identify limitations and uncertainties of SWAT has been carried out by Sophocleous *et.al.* (2000). SWAT was combined with MODFLOW (Modular Three Dimensional Finite Difference Ground Water Flow Model).

The results showed that SWAT distorted the shape of the watershed by using a mean distance of overland flow to the stream during transport processes. However, the study demonstrated that SWAT:

- Was capable of operating on a watershed scale with several sub-basins
- Allowed topographical, land use and management differences
- Was capable of simulating several management practices
- Could simulate long periods of time
- Could be calibrated through field testing

A study by Flay (2000) had the aim of understanding nitrate and phosphate dynamics in agricultural basins. It analyzed the ability of SWAT to model the effect of changes of land use patterns and practices. This study concluded on the main assets and drawbacks of SWAT.

Major shortcomings:

- Extensive data input requirements
- Difficulties of selecting appropriate parameters for calculation
- Subjectivity of selecting coefficients
- Limitations in simulating short-term events

Despite the complexity of the model, major benefits include: SWAT is applicable to decision-making in land management and is able to model the impacts on water quality and quantity such as cropping patterns, fertilizer applications, and pesticide applications and timing and amount of irrigation. An important issue to consider in the prediction of hydrology, sediment yield and water quality is uncertainties in the predictions. The main sources of uncertainties are:

I. Simplifications in the conceptual model. For example, then simplifications in a hydrologic model, or the assumptions in the equations for estimating surface erosion and sediment yield, or the assumptions in calculating flow velocity in a river,

II. Processes occurring in the watershed but not included in the model. For example, wind erosion, soil losses caused by landslides,

III. Processes that are included in the model, but their occurrences in the watershed are unknown to the modeler or unaccountable; for example, reservoirs, water diversions, irrigation, or farm management affecting water quality,

IV. Processes that are not known to the modeler and not included in the model. These include dumping of waste material and chemicals in the rivers, or processes that may last for a number of years and drastically changes the hydrology or water quality such as constructions of roads, bridges, tunnels and dams, and

V. Errors in the input variables such as rainfall and temperature.

2.6 Blue Nile Description

Ethiopia is situated in East Africa which lies between 3°30' and 14°50' North latitudes and 32°42' and 48°12' East longitudes. It has a surface area of about 1.127 million km^2. The country consists of three climatic zones depending on topography and geographic location: the cool zone above 2,400 meters where temperatures range from near freezing to 16°C; the temperate zone at elevations of 1,500 to 2,400 meters with temperatures from 16 to 30°C and the hot zone below 1,500 meters with both tropical and arid conditions and daytime temperatures ranging from 27 to 50°C.Annual rainfall varies from less than 100 mm in the low lands along the border with Somalia and Djibouti to 2400 mm in the southwest high-lands, with a national average of 744 mm/year.

The topography of Ethiopia ranges from very high mountain ranges (the Semien Mountains, Ras Dejen 4,620m, and the Bale Mountains), to one of the lowest elevation in Africa (the Danakil depression 125m).

The main rainy season is from June to September (longer in the southern high-lands) preceded by intermittent showers, from February to March; the rest of the year is mainly dry weather. Ethiopia is known for its enormous water resources potential. It is still known as the water tower of Africa, the source of the Nile River and many trans-boundary rivers.

The total annual runoff is estimated about 110 billion m^3, and only less than 5 % is used in the country, the remaining leaves the country as Trans boundary Rivers such as Blue Nile, Baro-Akobo, WabiShebele, Tekeze, Genale-Dawa etc. Ethiopia has three principal drainage systems (Ethiopia, 2008). The first and largest is the western system, that includes the watersheds of the (known as the Abbay in Ethiopia), the Tekeze, and the Baro rivers. All three rivers flow west to the White Nile in Sudan.

Blue Nile (Abbay) basin is the most important river basin of Ethiopia. It accounts for almost 20 percent of Ethiopia's land area; 50 percent of its total average rainfall; 25percent of its population; 39 percent of national cattle herd; and over 40 percent of cultivated land and crop production. Abbay River has an average annual run off of about 56.7 BCM and it contributes about 62 percent of Nile total at Aswan (MOWR, cited in Muluneh, 2005).

2.6.1 Location

Blue Nile Basin which is found in the western part of Ethiopia, between $7^0$45' and $12^0$45'N and $34^0$05' and $39^0$45'E is one of the largest basins in the country with high population pressure, degradation of land and highly dependent on agricultural economy (Tsegay, 2006). It covers an area of about 199812$km^2$with total perimeter of 2440km. The Anger River is one of the tributaries of the Abbay River (Awulachew 2010).The Blue Nile Basin (Abbay basin) is generally divided into 16 Sub-basins according to their configuration in topology, of which Anger Sub-basin is one of the sub-basins which contribute some percent of water to the Abbay basin. The Anger sub basin is located in the southern region of the Blue Nile Basin (Abbay basin).

Table 2.1: The 16 Sub Basins Of Blue Nile (Abbey), Ethiopia.(MOWR-1999)

No	***Sub Basin***	***Catchment Area(km^2)***
1	Lake tana	15294
2	Beshilo	13453
3	Weleka	6517
4	Jemma	16033
5	Muger	8318
6	Guder	7123
7	Fincha	4154
8	Dedessa	19943
9	**Anger**	**8146**
10	Dabus	21367
11	Beles	14426
12	South Gojam	17029
13	North Gojam	14618
14	Wonbera	13163
15	Dinder	15128
16	Rahad	8401

2.6.2 Topography

Anger sub basin has an area of 8146 km2. The altitude in Anger sub basin ranges approximately between 860 masl and 3210 masl. The highlands of the sub basin are higher in altitude, greater than 1800 masl up to 3210 masl. The lowlands have lower altitude less than 1200 masl in the western lowlands of the sub basin. (Awulachew 2010)

2.6.3 Climate

2.6.3.1 Rainfall

The Anger basin has an annual rainfall ranging approximately between 1280 mm and 2030 mm. Lower annual rainfall less than 1400 mm in the eastern lowlands of the sub basin and higher rainfall greater than 1600 mm in the highlands is observed.(Awulachew, 2010).

2.6.3.2 Temperature

The annual maximum and minimum temperature in the sub basin varies between 20^0C –32^0C and 16^0C -17^0Crespectively. Temperature is higher in the western lowlands with a maximum of 29^0C – 32^0C and minimum of 15^0C - 17^0C (Awulachew 2010).

2.6.3.3 Potential Evaporation

Potential Evapotranspiration (PET) in the sub basin is generally between 1360 mm and1925 mm per year. Potential Evapotranspiration is higher greater than 1800 mm/yr, in the lowlands where high temperature is observed. The highlands of the basin show lower Potential Evapotranspiration, less than 1600mm/yr.

2.6.4 Geology

The geology of the Anger basin is mainly dominated by Adigrat Sandstone and Basalt. There are Granite and Classics deposits.(Awulachew 2010).

2.6.4.1 Land Use/Land Cover

The terms land use and land/cover is often used interchangeably even though the distinction between the two is important. Land use refers to the actual economic activity for which the land is used whereas land cover refers to the cover of the earth's surface. The Anger sub basin is dominated by Woodlands and Forest. Pastoral lands were also used in the basin, with cultivated areas and state farms in parts of the sub basin (Awulachew 2010).

2.6.4.2 Soil

SWAT model requires different soil textural and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. The dominant soils in the Anger basin are Alisols, Acrisols, Nitosols and Leptosols (Awulachew 2010).

2.6.4.3 Agro-Ecological Zones

The watershed is characterized by tepid to cool and sub humid mid highlands, and hot to warm sub humid lowlands and the lowlands in the eastern parts of the basin being hot to warm moist lowlands (Awulachew 2010).

2.6.5 Socio Economic Aspect of the Sub Basin

2.6.5.1 Administrative Structure of the Sub Basin

Anger sub basin covers 15 weredas; Wayu Tuka, Bila Seyo, Sibu Sire, Guto Gida, Sasiga ,Gudaya Bila, Balo Jegonfoy, Abe Dongoro, Horo, Gida Kiremu, Yaso, Limu, Haro, Jarti Jardega, and Amuru. The total population of the weredas is 1,375,209 people (Awulachew 2010).

3. METHODOLOGY

3.1 Study Area

Anger watershed forms the southern part of Blue Nile (Abbay) basin in West Ethiopia. It is situated between $9^{0}0'00''$ to $10^{0}0'0''$ N latitude and $36^{0}0'00''$to $37^{0}0'00''$E longitude. It covers an area of 8146 square kilometers at present study. The altitude in Anger watershed ranges approximately between 820 masl and 3040masl. And the highlands of the sub basin are higher in altitude, greater than 1800 masl up to 3040masl.The lowlands have lower altitude less than 1200 masl in the western lowlands of the sub basin at present study. (as shown in figure-1).

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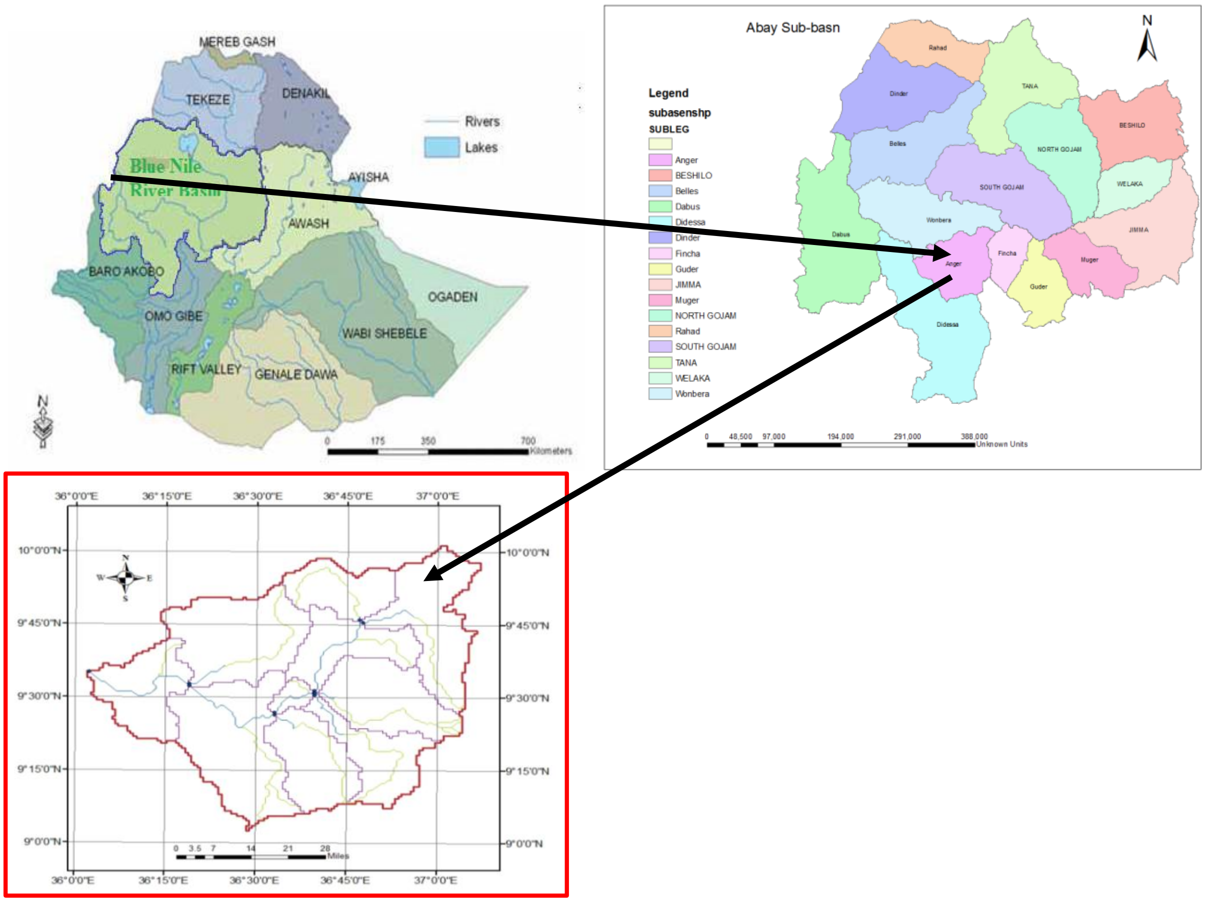


Figure 3.1: Location of Anger Catchment

3.2 Data Collection and Analysis

The necessary data that was collected and used for this study can be classified into spatial and time series data. Spatial data used are DEM, land use/cover and soil map of the study area and collected from MOWE. The time series data are Metrological and hydrological data and these data are collected from Ethiopian National Metrological Agency (ENMA) and MOWE respectively.

Table 3.1: SWAT Input Data Types and Their Corresponding Sources

Data type	Source	Period	Description	Remark
Weather	National Meteorological Agency of Ethiopia (Global Weather) Data for SWAT	1990-2013	Daily precipitation, Maximum and Minimum Temperature Wind speed Relative humidity and Solar radiation	Many of the station have long period Missing.
Hydrology	Ministry of Water, Irrigation and Energy of Ethiopia	1990-2013	Daily and monthly flow data	Have missing data
Land use/cover	Ministry of Water, Irrigation and Energy of Ethiopia	2015	Land use classification map	
Soils	Ministry of Water, Irrigation and Energy of Ethiopia	2015	Soil classification Map	
Terrain	Ministry of Water, Irrigation and Energy of Ethiopia	90mx90m	Digital Elevation Model	

Table 3.2: Location Details of the Weather Monitoring Stations

Weather monitoring station	**Coordinates**			Remark
	Latitude	**Longitude**	**Altitude (m. a. s. l)**	
Anger 1	9.267	36.3333	1350	
Nekmte	9.083	36.463	2080	
S /sire	9.040	36.872	1826	
Anger 2	9.523	36.562	1510	Used as weather generator station
Weather data-953669	9.523	36.875	1522	
Weather data-98366	9.835	36.562	2100	
Weather data-98369	9.832	36.875	1787	

Daily and monthly discharge data at different gauging stations in Anger basin were obtained from the Ministry of Water and Energy of Ethiopia. Most of the stations have short records and/or many missing data, which hinders the use of these stations for model calibration. Hence, a flow monitoring station called Anger 1with relatively long period of recorded data has been used for model calibration and validation. See table 3.3 for geographical location of Anger gauging station.

Table 3.3: Geographical Parameters of Anger 1 Gauging Station

Flow monitoring station	**Coordinates**		
	Latitude	**Longitude**	**Altitude (m. a. s. l)**
Anger 1	9.267	36.3333	1350

Source: Ministry of Water and Energy

Scarcity of weather data is one of the major problems impairing hydrologic modeling and, thereby, proper planning and management of water resources in data scarce watersheds. To minimize the effects of the problem, alternative data source is available, weather data from water base (Global Weather) website.

3.3 Materials Used

Models and software's used for estimation of stream flow and sediment yield in the study area were Arc GIS 9.3 extension of SWAT model that is Arc SWAT 2009, SWAT CUP-2012 and Software XLSTATA for missing data. The other soft ware's used in this study were PCPSTAT, Dew point (dew02) for statically calculates parameters of daily perception and average daily dew point of per month temperature using daily air temperature and humidity data respectively. It was used for input preparation of SWAT model, to extend the Arc SWAT model and to prepare in the watershed.

3.4 SWAT Description

The Soil and Water Assessment Tool (SWAT) Model was developed by the USDA Agricultural Research Service. This model is a watershed scale model that can predict the impact of changes in land management to water and sediment. It is physically based requiring specific information about soil, topography, weather, and land management practices within the watershed (Arnold et al., 1998). SWAT is a useful tool because watersheds that do not have any monitoring data can be modeled. It also can simulate large watersheds in a relatively short period of time (Arnold et al., 1998).

Arc SWAT, an Arc GIS extension, which is a graphical user interface for the SWAT (Soil and Water Assessment Tool), was used to model the hydrology of Anger watershed. SWAT is a river basin, or watershed, scale 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 (Winchell, Srinivasan,Luzio, & Arnold, 2009).

SWAT has been employed to model watersheds of different scales for different purposes. For example, Asres and Awulachew (2010) applied SWAT to the Gumara watershed of the Abbay Basin to predict sediment yield and runoff, to establish the spatial distribution of sediment yield and to test the potential of watershed management measures to reduce sediment loading from hotspots.

Similarly, Chekol, *et al.* (2007) used SWAT model to assess the spatial distribution of water resources and analyze the impact of different land management practices on hydrologic response and soil erosion in the Upper Awash River Basin watershed, Ethiopia, so as to gather information for effective watershed management. Both groups of investigators reported that they obtained good results.

Likewise, Singh, *et al.* (2013) applied SWAT to the Tungabhadra catchment in India for the measurement of stream flow, and reported that they obtained a result in which the observed and simulated data had excellent correlation during monthly calibration time step. Panhalkar (2014) also used SWAT to estimate the runoff of the Sutluj Basin, India,and reported a successful performance and applicability of SWAT mode.

3.5 Hydrological Component of SWAT

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. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water and sediments through the channel network of the watershed to the outlet.

The land phase hydrological cycle based on the water balance equation:

$$Sw_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

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).

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911). 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 was used to estimate surface runoff because of the unavailability of sub daily data for Green & Ampt method.

The SCS curve number equation is (USDA-SCS, 1972):

$$Qsurf = \left(\frac{(\mathrm{Rday}-0.2\mathrm{s})2}{(\mathrm{Rday}+0.8\mathrm{s})}\right) \quad (2)$$

In which, Qsurf is the accumulated runoff or rainfall excess (mm),

Rday is the rainfall depth for the day (mm),

S is the retention parameter (mm)

$$S = 25.4\left(\frac{100}{\mathrm{CN}} - 10\right) \quad (3)$$

SWAT 2009 version includes two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant evapotranspiration. The soil moisture method (equation 4) estimates runoff in shallow soils. But calculating daily CN as a function of plant evapotranspiration, the value is less dependent on soil storage and more dependent on antecedent climate.

$$S = \mathrm{Smax} * \left(\frac{\mathrm{SW}}{[\mathrm{SW}+\exp(\mathrm{w1}-\mathrm{w2}*\mathrm{SW})]}\right) \quad (4)$$

In which S is the retention parameter for a given day (mm),

Smax is the maximum value that the retention parameter can have on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm), and w1 and w2 are shape coefficients.

The maximum retention parameter value, Smax, is calculated by solving equation 5 using

$$Smax = 25.4\left(\frac{100}{CN1} - 10\right) \quad (5)$$

When the retention parameter varies with plant evapotranspiration, the following equation is used to update the retention parameter at the end of every day:

$$S=S_{Prev}+E_O*\exp\left(\frac{-cncoef- SPrev}{Smax}\right)-R_{day}-Q_{surf} \quad (6)$$

In which Sprev is the retention parameter for the previous day (mm),

Eo is the potential evapotranspiration for the day (mm/day),
cncoef is the weighting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant evapotranspiration,
Smax is the maximum value the retention parameter can achieve on any given day (mm),
Rday is the rainfall depth for the day (mm), and
Qsurf is the surface runoff (mm).

The initial value of the retention parameter is 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 moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with equations 7 and 8.

$$CN1 = CN2 - \frac{20*(100-CN2)}{(100-CN2+\exp[2.533-0.0636*(100-CN2)])} \quad (7)$$

$$CN3 = CN2 * \exp[0.00673 * (100 - CN2) \quad (8)$$

Typical curve numbers for moisture condition II are listed in various tables (Neitschetal.,). The values are appropriate for a 5 % slope. Williams (1995) developed an equation to adjust the curve number to a different slope:

$$\mathrm{CN2s} = \mathrm{CN2} - \frac{(\mathrm{CN3} - \mathrm{CN2})}{3} * [1 - 2 * \exp(-13.86 * \mathrm{slp})] + \mathrm{CN2} \qquad (9)$$

In which CN1 is the moisture condition I curve number,

CN2 is the moisture condition II curve number for the default 5 % slope,

CN3 is the moisture condition III curve number for the default 5 % slope,

CN2S is the moisture condition II curve number adjusted for slope and

slp is the average percent slope of the sub basin.

SWAT calculates the peak runoff rate with a modified rational method.

The rational formula is: $q\mathrm{peak} = \frac{\mathrm{C.i.Area}}{3.6}$

Where: qpeak: is the peak runoff rate (m^3/s),

C: is the runoff coefficient, i- is the rainfall intensity (mm/hr),

Area- is the sub basin area (km^2) and 3.6 is a unit conversion factor.

There are many methods that are developed to estimate potential evapotranspiration (PET).Three methods are incorporated into SWAT:

- The Penman-Monteith method (Monteith, 1965),
- The Priestley-Taylor method (Priestley and Taylor, 1972) and
- The Hargreaves method (Hargreaves et al., 1985).

The simulation of groundwater is partitioned into two aquifer systems i.e. an unconfined aquifer (shallow) and a deep-confined aquifer in each sub basin. The unconfined aquifer contributes to flow in the main channel or reach of the sub basin. Water that enters the deep aquifer is assumed to contribute to stream flow outside the watershed (Arnold et al., 1993).

3.5.1 Sediment Component

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

$$\text{Sed} = 11.8 \times (\text{Qsurf} \times \text{qpeak} \times \text{areahru})0.56 \times \text{KUSLE} \times \text{CUSLE} \times \text{PUSLE} \times \text{LSUSLE} \times \text{CFRG}$$

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 (m^3/s),
areahru is the area of the HRU (ha),
KUSLE is the soil erodibility factor (0.013 metric ton m^2 hr/ (m^3-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

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss.

3.6 Watershed Delineation

Watershed delineation is required to provide a boundary of the watershed. SWAT uses Arc Hydro algorithm for watershed delineation. The watershed delineation carries out advanced GIS functions to aid the user in segmenting watersheds in to several 'hydrologic ally' connected sub watersheds for use in watershed modeling in SWAT.

There are two methods for watershed delineation in SWAT model, one is the DEM-based method, which is based on the DEM of the study area and the other is the pre-defined method in which users can define the reaches and sub basins manually. Most of the researchers use the first method at present, which has high precision only in the area with certain terrain slope. During watershed delineation flow direction and flow accumulation process is done.

Digital elevation model (DEM) data, polygon Coverage of soils and land use, and point Coverage of weather stations was used as basic input to the model. The watershed is delineated using a using a 90m resolution digital elevation model (DEM) and digitized stream networks of the study area.

3.7 HRU Analysis

The sub-watershed delineation was followed by the determination of HRUs, which are unique soil and land use combinations within a sub-watershed modeled regardless of their spatial positioning. This describes better the hydrologic water balance and increases the accuracy of load predictions (Luzio et al. 2002). Hydrological response units are areas within a watershed that respond hydrologically similarly to given input. It is a means to representing the spatial heterogeneity of a watershed. With the introduction of hydrologic response unit (HRU), it is possible to expect similar hydrologic behavior in each unit, which can be modeled easily. Plenty of hydrological models use HRU as unit response for a sub basin.

SWAT predicts the land phases of the hydrologic cycle separately for each HRU and routes to obtain the total loadings of the sub watershed The HRUs can be determined either by assigning only one HRU for each sub-watershed considering the dominant soil/Land use combinations, or by assigning multiple HRUs for each sub-watershed considering the sensitivity of the hydrologic process based on a certain threshold values of soil/Land use combinations. After watershed delineation, the watershed was partitioned in to hydrologic response units (HRU), which are unique soil and land use combinations within in the watershed to be modeled.

In this study, Anger river watershed was sub divided into 33 sub-watersheds and 196 Number of multiple HRUs with 5 percent land use threshold, 10 percent soil threshold and 10 percent were adopted.

For modeling surface runoff and sediment yield we used the SCS curve number method and modified universal soil loss equation respectively. In order to identify the most important or sensitive model parameters before calibration, model sensitivity analysis was carried out using a built-in SWAT sensitivity analysis tool.

Soil parameter data such as soil depth, soil texture, hydraulic conductivity and bulk density, and land use data which are required for the hydrological modeling were obtained from the Ministry of Water, Irrigation and Energy of Ethiopia. See, respectively, table 3.4 and Figure 3.2 for detailed distribution and map of the sub-basin's soils.

Table 3.4: Detailed Distribution of Soil Types in Anger Watershed

SOIL	CODE	HYD GR	AREA (%)
EutricLeptosols	Ne12-3b-156	D	0.76
Haplic Nitisols	Ao63-3b-6	C	6.12
EutricVertisols	Bh12-3c-31	C	0.1
HaplicAlisols	Ne13-3b-158	C	55.11
RhodicNitisols	Be49-3c-20	C	8.48
HaplicAcrisols	Ne12-2c-155	D	18.99
EutricRegosols	Re59-2c-246	C	0.03
DystricLeptosols	Be8-3c-24	C	4.35

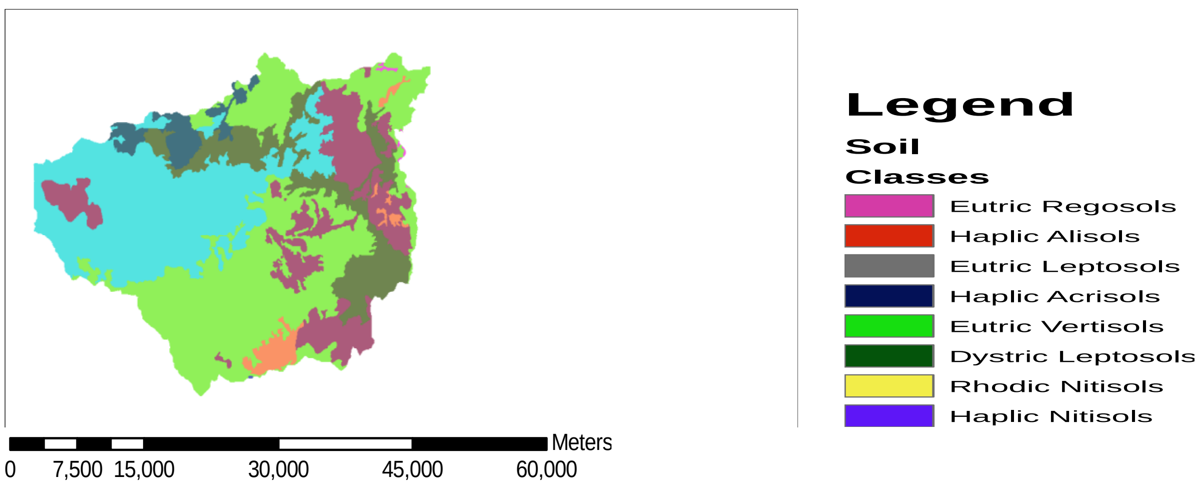


Figure 3.2: Soil map of Anger watershed

Anger watershed is predominantly covered with woodlands, followed by agricultural practices. The central and southern parts of the basin are predominantly cultivated (Figure 4).

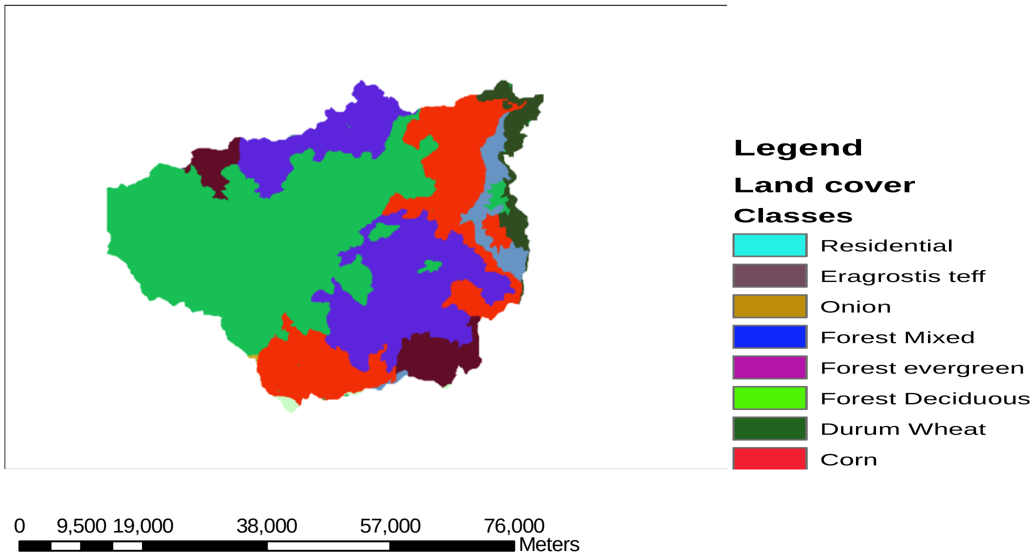


Figure 3.3: Major Land Use/Cover Distribution in the Watershed

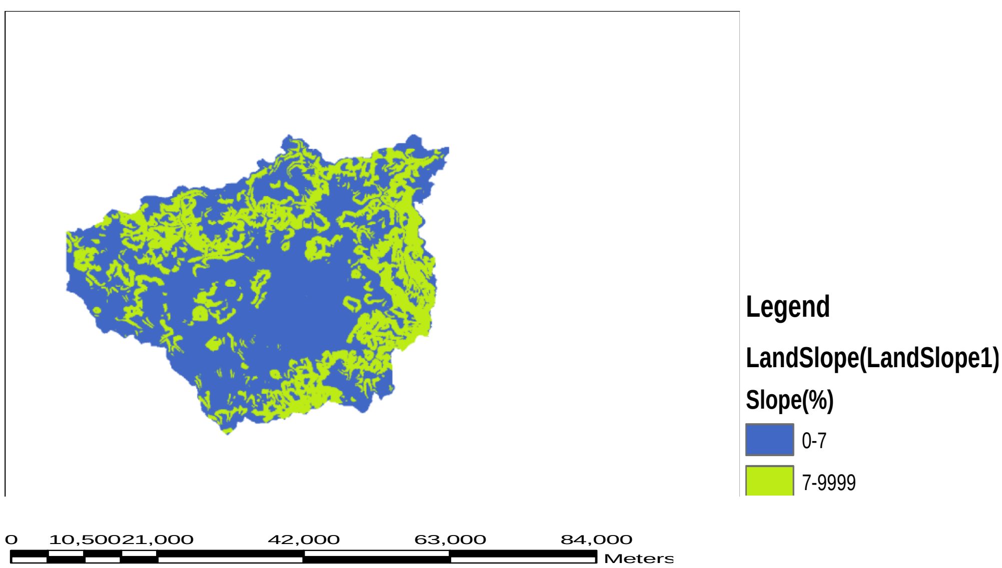


Figure 3.4: Land Slope Distribution in the Watershed

3.8 Sensitivity Analysis, Calibration and Validation

3.8.1 Sensitivity Analysis

We carried out Sensitivity analysis to identify sensitive parameter that significantly affected surface runoff, base flow and sediment yield. Curve number (CNII), available water capacity(SOL_AWC), average slope steepness (SLOPE), saturated hydraulic conductivity (SOL_K),maximum canopy storage (canmx) and soil depth (SOL_Z) and soil evaporation compensation factor (ESCO) were relatively high sensitive parameters that significantly affect surface runoff. Threshold water depth in shallow aquifer for flow (GWQMN), base flow Alpha factor (ALPHA_BF), and deep aquifer percolation fraction (rchrg.dp) were other parameters that mainly influence base flow.

In order to make calibration processes, it was crucial to find out the sensitive parameters using sensitivity analysis. Sensitivity analysis is important for a model to reduce the number of model parameters for calibration and to examine the more sensitive parameters, which in turns determines the main causes of water yield or sediment load from different practices and physical conditions. Thus, a sensitivity analysis was performed for the entire period (1990-2013).Results of sensitivity analysis controlling the most sensitive parameters for the watershed were ranking as the following (Table 3.5).

Table 3.5: SWAT Calibration Parameters with Their Respective Sensitivity Ranking and Fitted Values

Parameter name	**Description and units**	**Sensitivity Rank**	**Range of Values**		**Mean index**
			Minimum	**Maximum**	
CN2	Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (-)	1	35	98	0.157
ESCO	Soil evaporation compensation factor (fraction)	2	0	1	0.105
CANMAX	Maximum canopy storage(mm H2O)	3	0	10	0.061
SOL_AWC	Available soil water capacity (mm/mm)	4	0	1	0.028
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)	5	0	500	0.028
SOL_Z	Soil depth (mm H2O)	6	0	3000	0.025
GW_REVAP	Water in the shallow aquifer returning to the root zone inresponse to a moisture deficit during the time step (mm H2O)	7	0.2	0.02	0.021
CH_K2	Effective hydraulic conductivity in main channel alluvium(mm/hr).	8	0	150	0.011
ALPHA_BF	Base flow alpha factor (decimal)	9	0	1	0.011
GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur (mm)	10	0	5000	0.007
SOIL_K	Saturated hydraulic conductivity	11	0	100	0.003
GW_DELAY	Ground water delay time (days)	12	0	50	0.003

3.9 Modal Calibration

Model calibration is the process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions, while model validation involves running a model using input parameters measured or determined during the calibration process (Moriasi, *et al*, 2007).To perform such studies as the evaluation of the impact of alternative land management practices on stream water quality and quantity, first the model must be calibrated and validated for existing conditions (Arnold, et al, 2011). Proper model calibration is important in hydrologic modeling studies to reduce uncertainty in model simulations (Moriasi*et al*, 2007).

The calibration/validation process consists of three steps (Neitsch, Arnold, Kiniry, &Williams, 2011):

- Selecting some portion of observed data
- Running the model at different values for unknown parameters until fit to observations is good
- Applying model with calibrated parameters to remaining observations

The SWAT model for Anger hydrology was calibrated for recorded data at Anger 1 near Nekemt-Ethiopia flow station. The calibration procedure involved sensitivity analysis followed by semi-automated calibration procedure by SWAT-CUP 2012, where, at times, manual manipulation on the selection of calibration parameters was necessary. Anger 1 near Nekemt-Ethiopia station was selected for the availability of recorded flow data, even though the amount of missing data is still large.

The years 1990 and 1991 were used as a warm-up period to enable the model to initialize smoothly (Abbaspour K. C, 2014). Monthly flow data for 1997-2000 and 2001-2004 were used for calibration and validation, respectively. The Nash–Sutcliffe Efficiency **(**NSE**)** was used as an objective function to calibrate and validate the model using 12 flow sensitive input parameters included in the model (Table-6).The degree to which uncertainties are accounted for, is quantified by a P-factor which is the percentage of measured data bracketed by the 95 % prediction uncertainty (95PPU).

The 95PPU is calculated at the 2.5 % and 97.5 % levels of the cumulative distribution of an output variable obtained through Latin Hypercube Sampling method (Abbaspour et al., 2007).Another parameter measure quantifying the strength of calibration or uncertainty analysis is the R-factor which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The model was calibrated using the Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP, an interface that was developed for SWAT (Abbaspour K. C, 2014). SUFI-2 identifies a range for each parameter as follows:

1. 95% prediction uncertainty (95ppu) between the 2.5th and 97.5th percentiles contains a predefined percentage of the measured data, and
2. The average distance between the 2.5th and 97.5^{th} prediction percentiles is less than the standard deviation of the measured data (Abbaspour K. C, 2005).

3.9.1 Calibration Criteria

The goodness of calibration and prediction uncertainty is judged on the basis of the closeness of the p-factor to 100 % (i.e., all observations bracketed by the prediction uncertainty) and the R-factor to 1.

The two indices, i.e., the p-factor and the R-factor, are calculated by Equations

$$P - factor = \frac{1}{\mathrm{n}} \sum_{ti}^{n} \left({Y_{ti}}^{M}, 97.5\% - {Y_{ti}}^{M}, 2.5\% \right)$$

$$R - factor = \frac{\mathrm{P - factor}}{\sigma obs}$$

In which ${Y_{ti}}^{M}, 97.5\%$ and ${Y_{ti}}^{M}, 2.5\%$ represent the upper and lower boundaries of the 95PPU, and σ*obs* is the standard deviation of the measured data .The recommended visual observation should be followed by calculation of values for the model performance evaluation criteria: Root Mean Square Error (RMSE)-observations standard deviation ratio (RSR), Nash-Sutcliffe Efficiency (NSE), and Percent bias (PBIAS). Moriasi*et al,* (2007) describe the parameters as follows:

RMSE-Observation Standard Deviation Ratio (RSR): RSR is calculated as the ratio of the root mean square error and standard deviation of measured data, as shown in the following equation:

$$\boldsymbol{RSR} = \frac{\textbf{RMSE}}{\textbf{STDEVobs}} = \frac{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}} - \mathbf{yisim})\mathbf{2}}\ ]}{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}} - \mathbf{ymean})\mathbf{2}}]}$$

Where RMSE is root mean square error, $STDEFV_{obs}$ is standard deviation of observed data of the constituent being evaluated, y_i^{obs} is the $_i^{th}$ observation for the constituent being evaluated, y^{sim} is the $_i^{th}$ simulated value for the constituent being evaluated, y^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value.

Nash-Sutcliffe Efficiency (NSE**)**: The Nash-Sutcliffe Efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”).NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in the following equation:

$$\textbf{NSE}=\mathbf{1} - \frac{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}}-\mathbf{yisim})\mathbf{2}}]}{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}}-\mathbf{ymean})\mathbf{2}}]}$$

ENS ranges between $-\infty$ and 1.0 (1 inclusive), with ENS =1being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

Percent bias (PBIAS*)* Percent bias (PBIAS**)** measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of ***(****PBIAS*) is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. ***(****PBIAS*) is calculated with the following equation:

$$\boldsymbol{PBIAS} = \frac{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}} - \mathbf{yisim}) * (\mathbf{100})}}{[\sqrt{\sum_{i=1}^{n}(\mathbf{yi^{obs}})}]}$$

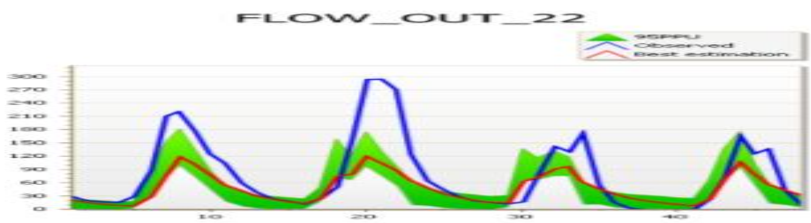
Where (PBIAS***)*** is the deviation of data being evaluated, expressed as percentage.

With these values, model performance can be judged based on general performance ratings as proposed by Moriasi, *et al*. (2007). Model simulation judged as satisfactory if NSE>0.5, RSR≤0.70 and PBIAS =±25% for flow and NSE>0.5, RSR≤0.70 and PBIAS =±55% for sediment. Moreover, Coefficient of Determination (R^2)**,** the index of correlation of measured and simulated values, has been used to evaluate the accuracy of the overall model calibration and validation. The value (R^2) ranges between 0 and 1. The more the (R^2) value of approaches 1, the better is the performance of the model and the (R^2) values of less than 0.5 indicate poor performance of the model.

4. RESULT AND DISCUSSION

4.1Model Calibration, Validation and Verification Results

Following the model sensitivity analysis and calibration procedure using SWAT-CUP'S SUFI-2 algorithm, the graphical (visual observation) method and values of statistical parameters recommended by Moriasi *et al.* (2007) were considered as adequate statistical values for acceptable calibration. The model was simulated 1000 times during both the calibration and validation periods. Figure 5 and Figure 6 are graphical representations of the comparison of observed and simulated flow values for, respectively, the calibration and validation periods at Anger1 near Nekemt, Ethiopia flow station.



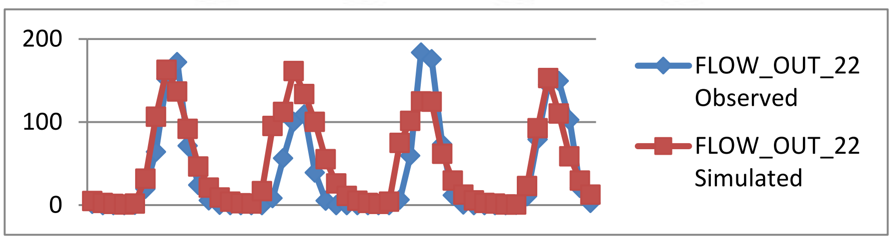


Figure 4.1: Comparison of Observed and Simulated Monthly Discharge for the Calibration Period (1997-2000)

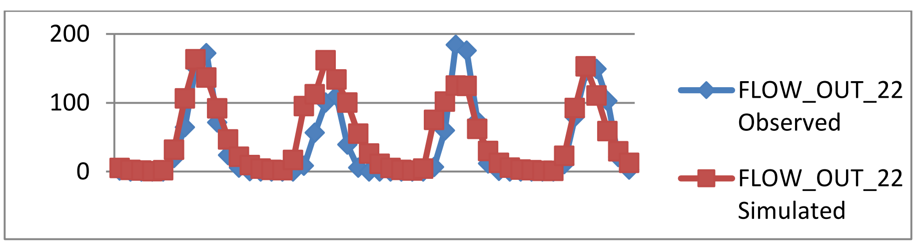


Figure 4.2: Comparison of Observed and Simulated Monthly Discharge for the Validation Period (2001-2004)

The two figures portray that there is good harmony between observed and simulated monthly flow for the calibration and validation periods, i.e, the graphs for observed data and the corresponding simulated values show similar patterns. This observation was evidenced using the well-known model evaluation parameters, which were used to assess the performance of the model. Among these, the values for Nash-Sutcliffe Efficiency *(NES)* and the coefficient of determination (R^2) were 0.75 for both the calibration and validation periods. *RMSE*-observation standard deviation ratio *(RSR)* was 0.54 and 0.54 for the calibration and validation periods, respectively (Table 4.1).

Table 4.1: SWAT-CUP Simulation Results for the Calibration and Validation Periods

Modal evaluation	Simulation Results		Remark
	Calibration	Validation	
RSR	0.54	0.54	Excellent
NSE	0.71	0.71	Excellent
PBIAS	-28.2	-28.2	Overestimation
R^2	0.75	0.75	Excellent
P-factor	0.19	0.19	
R-factor	0.67	0.67	

Overall, the model has demonstrated a very good performance

4.2 Water Resources Potential

4.2.1 Mean Annual Water Budget of Anger Watershed

The values of model for the present study show that the annual water yields of Anger watershed at the outlet was 2032.61mm, while the total annual rainfall was 2726.6mm.

The total water yield is calculated as:

Water yield= Surface runoff Q + lateral flow Q +Ground water Q –Transmission loss, (all in mm).

The lion's share (50%) of the water yield is comes from surface runoff ,Groundwater contribution to the stream flow, i.e. water from the shallow aquifer that enters the main channel during the time step, holds the second major share. It contributes 47% of the total water yield, 2. % constituted by lateral flow. Lateral flow is water flowing laterally within the soil profile that enters the main channel during the time step and about 1% of the flow is lost through transmission, i.e, the average rate of water loss from the reach by transmission through the streambed during the time step. Table 4.2 and Figure 4.3 show the details.

Table 4.2: Average Monthly Basin Values of Anger Watershed

Month	Rain fall (mm)	Surf Q (mm)	Lat Q (mm)	Water yield(mm)	Sediment yield (T/HA)	ET (mm)	PET (mm)
January	16.47	2.24	0.57	24	0.17	26.28	162.93
February	18.82	2.89	0.37	10.68	0.11	35.9	180.9
March	53.03	6.09	0.45	11.81	0.33	70.15	195.82
April	87.18	10.34	0.72	15.76	0.25	60	187.7
May	222.26	50.7	1.82	59.77	1.1	69.68	162.57
June	442.72	166.33	5.27	204.5	4.85	65.19	113.2
July	638.03	310.93	9.89	427.08	13.26	50.88	81.64
August	634.82	311.96	11.6	500.59	16.7	53.64	84.97
September	388.74	156.61	10.02	365.1	10.56	66.59	113.7
October	159.34	55.55	5.91	233.7	4.69	57.25	138.68
November	49.35	12.6	2.64	120.61	0.78	38.66	142.54
December	16.28	2.14	1.12	59.29	0.22	27.58	153.82
Total mean Annual values	**2726.6**	**1088.33**	**50.37**	**2032.61**	**53.017**	**620.9**	**1713.9**

Where Surf Q=surface runoff, Lat Q=lateral flow, Water yield=total water yield, ET=evaporation, PET=potential evapotranspiration

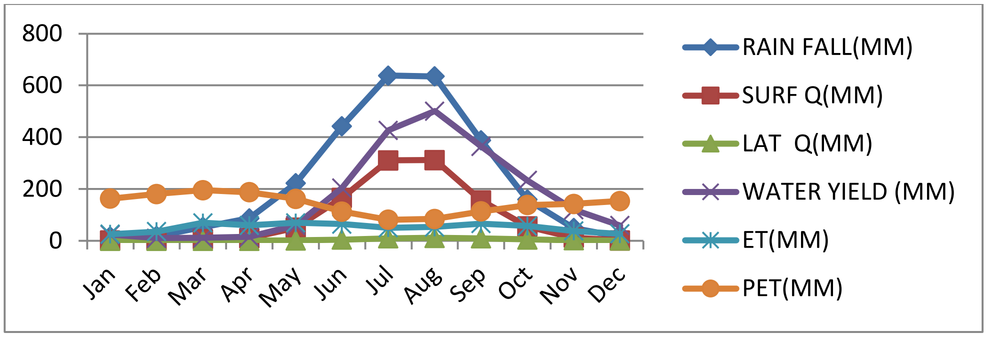


Figure 4.3: Simulated Average Basin Values of Anger Watershed at It's Out

The results show that the average runoff coefficient is 0.24, in Anger watershed contributes an annual water yield of 3.97 BCM (i.e., about 7.24% of the total flow of Abbay River as measured to estimated total mean annual flow from the Abbay Basin (54.8 BCM) as measured at the Sudan boarder (Awulachew, *et al*, 2007) and model simulation output annual average suspended sediment yield of the Anger watershed was **53.017T/HA**

4.3 Comparison of Measured and Simulated Sediment Concentration

A visual comparison of the observed and simulated daily sediment concentration of Anger River is presented in Table 4.3 and figure 4.4.

Table 4.3: Comparison of Daily Measured and Simulated Sediment Concentration

Month	Observed sediment conc.(mg/l)	Simulated sediment conc.(mg/l)
15-Aug-92	474.33	888.20
5-Sep-92	272.67	1143.00
31-Aug-94	790.79	1605.00
28-Jan-95	102.73	39.44
7-Aug-95	275.20	45.99
31-Aug-95	795.90	45.99
5-Sep-95	795.90	45.69
7-Aug-96	283.00	48.43
2-Sep-04	1191.50	50.86
31-Aug-06	1796.15	68.24
1-Feb-07	1231.08	39.92
19-Jul-07	339.75	49.57
17-Nov-07	427.55	48.28
18-Mar-08	167.82	32.54
28-Jun-08	185.54	100.00
30-Aug-08	749.04	1525.00
2-Sep-08	745.88	521.70
26-Aug-09	955.50	3881.00
3-Jan-11	2742.57	61.92

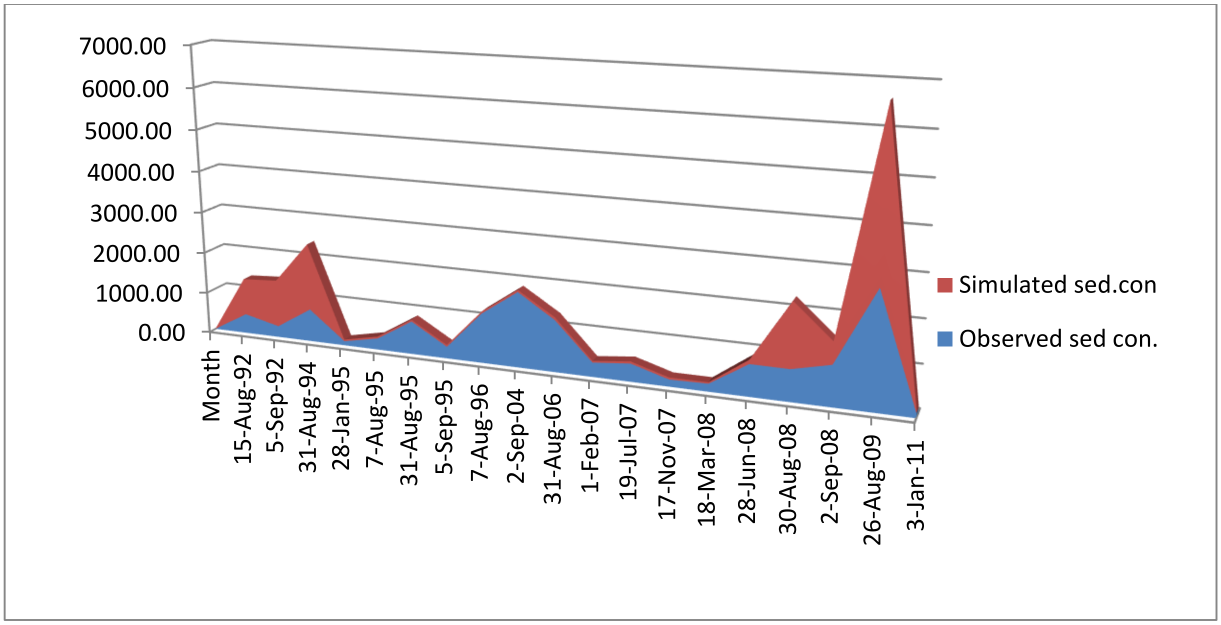


Figure 4.4: Comparison of Observed and Simulated Daily Sediment Concentration.

Based on this comparison of the figure 4.4 the observed and simulated daily sediment concentration is almost similar regardless of some measuring sediment data at the starting and the endpoints of the graph. Lack of adequate data on sediment delivery in the catchment was a problem in Calibrating and validating the sediment yield. The result will be more reliable if observed sediment data were available for calibration and validation.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The monthly and annual stream flow and sediment yield of Anger watershed have been simulated by a SWAT hydrologic model, a model which performed very well. Besides, the monthly and annual precipitation and evapotranspiration have been simulated and evaluated, the performance of SWAT model using SWAT-CUP's SUFI-2 algorithm calibration and validation statistics. A good agreement between measured and simulated monthly stream flow was demonstrated by the model performance efficiency indicators, correlation coefficient (R^2) and the Nash-Sutcliffe Efficiency (ENS) are found to be 0.75 and 0.71 for calibration periods (1997 -2000) and validation periods (2001-2004) respectively.

Due to scarcity of observed sediment data, the model was not calibrated for sediment yield. However, the simulated sediment concentration was compared with scarcely available observed sediment concentration and very good agreement was obtained.

The study shows that, the SWAT model simulates well both for stream flow and sediment yield and also shows that in data scarce areas, the use of satellite data in conjunction with datasets from a few conventional weather monitoring stations can give reliable results of annual stream flow and suspended sediment yield in the Anger watershed.

Overall, SWAT performed well in simulating stream flow and sediment yield at the watershed scale and thus can be used as a planning tool for watershed management.

5.2 Recommendation

Lack of adequate data on sediment delivery in the catchment was a problem in Calibrating and validating the sediment yield. Although the study was conducted only by one land use map, it would be more effective if maps of different time were used in order to analyze the trend and better result would be achieved. The result will be more reliable if observed sediment data were available for calibration and validation. Therefore, further studies will be suggested to test the accuracy of the predictions having different land use map and by measuring sediment concentration from gauging stations.

In this study, in addition to simulating stream flow and sediment yield, attempt were made to assess potential of the surface runoff and Ground water in the Anger watershed that can help planners, decision makers and other different stakeholders to plan and implement surface runoff for irrigation development and Ground water for domestic and household water supplies in rural areas using hand-dug wells, shallow wells and boreholes.

On the other hand sedimentation of reservoirs of various purposes, erosion of agricultural soil, and degradation of cultivable and potential areas are big challenges in the watershed for many years and will continue in the future except appropriate mitigation measures are taken. To manage this problem appropriate soil and water conservation practices has to made to control the stream flow and sedimentation problems in the Anger watershed.

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APPENDIXE

Table A: Flow Data (1997-2000) And Calibration Results With SWAT CUP-2012 at Sub Basin 22

1	flow_out_1_1995	57.59012903	37	flow_out_1_1998	39.1613871
2	flow_out_2_1995	20.62542857	38	flow_out_2_1998	24.90939286
3	flow_out_3_1995	17.43096774	39	flow_out_3_1998	18.57587097
4	flow_out_4_1995	16.48173333	40	flow_out_4_1998	12.5946
5	flow_out_5_1995	21.07509677	41	flow_out_5_1998	23.91303226
6	flow_out_6_1995	37.163	42	flow_out_6_1998	51.24426667
7	flow_out_7_1995	71.21806452	43	flow_out_7_1998	159.9092581
8	flow_out_8_1995	206.8470323	44	flow_out_8_1998	293.6069677
9	flow_out_9_1995	182.2581333	45	flow_out_9_1998	295.1457667
10	flow_out_10_1995	101.5281935	46	flow_out_10_1998	271.5722581
11	flow_out_11_1995	52.85986667	47	flow_out_11_1998	124.9477
12	flow_out_12_1995	35.15090323	48	flow_out_12_1998	64.79509677
13	flow_out_1_1996	26.04990323	49	flow_out_1_1999	46.18316129
14	flow_out_2_1996	15.97148276	50	flow_out_2_1999	28.92407143
15	flow_out_3_1996	15.9076129	51	flow_out_3_1999	20.11025806
16	flow_out_4_1996	12.92183333	52	flow_out_4_1999	16.41703333
17	flow_out_5_1996	38.52796774	53	flow_out_5_1999	12.97593548
18	flow_out_6_1996	75.20983333	54	flow_out_6_1999	17.85013333
19	flow_out_7_1996	163.6305484	55	flow_out_7_1999	78.65741935
20	flow_out_8_1996	210.7180323	56	flow_out_8_1999	144.3372258
21	flow_out_9_1996	246.7811333	57	flow_out_9_1999	132.2670667
22	flow_out_10_1996	174.5891613	58	flow_out_10_1999	178.9607742
23	flow_out_11_1996	124.9854333	59	flow_out_11_1999	55.2871
24	flow_out_12_1996	98.85553333	60	flow_out_12_1999	16.08158065

25	flow_out_1_1997	30.53683871
26	flow_out_2_1997	21.22564286
27	flow_out_3_1997	17.40987097
28	flow_out_4_1997	16.4502
29	flow_out_5_1997	29.70983871
30	flow_out_6_1997	89.008
31	flow_out_7_1997	210.7782581
32	flow_out_8_1997	222.5320323
33	flow_out_9_1997	177.2123333
34	flow_out_10_1997	125.8218387
35	flow_out_11_1997	105.3600667
36	flow_out_12_1997	60.28925806

61	flow_out_1_2000	3.189645161
62	flow_out_2_2000	0
63	flow_out_3_2000	0
64	flow_out_4_2000	0.024766667
65	flow_out_5_2000	1.198709677
66	flow_out_6_2000	22.53623333
67	flow_out_7_2000	72.30777419
68	flow_out_8_2000	171.5919355
69	flow_out_9_2000	128.4192
70	flow_out_10_2000	139.0874839
71	flow_out_11_2000	42.20496667
72	flow_out_12_2000	13.11958065

```
Goal_type= R2   No_sims= 16    Best_sim_no= 8   Best_goal = 7.524430e-001

Variable        p-factor  r-factor  R2   NS   bR2     MSE      SSQR      PBIAS  KGE  RSR  MNS  VOL_FR
FLOW_OUT_22     0.19      0.67      0.75 0.71 0.6075  9.2e+002 3.7e+002  -28.2 0.68 0.54 0.55 0.78


---- Results for behavioral parameters ---
Behavioral threshold= 0.300000
Number of behavioral simulations = 16

Variable        p-factor  r-factor  R2   NS   bR2     MSE      SSQR      PBIAS  KGE  RSR  MNS  VOL_FR
FLOW_OUT_22     0.19      0.67      0.75 0.71 0.6075  9.2e+002 3.7e+002  -28.2 0.68 0.54 0.00 0.78
```

Table B: Flow Data (2001-2004) And Validation Results With SWAT CUP-2012 at Sub Basin 22

1	flow_out_1_2001	1.662419355
2	flow_out_2_2001	0
3	flow_out_3_2001	0
4	flow_out_4_2001	0
5	flow_out_5_2001	0.243096774
6	flow_out_6_2001	19.44986667
7	flow_out_7_2001	64.28135484
8	flow_out_8_2001	151.6517419
9	flow_out_9_2001	172.1463667
10	flow_out_10_2001	71.41845161
11	flow_out_11_2001	24.04326667
12	flow_out_12_2001	5.804387097
13	flow_out_1_2002	0.328483871
14	flow_out_2_2002	0
15	flow_out_3_2002	0
16	flow_out_4_2002	0
17	flow_out_5_2002	0
18	flow_out_6_2002	8.3703
19	flow_out_7_2002	56.66629032
20	flow_out_8_2002	100.3045806
21	flow_out_9_2002	109.3437667
22	flow_out_10_2002	39.08751613
23	flow_out_11_2002	5.5641
24	flow_out_12_2002	0.050903226
25	flow_out_1_2003	0
26	flow_out_2_2003	0
27	flow_out_3_2003	0
28	flow_out_4_2003	0
29	flow_out_5_2003	0
30	flow_out_6_2003	6.643633333
31	flow_out_7_2003	59.69906452
32	flow_out_8_2003	183.8616452
33	flow_out_9_2003	175.6568
34	flow_out_10_2003	73.53280645
35	flow_out_11_2003	11.83073333
36	flow_out_12_2003	0.922451613
37	flow_out_1_2004	0
38	flow_out_2_2004	0
39	flow_out_3_2004	0
40	flow_out_4_2004	0
41	flow_out_5_2004	0.27983871
42	flow_out_6_2004	10.9276
43	flow_out_7_2004	79.30212903
44	flow_out_8_2004	144.8684194
45	flow_out_9_2004	149.3288333
46	flow_out_10_2004	102.7189677
47	flow_out_11_2004	20.90603333
48	flow_out_12_2004	2.853451613

Goal_type= R2 No_sims= 16 Best_sim_no= 8 Best_goal = 7.524430e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR
FLOW_OUT_22	0.19	0.67	0.75	0.71	0.6075	9.2e+002	3.7e+002	-28.2	0.68	0.54	0.55	0.78

---- Results for behavioral parameters ---

Behavioral threshold= 0.300000

Number of behavioral simulations = 16

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR
FLOW_OUT_22	0.19	0.67	0.75	0.71	0.6075	9.2e+002	3.7e+002	-28.2	0.68	0.54	0.00	0.78

Table C: Statistical Analysis of Daily Precipitation Data (1990 - 2013)

```
Input Filename = p98366.txt
Number of Years = 24
Number of Leap Years = 6
Number of Records = 8977
Number of No Data values = 0
```

Month	PCPMM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	8.33	1.1261	7.1183	0.0846	0.6788	6.88
Feb.	7.74	1.0396	7.3263	0.1052	0.6264	7.25
Mar.	44.83	4.4396	5.8748	0.1915	0.7544	14.25
Apr.	82.26	6.1787	4.1830	0.2788	0.8071	18.79
May.	275.12	11.7808	2.0332	0.3169	0.9003	25.08
Jun.	567.04	12.3484	1.1876	0.7500	0.9623	29.83
Jul.	804.60	13.6857	1.1380	0.2787	0.9677	31.00
Aug.	781.44	13.5746	1.0911	0.3154	0.9677	31.00
Sep.	456.16	12.0724	1.6734	0.4706	0.9545	29.29
Oct.	186.16	9.4757	2.5889	0.2511	0.8472	21.54
Nov.	76.15	6.6401	4.4920	0.1544	0.7391	12.46
Dec.	13.88	1.9768	7.3399	0.0901	0.6685	7.42

PCP_MM = average monthly precipitation [mm]
PCPSTD = standard deviation
PCPSKW = skew coefficient
PR_W1 = probability of a wet day following a dry day
PR_W2 = probability of a wet day following a wet day
PCPD = average number of days of precipitation in month

Table D: Average Daily Dew Point Temperature for Period (1990 - 2013)

This file has been generated by the program 'dew02.exe'
Input Filename = dw02.txt
Number of Years = 24
Number of Records = 8766

Number of No Data Values
tmp_max = 0
tmp_min = 0
hmd = 0

Average Daily Dew Point Temperature for Period (1990 - 2013)

Month	tmp_max	tmp_min	hmd	dewpt
Jan	30.93	13.90	0.38	-44.44
Feb	33.14	15.35	0.31	-45.48
Mar	33.40	16.66	0.36	-43.86
Apr	33.05	16.83	0.43	-42.37
May	30.64	15.68	0.62	-40.00
Jun	25.16	14.11	0.85	-38.91
Jul	21.40	13.31	0.92	-39.63
Aug	21.43	13.50	0.93	-39.50
Sep	23.86	13.02	0.89	-39.15
Oct	26.10	12.27	0.75	-40.22
Nov	28.51	12.90	0.59	-41.42
Dec	29.92	13.36	0.45	-43.48

tmp_max = average daily maximum temperature in month [°C]
tmp_min = average daily minimum temperature in month [°C]
hmd = average daily humidity in month [%]
dewpt = average daily dew point temperature in month [°C]

Table E: Average Max of Precipitation used for weather generator

Month	*Max perception*	Max Daily half hour
Jan	12.73384	0.265
Feb	18.62612	0.388
mar	43.26467	0.901
Apr	80.26373	1.672
may	122.1371	2.545
Jun	77.73172	1.619
Jul	101.4227	2.113
Aug	95.90203	1.998
Sep	81.18209	1.691
Oct	67.68608	1.410
Nov	27.05726	0.564
Dec	18.87932	0.393

Table F: Std Dev of Min Temperature Used for Weather Generator

Month	*Std Dev of min Temperature*
Jan	2.367030411
Feb	2.412125408
mar	2.03151068
Apr	1.566333611
may	1.352642092
Jun	1.278240427
Jul	1.554647312
Aug	1.699156268
Sep	1.620743846
Oct	1.718287413
Nov	1.961926314
Dec	2.09208846

Table G: Std Dev of Max Temperature Used for Weather Generator

Month	Std Dev of max Temperature
Jan	2.495846916
Feb	2.640089438
mar	3.092185914
Apr	3.30849209
may	4.42227914
Jun	4.033583474
Jul	2.88646328
Aug	2.335299155
Sep	2.557892977
Oct	2.742570345
Nov	2.60895987
Dec	2.083551223

Table H: Average of Wind used for weather generator

Month	Average of Wind
Jan	1.69781338
Feb	1.805908024
mar	1.878322089
Apr	1.948348765
may	1.841134993
Jun	1.60943816
Jul	1.429020709
Aug	1.345775404
Sep	1.388423492
Oct	1.686490768
Nov	1.786600346
Dec	1.752381322

Table I: Average of Solar Radiation Used for Weather Generator

Month	Average of Solar Radiation
Jan	21.72306242
Feb	23.40026388
mar	23.29287878
Apr	23.55493811
may	23.12383503
Jun	20.89780075
Jul	16.05016268
Aug	17.00695269
Sep	22.62246086
Oct	24.49894747
Nov	22.66431151
Dec	21.66530863

Table J: Average month perception of Anger 1 station

Month	Average of perception
Jan	0
Feb	0.55
mar	0.710290323
Apr	2.971833333
may	5.596774194
Jun	11.91
Jul	17.61612903
Aug	20.46451613
Sep	9.923333333
Oct	1.029032258
Nov	0.026666667
Dec	0.022580645

Table K: Average month perception of Nekmte station

Month	Average of perception
Jan	2.677975806
Feb	4.366814159
mar	5.208198925
Apr	6.262048611
may	8.596264785
Jun	10.66586667
Jul	8.905647849
Aug	8.643145161
Sep	6.203888889
Oct	3.031854839
Nov	1.86375
Dec	1.370026882

Table L: Average month perception of S/Sire station

Month	Average of perception
Jan	0.407897849
Feb	0.368362832
mar	1.576111559
Apr	2.527166667
may	5.189466398
Jun	10.39088056
Jul	11.15368952
Aug	10.0643629
Sep	6.665165278
Oct	2.767895161
Nov	1.158944444
Dec	0.365818548

Table M: Average Max and Min Temperature of Anger 1 station

Month	**Min Temperature**	**Max Temperature**
Jan	14.75878763	32.2769086
Feb	16.43365929	34.43439086
mar	17.78172177	35.02266398
Apr	18.05563611	34.36265972
may	17.33102016	31.80786156
Jun	15.69330417	28.52464583
Jul	14.71533199	25.92717204
Aug	14.82631989	25.83475538
Sep	14.75552083	27.54160972
Oct	14.75268414	29.16466398
Nov	14.96270556	31.18972083
Dec	14.58135484	31.98966398

Table N: Average Max and Min Temperature of Nekmte station

Month	**Min Temperature**	**Max Temperature**
Jan	12.38718548	26.16237097
Feb	13.61183923	27.95321534
mar	14.3456828	28.19627016
Apr	14.79627361	27.68291667
may	13.92209005	25.47104167
Jun	12.94409444	22.629125
Jul	12.79185215	20.91165323
Aug	12.82017339	21.02724597
Sep	12.83180694	22.55699583
Oct	12.7811828	23.8219086
Nov	12.57180556	24.35569444
Dec	12.13224059	25.05

Table O: Average Max and Min Temperature of S/Sire station

Month	**Min Temperature**	**Max Temperature**
Jan	12.83447849	30.02301478
Feb	13.69203835	31.5045
mar	14.52420968	31.42250538
Apr	15.01215833	30.6369125
may	14.62427419	28.81463978
Jun	13.85688333	25.08407361
Jul	13.86348253	23.44218145
Aug	13.90559409	23.81380376
Sep	13.54449722	25.67950694
Oct	13.09350538	27.67660484
Nov	12.54114583	28.67225278
Dec	12.26738306	29.42721909